Assessment of Shock Collars as Nonlethal Management for Wolves in Wisconsin

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ABSTRACT Lethal control alone has not proven entirely effective in reducing gray wolf (*Canis lupus*) depredations in chronic problem areas. Opponents of lethal control argue that more emphasis should be placed on integrating nonlethal strategies into current management. However, few evaluations have tested the effectiveness of nonlethal options. We compared behavior patterns in terms of frequency and duration of bait station visits for 5 wolves fitted with shock collars to 5 control animals inhabiting wolf pack territories in northern Wisconsin during summers of 2003 and 2004. Shock collared wolves spent less time and made fewer visits to bait station zones than did control animals. During and after shocking, wolves shifted 0.7 km away from the bait station zone. Although active shocking did restrict wolf access, which could be useful in controlling wolf depredations during a limited time period, conditioning was not clearly demonstrated once shocking ceased. The effect of shock collar design and operation on long-term conditioning and shock-conditioned wolves on pack behavior needs further study. If long-term conditioning is possible, shock collars could be used by wildlife managers as a nonlethal wolf management method in chronic problem areas where lethal control has proven ineffective. (JOURNAL OF WILDLIFE MANAGEMENT 73(4):518–525; 2009)

DOI: 10.2193/2007-066

KEY WORDS behavior, *Canis lupus*, gray wolf, lethal control, livestock depredation, nonlethal management, shock collars, site-aversive conditioning, Wisconsin.

Depredation of livestock by gray wolves (*Canis lupus*) is becoming a major issue in the Great Lakes region (Fritts et al. 1992, Mech 1998). Livestock depredations will increase as wolves disperse into agricultural landscapes (Kellert 1991, Mech 1995, Treves et al. 2002). Chronic problem areas (e.g., farms that suffer livestock losses for ≥3 consecutive yr) will expand in the Upper Peninsula of Michigan and northern Wisconsin, USA (Fritts et al. 1992, Wisconsin Department of Natural Resources [WDNR] 1999, Mech 2000). Michigan and Wisconsin residents currently favor wolf recovery, but support could change if human–wildlife conflicts continue to increase (Dorrance 1983, Mech 1995).

Lethal control is the primary strategy used to manage wolf populations (Berryman 1972, Archibald et al. 1991, Mech et al. 2000). However, lethal methods alone have not eliminated wolf depredations (Fritts et al. 1992, Mech 1995, Musiani et al. 2005). Depredations often reoccur within a year after lethal control (Bradley et al. 2005). In the case of recovering wolf populations (e.g, Mexican gray wolf [*C. lupus baileyi*] and the red wolf [*C. rufus*]), where numbers are low and each animal is considered valuable, lethal control may remain a last resort (Parker and Phillips 1991, Peek et al. 1991).

Nonlethal control methods are publicly more acceptable than lethal options (Reynolds 1996). However, lethal control and nonlethal control should not be viewed as mutually exclusive. If effective, nonlethal control options could be developed and integrated with current management, negative consequences of wolf depredations could be further mitigated. Although many different forms of nonlethal control exist, few have been thoroughly tested on free-ranging wild wolves (Gehring et al. 2006).

Shock collars are one of the least understood methods of nonlethal control for wolves. They differ from other forms of nonlethal control in that they could result in behavioral conditioning if the target animal is able to establish a connection between a specific behavior and a negative consequence (e.g., pain). If found to be effective, shock collars may offer site-specific avoidance by conditioning wolves to avoid livestock pastures, thereby preventing depredations. Shock collars are regularly used to train or condition domestic dogs and the low-impulse corrective shock is considered humane.

Shivik et al. (2003) tested shock collars on captive wolves and reported that shock collars were difficult to use on wolves due to logistical and behavioral variability. Although this method of control has shown inconclusive results on captive wolves, Andelt et al (1999) reported conditioning captive coyotes (*C. latrans*). Andelt et al. (1999), Cooper et al. (2005), and Schultz et al. (2005) also reported promising results on free-ranging wild canids. Prior to this research, shock collars had not been tested on free-ranging wolves in a controlled experiment. Our objective was to determine if current shock collar technology could effectively deter free-ranging wolf movements from using a desirable site.

