ELECTRIC FENCING: A TECHNIQUE DESIGNED TO INCREASE WATERFOWL NESTING SUCCESS

by

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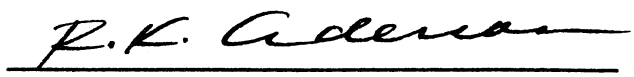

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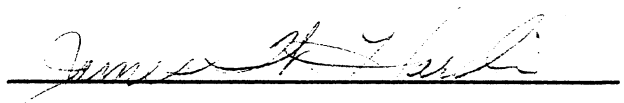

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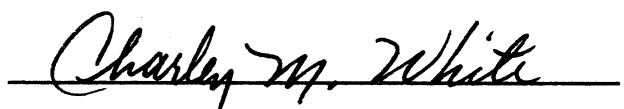

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Abstract

Predation is a major factor causing the decline of waterfowl nesting success in the prairie pothole region of North America. Predator reduction using lethal methods increases nesting success but is unacceptable. The study was conducted in west-central Minnesota during the 1980 and 1981 waterfowl nesting seasons. The objective was to determine if electric fences would function in field situations as a non-lethal predator management technique and increase waterfowl nesting success. Six electric fences, enclosing 105 ha of nesting cover, were constructed on Waterfowl Production Areas (WPA's). Nearby WPA's consisting of similar cover served as controls. Waterfowl nesting, simulated nest, and small mammal relative abundance studies were conducted to determine differences between predator activity in fenced (treatment) and unfenced (control) areas. Results for the 2-year study period: waterfowl nesting success was 60% and 24% as calculated by the conventional method and 35% and 8% as calculated by the Mayfield method in treatment and control areas respectively; simulated nest success was 48% and 25% in treatment and control areas respectively; small mammal relative abundance (captures/100 trap nights) was 17.14 and 10.20 in treatment and control areas respectively. Based on a 20-year proration, each additional duckling produced in the treatment areas cost an estimated $2.18. Dikes, peninsulas, and small areas (1-10ha) that are managed for maximum waterfowl production are recommended locations for electric fences.

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INTRODUCTION

Waterfowl nesting success in the prairie pothole region of North America has declined drastically during the past 45 years. Kalmbach (1939) reported an average nesting success of 60% for 22 studies conducted in the prairie states and provinces during the 1930's. More recently, nesting success in these areas has ranged from 10-35% (Keith 1961, Moyle 1964, Teer 1964, Evans and Wolfe 1967, Smith 1971, Stoudt 1971, Higgins 1977). The decline was attributed primarily to changing land use patterns that caused a decrease of available habitat (Miller 1971) and an increase in mammalian predation (Nelson and Duebbert 1974).

Attempts to increase waterfowl production have historically concentrated on the preservation or restoration of wetlands and manipulation of associated nesting cover. Although important, these management techniques have failed to ensure the 70% nesting success standard which has been set by waterfowl managers. Bellrose and Low (1978) recommend that management efforts deal with the production of more waterfowl per unit of available cover.

Waterfowl nesting success has been temporarily increased by reducing predation (Kalmbach 1939, Ellig 1955, Balser et al. 1968, Lynch 1972, Schranck 1972, Duebbert and Kantrud 1974, Duebbert and Lokemoen 1980). However, the direct removal of predators by shooting, trapping, and poisoning is socially, biologically, and economically unacceptable.

Barrier fencing to deter mammalian predators is one possible non-lethal alternative. Wire and wooden-stake fences were used in the 1890's to deter coyotes (Canis latrans) (Young and Jackson 1951). Electric fences were first used in the 1930's in an attempt to control ungulate and mammalian predator populations (McAtee 1939). This technique has

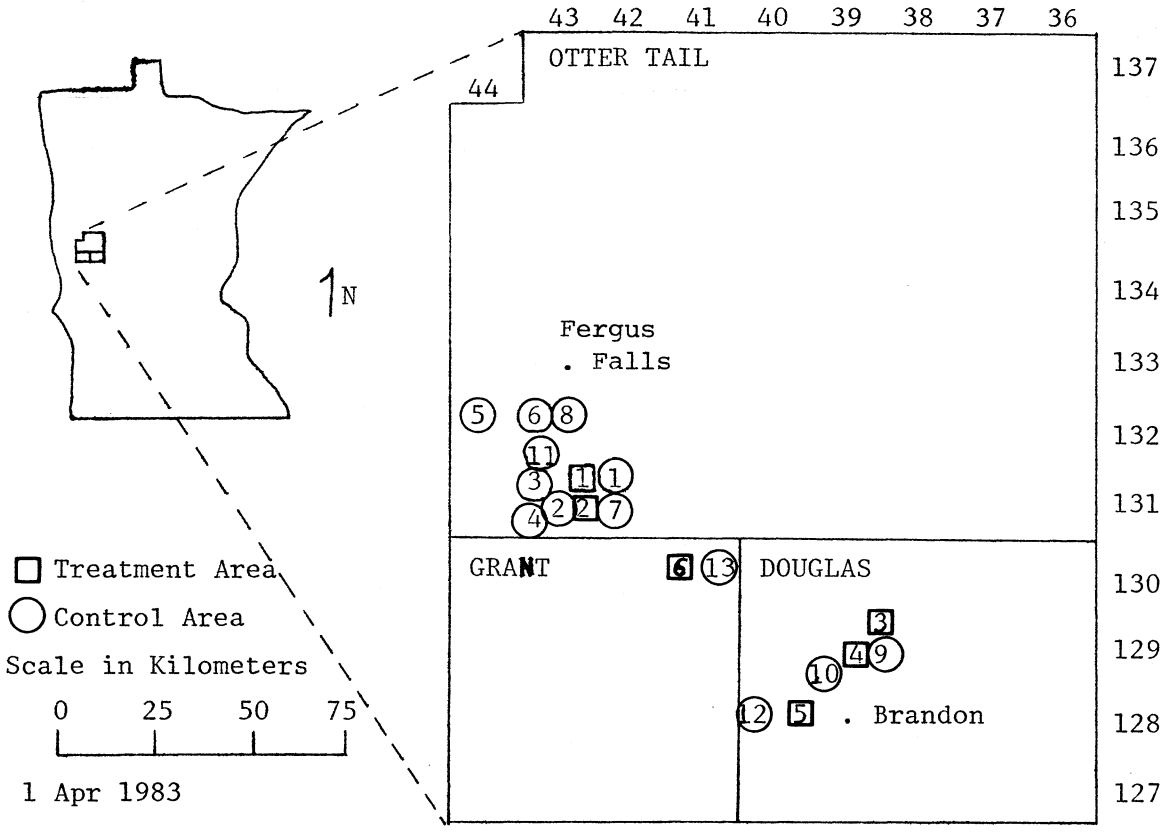
been modified to increase the efficiency of control. A new electric fence system using high powered, low impedance energizers has been developed in Australia and New Zealand (Nesbitt 1978). These new energizers effectively charge long fence lines. The technique has recently been used to deter red foxes (Vulpes vulpes) from terneries (Forster 1975, Patterson 1977, Minsky 1980).

The objective of this study was to determine if waterfowl nesting success could be increased by using electric fencing as a deterent to mammalian predators. The field research was conducted from 7 April-15 August 1980 and from 23 March-8 August 1981 while I was employed by the U. S. Fish and Wildlife Service, Mid-Continent Waterfowl Management Unit, Fergus Falls, Minnesota.

STUDY AREA

The study was conducted on selected Waterfowl Production Areas located in Otter Tail, Douglas, and Grant Counties in west-central Minnesota (Fig. 1). These counties are on the eastern border of the prairie pothole region.

Western Minnesota was last glaciated by the Wisconsin Glacier. The Fergus Falls Moraine, a prominent feature of the glacier extends across eastern Otter Tail and Grant Counties, and western Douglas County. Large, deep lakes and small wetlands important to migrating waterfowl are present in this area. West of the Fergus Falls Moraine is a till plain that contains numerous potholes and shallow lakes formed in old glacial valleys. A remnant beachline of Glacial Lake Aggassiz with many shallow wetlands and native grasslands exists in western Otter Tail and Grant Counties. Agriculture is limited here because the soils are sandy and



Study Area	Legal Description	Hectareage
T-1	T131N, R43W, Sec. 12	44.4
T-2	T131N, R43W, Sec. 12	32.1
T-3	T129N, R39W, Sec. 18	9.9
T-4	T129N, R39W, Sec. 18	7.2
T-5	T128N, R40W, Sec. 7	10.1
T-6	T130N, R41W, Sec. 36	2.0
C-1	T131N, R42W, Sec. 9	9.7
C-2	T131N, R43W, Sec. 1&2	19.6
C-3	T131N, R43W, Sec. 3	21.0
C-4	T131N, R43W, Sec. 5	9.4
C-5	T132N, R44W, Sec. 12	24.3
C-6	T132N, R43W, Sec. 27	11.3
C-7	T131N, R42W, Sec. 6	31.7
C-8	T132N, R43W, Sec. 14&23	23.7
C-9	T129N, R39W, Sec. 18	9.3
C-10	T129N, R39W, Sec. 18	11.5
C-11	T132N, R43W, Sec. 33	20.3
C-12	T128N, R40W, Sec. 7	10.0
C-13	T130N, R41W, Sec. 36	2.0

Fig. 1. Location and hectareage of treatment (T-N) and control (C-N) areas.

gravelly. East of the Fergus Falls Moraine in Douglas, and a small portion of Otter Tail County, is a region of till plain with outwash sands and minor morainic features that is partially wooded and contains many wetlands and lakes.

The northern and western portions of the study area drain west to the Red River. The south-central portions drain south to the Minnesota River. The south-eastern portions are drained by the Red Eye, Wing, and Leaf River watersheds.

There are 9 soil associations on the study area (McMiller 1954). Approximately 70% of the land has been developed into cropland or pasture.

The continental-type climate is characterized by warm, moist summers and cold, dry winters, distinguished by wide and rapid variations in temperature and precipitation. The average temperatures are -10 C during the winter and 21 C during the summer. The average annual precipitation varies from 56cm in the western portions to 66cm in the northeastern portions of the study area. Approximately 75% of the annual precipitation occurs during April-September.

There were approximately 1,700 lakes and 13,000 Class III-VIII wetlands (Steward and Kantrud 1971) on the study area in 1974 (Minnesota DNR 1974). Many of the wetlands have been drained since then.

Vegetation on the study area consisted of 4 distinctive plant assemblages: 1) prairie (42%); 2) hardwood forest (38%); 3) oak and oak savannah, aspen parkland (18%); 4) conifer forest (2%), (Madsen and Neaville, U.S. Fish and Wildl. Serv., Fergus Falls, unpubl. data).