STUDY AREA

We conducted our study in a 9,000-km^2 section of north-central Wisconsin. This area included Ashland, Forest, Iron,

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Lincoln, Price, Oneida, and Vilas counties and bordered the western edge of the Upper Peninsula of Michigan. Most of the study area was an ecological landscape type classified as Northern Highlands by the WDNR (WDNR 2000). The study area was 64% forested and encompassed federal, state, county, timber company, and private land. Most of the study area was accessible through secondary, 2-track, or retired logging roads. A portion of the public and private land was gated and restricted to foot travel for the general public. Horse, all-terrain vehicle, truck, bicycle, and foot travel were all common on the remaining roads and trails. Agriculture, although not abundant, was present principally as cranberry, potato, soybean, and livestock production. Beef and dairy cattle operations occurred at a combined density of 12.8 head/km^2 in northern Wisconsin (Treves et al. 2002).

Wydeven et al. (2004) and Wydeven and Wiedenhoeft (2004) estimated that 40 wolf packs with an average of 3.5 animals per pack occurred within this area (i.e., 140 wolves) with a mean density of 1.5 wolves per 100 km^2. White-tailed deer (*Odocoileus virginianus*) occurred at approximately 1,800 per 100 km^2 within the study area (WDNR 2000). The average home-range size of wolf packs within the study area was 150 km^2 (WDNR 2000; Wydeven et al. 2004).

METHODS

We extensively scouted wolf packs within the study area via scat and track surveys, which included both driving and walking forest trails within wolf pack territories and visually observing tracks and scat. We selected packs for study based on the following criteria. First, we gave priority to packs with accessible roads within their territories because of our need to transport equipment and bait in and out of each site. Thus, we also preferred packs that readily used roads or forest trails. Lastly, we tried to select packs with ≥3 adult animals, because these packs tended to be more established and less apt to move or disperse. Once we identified study packs for each season, we randomly assigned each pack to treatment or control.

We captured one wolf within each pack and chemically immobilized it with 10 mg/kg of ketamine hydrochloride and 2 mg/kg of xylazine hydrochloride via an intramuscular injection (Kreeger 1996). We captured wolves using either a modified Newhouse number 14 foot-hold trap (Kuehn et al. 1986) with McBride springs and breakaway pan device, a Cable Restraining Device (17.78 cm × 19.70 cm cable with a stop at 38 cm), or a McBride number 7 foot-hold trap with Kevlar padded jaws. Once wolves were immobilized, we monitored them for temperature, respiration, and pulse. We sexed, weighed, measured, and pit-tagged wolves. We defined age based on tooth eruption and wear patterns (Van Ballengerghe and Mech 1975). We collected blood samples from all wolves for health and genetic analysis conducted by the WDNR. We fitted all healthy adult wolves (>1 yr) with a 400-g radiocollar with a 2-hour mortality sensor (Telonics, Inc., Mesa, AZ). In 2003, we also placed Televilt Global Positioning System (GPS) collars on 3 wolves, but all of these collars failed (see Results). We fitted treatment wolves with an Innotek Training Shock Collar (Invisible Fence Technologies, Garrett, IN) in addition to the radiocollar.

During the 2003 field season, we fitted shock collar units with factory probes onto a separate collar with the probes on the underside of the neck, which we shaved down to the skin to ensure probe contact (Fig. 1). In 2004 we fitted shock units with custom rounded probes and mounted them on the back of the radiocollar (i.e., back of the neck) via a custom drop-off design (Fig. 1). This new design had an extended battery life and was proven to eliminate damage to or irritation of the necks of animals wearing them (Hawley 2005). Also, we tested all shock collars for shock consistency before we fitted them on a wolf during the 2004 season. Our research was approved by the Institutional Animal Care and Use Committee at Central Michigan University (IACUC no. 01-03).

Adult wolves found to have major health problems (e.g., sarcoptic mange) and pups of the year were not included in our study. We fitted pups with radiocollars only for WDNR population monitoring. We intravenously administered 0.15 mg/kg of yohimbine hydrochloride to all chemically immobilized wolves as a reversal agent before releasing them (Kreeger 1996).

When possible, we selected control wolves from wolves that had been previously radiocollared by the WDNR to have experiments running concurrently. If possible we radiocollared and used as controls captured wolves that we did not shock-collar and use as treatments. Within treatment packs, we captured a second animal only if the first proved unusable in the experiment. To avoid variation in wolf behavior and movement patterns, we conducted all research during the rendezvous season, when adult wolves leave pups in a designated area between hunting and territorial excursions. We conducted experiments ≥1.6 km from capture sites to avoid site aversion by recently captured wolves.