A legal description and the hectareage of each electric fenced (treatment) and unfenced (control) area is shown in Fig. 1. Hereafter,

the treatment and control areas will be individually recognized as T-N and C-N respectively. All treatment and control areas were composed of undisturbed cool-season grass-legume cover except T-1, T-2, C-4, C-5, C-8, and C-9 which were seeded to warm-season native grasses in 1978.

MATERIALS AND METHODS

Electric fences were constructed on selected Waterfowl Production Areas (WPA's). The cover enclosed by the fences served as treatment areas. Similar cover on nearby unfenced WPA's served as control areas. Mammalian predators remaining inside the treatment areas after the fences were charged were removed. Waterfowl nesting success, simulated nest success, and small mammal relative abundance studies were conducted on the treatment and control areas.

Electric Fences

Six treatment areas were fenced on selected WPA's during the 1978 and 1979 field seasons. These fences enclosed 105ha of nesting cover. WPA's with vegetation similar ($P > 0.05$) to that found on the treatment areas were selected as control areas. The visual obstruction of the vegetation was measured using the technique described by Robel, et al. 1970. Control areas consisted of 152ha and 105ha of nesting cover during 1980 and 1981 respectively.

Treatment areas T-1, T-3, T-4, and T-5 were enclosed with 7-wire fences; T-2 with a 9-wire fence. Treatment area T-6, a 2-ha peninsula, was separated from the mainland by a 5-wire fence. A 1.3cm mesh hardware cloth skirt was installed on the lower 46cm of this fence to deter small mammals. A wire was also suspended 9cm above the water and extended 11m perpendicularly from each shoreline to deter swimming predators. The

hardware cloth skirt was installed under this wire also. The 3 fence designs are illustrated in Fig. 2. The wires on all fences were alternately charged and grounded (except the fence enclosing treatment area T-6, see Fig. 2). The wire nearest the earth was charged. The fences enclosing treatment area T-3 through T-6 were each powered by an E-12 Energizer (Gallagher Electronics Ltd., Hamilton, New Zealand) and a 12-V deep cycle battery. The fences enclosing treatment areas T-1 and T-2 were wired in series in 1980 and powered by a BEV-II Energizer and 110-V powerline. The latter system included a GTO Power Inverter and 12-V battery which functioned as a backup unit in the event of 110-V power failures. The fence enclosing treatment area T-1 was converted from the 110-V power system to 3 E-12 Energizers and three 12-V batteries during 1981. The fences were constructed with 12.5 gauge smooth wire. All corners were anchored with wood posts. Wood posts and fiberglass posts were driven alternately about every 11m.

A soil sterilant "Oxy Ureabor" was applied on a 2m wide strip of ground centered on the fence to prevent vegetative growth which would cause short-circuits. The fences were charged during late-April 1980 and early-April 1981.

Predator Removal

Leghold and live traps with a variety of baits and lures were used to remove predators from the treatment areas. Trapping was initiated when the fence was charged and the traps were checked daily until all resident predators (those remaining inside a treatment area after the fence was charged) were removed. Traps were reset and rebaited biweekly throughout the field season after residents were removed.

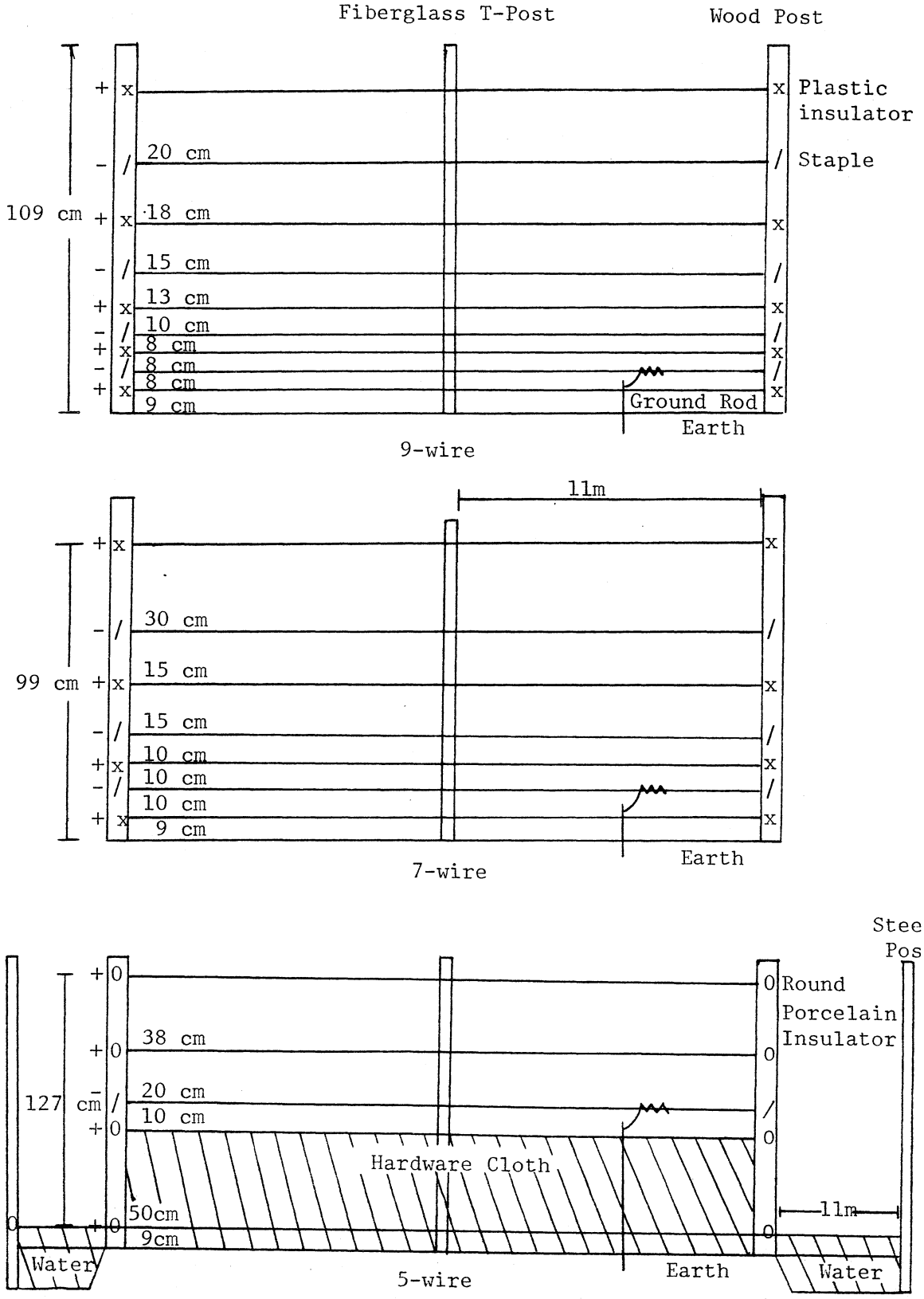


Figure 2. Electric fence designs.

Scent stations (Linhardt and Knowlton 1975) were installed in each enclosure to determine the presence of any predators. Additional traps were set in the enclosure when a predator disturbed a scent station.

Waterfowl Nesting Study

Nest searches were conducted on all treatment and control areas about 3 weeks after the fences were charged, and thereafter on about 20-day intervals. The nest searches were terminated in late-July. Nests were located by flushing hens with a heavy, 60m chain pulled through the nesting cover between 2 vehicles. The peninsula (treatment area T-6) was searched with a rope and chain device (Earl 1950) dragged by field workers. Eggs were candled to determine the stage of incubation (Weller 1956). Nests were marked with a flagged lathe placed 5m east of the nest. The fate of nests was determined on subsequent visits using methods described by Rearden (1951) and Einarson (1956). Treatment areas T-1 through T-6 were searched both years of the study. Control areas C-1 through C-10 were searched during 1980; control areas C-2, C-4, C-6, and C-8 through C-11 were searched during 1981.

One or more eggs in a depression were considered to constitute a nest, and if at least 1 egg hatched the nest was deemed successful. Nesting success was calculated by the conventional method of dividing the number of hatched nests by the sum of the hatched plus destroyed nests. These calculations are presented to allow comparisons with historic nesting studies. The data were tested by Chi-square at the 0.05 level of probability with 1 degree of freedom. Miller and Johnson (1978) recognized that periodic nest searches are more likely to reveal a successful than an unsuccessful nest. When this occurs, nesting success is biased upwards. Mayfield (1961, 1975) proposed a method of estimating

nesting success from nests observed during all or any portion of the period between nest initiation and hatching. The 40% modification of the Mayfield method (Johnson 1979) was used to determine hatching rates in this study. This method adjusts Mayfield's midpoint assumption to 40%, because long nest search intervals give too much exposure to destroyed nests. Nests that were deserted, destroyed by field workers, or not relocated were omitted from nesting success calculations.

Simulated Nest Study

Simulated nests, consisting of 3 fresh chicken eggs placed in shallow depressions, were installed in treatment areas T-2 through T-6 during 1980 and T-1 through T-6 during 1981. Simulated nests were also installed in control areas C-2, C-6, C-9, C-10, C-12, and C-13 during 1980 and in C-2, C-4, C-6, and C-8 through C-13 during 1981. The eggs were covered with residual vegetation and disturbed vegetation was restored as closely as possible to its original position. The nests were positioned at 100m intervals. Nests were marked with a flagged, willow wand placed 5m to the west. After a period of 35 days the nests were visited to determine their fate. A nest was considered to be successful when the 3 eggs were unmolested. Nests that were not relocated were omitted from nest success calculations. The data were tested by Chi-square at the 0.05 level of probability with 1 degree of freedom. This aspect of the study was conducted during late-June through early-August.

Small Mammal Relative Abundance Study

Snap-traps were installed on transect lines in study areas T-3 through T-6, C-9, C-10, C-12, and C-13 both years of the study. Each transect contained 5 trap stations positioned at 50m intervals. A trap station consisted of a large rat trap riveted to a lathe which was driven

into the earth until the trap was 15cm above the earth, and 2 snap-traps, each tied to the lathe with 1m of string and positioned north and south of the lathe. Traps were baited daily with a mixture of peanut butter, oatmeal, and raisins. Catch/effort calculations were corrected to account for sprung traps as suggested by Nelson and Clark (1973). The data were tested by Chi-square at the 0.05 level of probability with 1 degree of freedom. Trapping was conducted for 9 and 10 consecutive days prior to disconnnecting the fences during 1980 and 1981 respectively.

RESULTS AND DISCUSSION

Waterfowl Nesting Success

Waterfowl nesting success (WNS) was significantly higher ($P < 0.05$) in the treatment than the control areas during both years of the study (Table 1). Eggs hatched in 38 of 51 nests (75%) in treatment areas and 27 of 107 nests (25%) in control areas during 1980. Eggs hatched in 43 of 85 nests (51%) in treatment areas and 20 of 89 nests (22%) in control areas during 1981. WNS for the 2 years combined, as calculated by the conventional method, was 60% and 24% in treatment and control areas respectively. WNS, as calculated by the Mayfield method, was 52% in treatment areas and 8% in control areas during 1980; 28% in treatment areas and 8% in control areas during 1981. WNS for the 2 years combined, as calculated by the Mayfield method, was 35% and 8% in treatment and control areas respectively. Based on a test suggested by Johnson (1979), the average daily survival rate of the nests in the treatment areas was significantly higher ($P < 0.05$) than in the control areas during both years of the study (Appendix A).

The decline of nesting success from 75% during 1980 to 51% during 1981 is attributed to increased predation. The total number of nest

Table 1. Success of waterfowl nests (%) on treatment (T) and control (C) areas as calculated by the conventional (CO) and Mayfield (MA) methods, 1980-81.

Year	Study Area	Nests N	CO[a]	MA[b]
1980	T	51	75	52
	C	107	25	8
1981	T	85	51	28
	C	89	22	8
Combined Years	T	136	60	35
	C	196	24	8

[a] (x^2 = 24.60, df=1, $P < 0.05$, 1980; x^2 = 13.69, df=1, $P < 0.05$, 1981)

[b] (f = 20.34, df=1, $P < 0.05$, 1980; f = 11.98, df=1, $P < 0.05$, 1981)

predators removed from treatment areas was 21 during 1980 and 44 during 1981 (Table 2). These totals include the removal of 6 and 8 resident predators during 1980 and 1981 respectively. Sixteen (31%) of the remaining 51 predators were crows (Corvus brachyrhynchos), Franklin ground squirrels (Spermophilus franklinii), and feral cats which the fences were not designed to deter (Appendix B); 7 of the remaining 51 predators (14%) were removed from a treatment area within 2 days after the fence enclosing that area had ceased to properly operate. Direct observations of predators crossing the fences were not possible. However, if trapping effectively removed predators within 2 days, it appears that a minimum of 6 and 23 predators penetrated the barriers when they were operating at full power during 1980 and 1981 respectively. The inability of fences to deter predators the 2nd year indicates that some individuals may have learned to avoid or tolerate the electrical shock.

Forty-nine percent of the nest destruction in the treatment areas was caused by ground squirrels (Spermophilus spp.), a predator the fences were not designed to deter; 34% was caused by small carnivores; and 17% could not be identified by the remains at the nest site. Red foxes (Vulpes vulpes) present in treatment area T-1 during 1981 causes 75% of the total nest destruction caused by small carnivores in the enclosures both years of the study. In the control areas only 6% of the nest destruction was caused by ground squirrels and 77% was caused by small carnivores. Ground squirrels may become a compensatory predator in areas protected from larger carnivores.

Waterfowl nesting in the treatment areas produced 350% and 215% more young/ha than waterfowl nesting in the control areas during 1980

Table 2. Number of nest predators removed from treatment area (T-N), 1980-81.

Treatment Area	Year	
	1980	1981
T-1	5	20
T-2	6	7
T-3	6	5
T-4	1	7
T-5	3	5
T-6	0	0
Total	21	44

and 1981 respectively (Appendix C). Nest densities were not particularly high. A goal of waterfowl researchers has been to discover ways to obtain densities of 2.5 or more nests/ha on lands managed for waterfowl production (Nelson and Duebbert 1974). Nest densities were lower than 2.5 nests/ha on all study areas except treatment area T-6 (the 2-ha peninsula) where 6 nests/ha were found both years of the study (Appendix C).

All species of waterfowl layed slightly smaller clutches in the treatment than the control areas. For example, the average clutch size for mallards (Anas platyrhynchos) was 9.6 in treatment areas and 9.9 in control areas; and for blue-winged teal (Anas discors) was 10.3 in treatment areas and 10.6 in control areas. Waterfowl normally lay fewer eggs with each successive nesting attempt. This indicates that the treatment areas were used by renesting waterfowl. Nests initiated in treatment areas after 15 May, however, were less successful. Sixty-nine percent of the nests located in treatment areas were initiated after 15 May; 55% of them successfully hatched. Nesting success in treatment areas prior to 15 May was 75%.

Simulated Nest Success

Success of simulated nests was significantly higher ($P < 0.05$) on treatment than control areas both years of the study (Table 3). Twenty-five (51%) of 49 and 12 (19%) of 63 of the simulated nests were successful during 1980 in treatment and control areas respectively. Forty-four (47%) of 94 and 28 (28%) of 100 of the simulated nests were successful during 1981 in treatment and control areas respectively. Simulated nest success for the 2 years combined was 48% and 25% in treatment and control areas respectively.

Table 3. Success of simulated nests (%) installed on treatment (T) and control (C) areas, 1980-81.

Year	Study Area	Nests N	Successful Nests
1980	T	49	51
	C	63	19
1981	T	94	47
	C	100	28
Combined Years	T	143	48
	C	163	25

(x^2 = 11.3, df=1, $P < 0.05$, 1980; x^2 = 5.1, df=1, $P < 0.05$, 1981)

I did not expect natural and simulated nest success to be similar. In Byer's (1974) study, predation rates were higher on simulated than on natural nests. Hammond (1968) reported higher predation rates on natural than simulated nests. Simulated nests may have been less successful than natural nests in this study because the nests were deployed late in the nesting season when predators were more active.

Small Mammal Relative Abundance Study

Small mammals were more abundant ($P < 0.05$) on combined treatment than combined control areas both years of the study (Table 4). The small mammal relative abundance (SMRA) was 23.20 and 12.24 captures/100 trap nights in combined treatment and combined control areas respectively during 1980. The SMRA was significantly higher ($P < 0.05$) in treatment areas for all 3 of the treatment and control comparisons (Appendix E). The SMRA was 12.61 and 8.59 captures/100 trap nights in combined treatment and combined control areas respectively during 1981. However, only 1 of the 3 comparisons indicated a significantly higher ($P < 0.05$) SMRA in the treatment area. This was most likely a function of the increased predator activity in those 2 treatment areas late in the 1981 nesting season when the SMRA study was conducted. The SMRA for the 2 years combined was 17.14 and 10.20 captures/100 trap nights in treatment and control areas respectively.

The presence of higher small mammal populations in areas protected from carnivore activities could have the following detrimental effects on nesting waterfowl: 1) ground squirrels increase and become a compensatory predator; 2) avian and possibly mammalian predators are attracted to the readily available food source; 3) lower stem densities make the vegetation less attractive as nesting cover.

Table 4. Small mammal relative abundance (SMRA; captures/100 trap nights) on treatment (T) and control (C) areas, 1980-81.

Year	Study Area	Trap Nights N	SMRA
1980	T	810	23.20
	C	810	12.24
1981	T	900	12.61
	C	900	8.59
Combined Years	T	1,710	17.14
	C	1,710	10.20

(x^2 = 25.74, df=1, $P < 0.05$, 1980; x^2 = 6.63, df=1, $P < 0.05$, 1981)

Fence Maintenance, Operation, and Costs

A small amount of maintenance was necessary to prepare the fences for operation during April. Wires were tightened and wire spacings were checked prior to connecting the power sources. The soil sterilant was still effective where it had been applied during 1979.

The fences were visited daily throughout the nesting season to ensure continuous operation. The number of times the electric fence is visited must be kept at a minimum if electric fencing is to become a practical management technique. There are certain "high risk" days when the fences should be visited. One such "high risk" day is immediately after a rain, wind, and/or electrical storm. A fence was not operating during 31 of 1,405 visits during this study. Twenty-five (81%) of these 31 visits occurred the day following a storm; 8 times heavy rain accumulated in low spots along the fenceline and caused a short-circuit with the bottom wire; 7 times wet vegetation became lodged against wires and drained the energy from a battery; 4 times lodged vegetation caused excessive short-circuits; 3 times wires were broken when lodged vegetation caused wind resistance; and 2 times fences were struck by lightning. Flood-gate controllers and lightning arrestors were installed to eliminate damage caused by heavy rains and lightning respectively. The remaining 6 visits when a fence was not operating occurred other than the day after a storm; 4 times corroded terminals on an energizer caused a malfunction; 1 time several plains pocket gophers (Geomys bursarius) covered the bottom wires with mounds of soil; and 1 time a white-tailed deer (Odocoileus virginianus) became entangled in a fence and broke several wires. Visual observations indicated that predators became more active after storms. The perimeter of any fence not operating should be investigated for

predator sign. Also, scent stations should be visited for identification of any predator which may have penetrated the barrier. It may be necessary to trap and remove predators that enter the enclosure.

One battery provided sufficient energy to power 1 energizer for 10 days on 5000m of wire. The batteries had to be recharged at 7-10 day intervals depending on moisture conditions. Two batteries wired in series would reduce the number of times batteries had to be changed during the nesting season. The use of 110-V power sources or solar generators would eliminate battery changes.

It cost about $13,300 during 1978 and 1979 to construct the 6 electric fences. The cost of materials was $1.19/m; equipment rental was estimated at $0.18/m; and labor was estimated at $0.40/m; total cost was $1.79/m or $126.66/ha enclosed. The cost of construction materials is inversely related to the size of the fenced area because the perimeter/ha decreases as the area enclosed increases.

Waterfowl nesting in the electric fence enclosures produced 2.9 more ducklings/ha than those nesting in control areas. The expected life of the fences is 20 years. At this rate of production, the enclosures would produce 6,090 additional ducklings after 20 years. The cost/additional duckling would be $2.18. This figure does not include yearly fence maintenance and operation. The number of additional ducklings produced in the fenced areas may increase yearly if the fences remain effective. In a study conducted in South Dakota, dabbling ducks responded to a predator-reduced environment with increased nest densities, hatching success, and breeding populations (Duebbert and Lokemoen 1980).

MANAGEMENT RECOMMENDATIONS

Electric fences should be installed in areas that have a history of repeated nesting attempts but low production due to high nest destruction rates by predators. The parcel should be comprised of dense, upland nesting cover located near a diverse, stable wetland complex. For an initial electric fencing attempt in an area, I suggest enclosing 1-10ha of nesting cover. Fencing parcels < 1ha is uneconomical unless nesting density is high and the maintenance of a fence surrounding a parcel > 10ha is time-consuming, especially in rolling terrain. Installing electric fences on dikes, which provide the majority of the nesting cover on some waterfowl production areas, should be investigated. These dikes are often major predator travelways and, therefore, usually low in production. A small amount of fencing material would be required to exclude predators from a section of dike. A charged wire extended over water from both shorelines could be used to deter swimming predators. A 1.3cm hardware cloth skirt could be installed on the lower 30cm of the fence to exclude small mammals because newly hatched ducklings can move to brood-rearing water without crossing the fenceline. The skirt would be especially valuable in areas where ground squirrels are present. Drive-through lift gates could be constructed in the fenceline to allow vehicle access for dike maintenance and other travel. Peninsulas are also desirable locations for electric fences. Waterfowl nesting on a 2-ha peninsula in this study produced 90 ducklings during 1 nesting season. Here, a large parcel of nesting cover was protected from mammalian predators with a small amount of fencing material.

The proper construction of the electric fence is extremely critical. The fence must be well-designed, preferably located on uplands with a

minimum of geographical relief, and constructed with high-quality materials by competent personnel. A well-designed fence, constructed of high quality materials, should last 20 years with a minimum of maintenance.

RESEARCH RECOMMENDATIONS

Future research conducted on the electric fencing technique should include determinations of the effectiveness of the barriers over a period of several years and methods of reducing costs. In this study, it appeared that predators became acclimated to the fences. Predators entered the enclosures more readily as the nesting season progressed, especially during the 2nd year of the study. The effectiveness of the barriers should be monitored over several years. A study should be conducted in a controlled environment to determine that which constitutes a reliable, minimum barrier. A determination of the number of wires, wire spacings, and power required to deter various predators would be valuable. This information would reduce the cost of materials and ensure the electrical safety of the fences. Different fence designs, e.g., offset wires of various heights, baited wires, or fencing which includes a nylon mesh, may prove to be more effective.

An effort should be made to determine the predator densities in the area surrounding the electric fence. Field observations of predator reactions to electric fence encounters would help verify the effectiveness of the barriers.

It is possible that additional ducklings produced may be limited by other factors before they reach the flight stage. If this is the case, the contribution of electric fencing to the fall flight of waterfowl may be negligible. Future studies should include intensive surveys of broods produced by marked hens and/or web-tagging ducklings to determine the survival rate of ducklings produced.

CONCLUSION

Electric fences designed to deter mammalian nest predators are an effective, non-lethal technique which will increase waterfowl nesting success. In this study, waterfowl nesting success, simulated nest success, and small mammal relative abundance were higher in areas protected by electric fences than in unprotected areas. The fences functioned adequately in field situations with minimal maintenance. The technique should be applied on areas under intensive management where the objective is to obtain maximum waterfowl production. The initial cost is high, but the benefits prorated over 20 years are economically justifiable. This technique could significantly increase the number of waterfowl produced annually on selected areas if properly installed and maintained electric fences remain effective, and ducklings produced survive until the flight stage. Electric fencing should be considered by wildlife managers and game farm operators who wish to increase waterfowl production on small areas.

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Appendix A. Data used in calculation of conventional (CO) and Mayfield (MA) nesting success (%) on treatment (T-N) and (C-N) areas, 1980-81.

Year	Study Area	Nests N	Successful Nests	Exposure Days	Average Nest Life	Daily Survival Rate	Nesting Success CO	Nesting Success MA
1980	T-1	3	3	45.0	33.0	1.0000	100	100
	T-2	17	13	200.0	33.2	.9800	77	51
	T-3	9	5	131.0	33.0	.9695	56	36
	T-4	11	6	139.2	33.2	.9641	55	30
	T-5	1	1	15.0	33.0	1.0000	100	100
	T-6	10	10	117.0	33.4	.9145	100	100
Totals or Averages		51	38	647.2	32.6	.9799	75	52
	C-1	7	5	72.2	33.6	.9723	71	39
	C-2	35	0	305.6	33.0	.8855	0	2
	C-3	7	1	55.2	33.0	.8913	14	2
	C-4	7	2	79.4	33.0	.9370	29	12
	C-5	18	4	152.2	33.5	.9080	22	4
	C-6	2	0	19.2	33.0	.8958	0	3
	C-7	18	10	242.2	33.2	.9670	56	33
	C-8	5	3	74.0	33.0	.9730	60	41
	C-9	4	0	27.6	33.5	.8551	0	1
	C-10	4	2	44.6	33.3	.9552	50	22
Totals or Averages		107	27	1,072.2	33.2	.9254	25	8
1981	T-1	19	2	213.8	33.0	.9205	11	6
	T-2	17	9	237.0	33.1	.9662	53	32
	T-3	19	16	288.2	33.2	.9896	84	71
	T-4	12	8	175.6	33.3	.9772	67	46
	T-5	9	5	126.0	32.9	.9683	56	35
	T-6	9	3	72.2	33.4	.9169	33	6
Totals or Averages		85	43	1,112.8	32.8	.9623	51	28
	C-2	21	3	199.6	33.1	.9098	14	4
	C-4	5	0	32.4	32.6	.8457	0	0
	C-6	12	8	154.4	33.1	.9741	67	42
	C-8	31	2	302.0	33.0	.9042	7	4
	C-9	7	1	61.2	33.0	.9020	14	3
	C-10	10	5	135.4	33.0	.9631	50	29
	C-11	3	1	50.0	33.0	.9600	33	26
Totals or Averages		89	20	935.0	33.0	.9262	22	8

Appendix B. Number and species of nest predators removed from treatment areas (T-N), 1980-81.

Species	T-1		T-2		T-3		T-4		T-5		T-6	
	1980	1981	1980	1981	1980	1981	1980	1981	1980	1981	1980	1981
Striped Skunk (*Mephitus mephitus*)	5	15	4	4	0	2	1	3	2	3	0	0
Red Fox (*Vulpes vulpes*)	0	1	1	0	0	0	0	0	0	1	0	0
Raccoon (*Procyon lotor*)	0	1	1	1	0	0	0	0	0	0	0	0
Badger (*Taxidea taxus*)	0	0	0	0	0	0	0	0	0	1	0	0
Feral cat[a]	0	0	0	0	3	0	0	3	0	0	0	0
Franklin Ground Squirrel[a] (*Spermophilus franklinii*)	0	0	0	0	3	3	0	1	1	0	0	0
Crow[a] (*Corvus brachyrynchos*)	0	3	0	2	0	0	0	0	0	0	0	0
Total	5	20	6	7	6	5	1	7	3	5	0	0

[a]Fences were not designed to exclude these species.

Appendix C. Nesting data for treatment (T-N) and control (C-N) areas, 1980-81.

Year	Study Area	Nests/ha	Ducklings Produced/ha
1980	T-1[a]		
	T-2[b]	0.95	6.03
	T-3	1.01	4.85
	T-4	1.81	8.33
	T-5	0.20	0.89
	T-6	6.00	41.50
Average		1.14	6.54
	C-1	0.93	4.23
	C-2	1.80	0.00
	C-3	0.38	0.48
	C-4	0.75	2.26
	C-5	0.86	1.73
	C-6	0.18	0.00
	C-7	0.79	2.74
	C-8	0.25	0.13
	C-9	0.43	0.00
	C-10	0.35	1.39
Average		0.81	1.87
1981	T-1	0.50	0.34
	T-2	0.56	2.51
	T-3	2.02	16.26
	T-4	1.94	10.83
	T-5	0.89	4.95
	T-6	6.00	16.00
Average		0.90	3.95
	C-2	1.13	1.44
	C-4	0.54	0.00
	C-6	1.24	6.64
	C-8	0.20	0.40
	C-9	1.39	0.88
	C-10	0.75	0.97
	C-11	0.87	4.52
Average		0.91	1.84

[a]Data not included because of control burn.

Appendix D. Data used in calculation of simulated nest success (%) on treatment (T-N) and control (C-N) areas, 1980-81.

Year	Study Area	Nests N	Successful Nests	Success
1980	T-2	19	9	47
	T-3	10	2	20
	T-4	8	4	50
	T-5	10	8	80
	T-6	2	2	100
Totals or Averages		49	25	51
	C-2	20	1	5
	C-6	15	4	27
	C-9	8	4	50
	C-10	8	3	38
	C-12	10	0	0
	C-13	2	0	0
Totals or Averages		63	12	19
1981	T-1	35	12	34
	T-2	31	10	32
	T-3	10	8	80
	T-4	7	6	86
	T-5	9	6	67
	T-6	2	2	100
Totals or Averages		94	44	47
	C-2	16	3	19
	C-4	4	1	25
	C-6	10	7	70
	C-8	21	1	5
	C-9	10	5	50
	C-10	7	2	29
	C-11	20	6	30
	C-12	10	2	20
	C-13	2	1	50
Totals or Averages		100	28	28

Appendix E. Small mammal relative abundance (captures/100 trap nights) on treatment (T-N) and control (C-N) areas, 1980-81.

Species	1980						1981					
	T-3	C-9	T-4	C-10	T-6	C-13	T-3	C-9	T-4	C-10	T-6	C-13
Meadow Vole (Microtus pennsylvanicus)	8.08	4.50	22.01	3.13	25.67	0.00	3.47	0.94	0.72	2.17	2.91	2.95
Masked Shrew (Sorex cinereus)	1.94	1.50	0.48	4.02	12.83	12.44	7.20	1.65	7.23	7.58	5.82	5.90
Shorttail Shrew (Blarina brevicauda)	0.00	0.60	0.00	0.00	5.35	3.83	0.74	0.00	0.36	0.00	0.00	0.00
Meadow Jumping Mouse (Zapus hudsonicus)	1.94	0.30	0.48	0.89	1.07	1.91	1.24	0.71	0.72	1.44	0.00	0.00
Thirteen-lined Ground Squirrel (Spermophilus tridecemelineatus)	1.62	1.20	1.44	0.89	2.14	0.96	0.00	0.47	0.36	0.00	0.00	0.00
Arctic Shrew (Sorex arcticus)	0.32	1.20	0.00	0.45	0.00	0.00	1.74	0.94	0.36	1.08	0.73	0.74
White-footed Deer Mouse (Peromyscus maniculatus)	0.00	0.30	0.00	0.00	0.00	1.91	0.00	0.00	0.00	0.36	2.18	2.21
Franklin Ground Squirrel (Spermophilus franklinii)	0.97	0.60	0.00	0.00	0.00	0.96	0.00	0.24	0.36	0.00	0.00	0.00
Short-tailed Weasel (Mustela ermina)	0.32	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Totals	15.19[a]	11.10	24.41[a]	9.38	47.06[a]	22.01	14.39[a]	4.95	10.11	12.63	11.64	11.80

[a]Difference in treatment and control SMRA comparison significant ($P < 0.05$).