We identified as bait sites forest trail intersections within each wolf's territory. We selected bait sites based on historic WDNR telemetry location data and track and scat surveys. For each site we defined an inner shock zone (extending 30 m from the center of the intersection) and an outer detection zone (extending from 30 m to 75 m from the center of the intersection). We baited the centers of the sites with one road-killed deer every 2–3 days as needed. We monitored all bait sites for tracks by brushing soil around the site before leaving and checking for new tracks upon arrival. We set up radio data loggers (HABIT Research Ltd., Vancouver, BC, Canada) to monitor wolf movements at each site. We used deep-cycle marine batteries to power data loggers, which lasted for approximately 2 months. We mounted data loggers in trees with antennas extending approximately 3 m above the ground. We used only trees with thick cover to conceal data loggers from wolves and humans. Data loggers scanned defined very high frequencies (VHF) for percent signal strength and recorded the date and

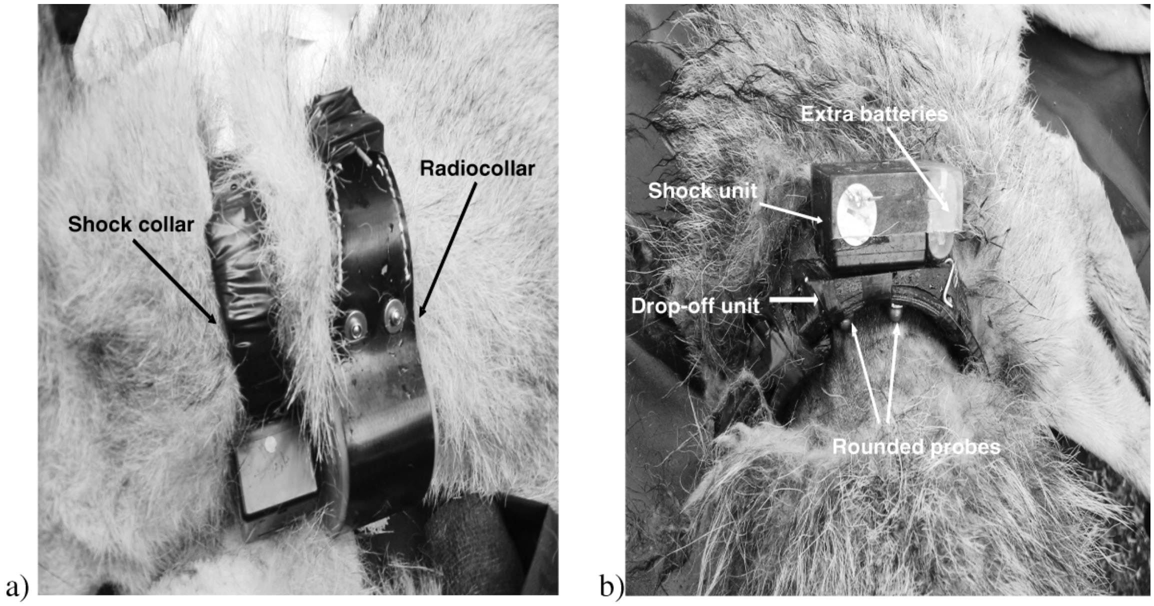

Figure 1. (a) Original shock collar design used on gray wolves in northern Wisconsin, USA, during the 2003 (Jun–Sep) field season. Example of shock collar placement used in 2003 treatment showing a wolf fitted with both Innotek (Invisible Fence Technologies, Garrett, IN) shock collar and Telonics (Telonics, Inc., Mesa, AZ) very high frequency (VHF) radiocollar. (b) New shock collar design used on gray wolves in northern Wisconsin during the 2004 field season. Example of shock collar placement used in 2004 treatment showing a wolf fitted with new shock collar design with Innotek shock unit mounted on the back of the Telonics VHF radiocollar. New shock collar design included 2 externally mounted 3-volt lithium batteries encased in a high-density polymer to extend battery life, rounded probes, and drop off designed to release shock unit in 2–3 months time. We shaved skin under the shock unit to ensure probe contact.

time the animal spent in the area. We calibrated percent signal strengths representing each zone by testing 10 Telonics radiocollars held at 50 cm above the ground. When the data logger began picking up a signal (>1%) the collar was approximately 75 m from the center of the zone (i.e., start of the detection zone). When the signal strength reached a mean of 20% (SD = 1.2%), the collar was approximately 30 m from the center of the zone (i.e., the start of the shock zone). As such, we considered a wolf recorded at 1–19% signal strength in the detection zone, and we considered a wolf recorded at 20–100% signal strength in the shock zone (Fig. 2). Data loggers allowed us to monitor all radiocollared wolves for time of visit to the shock and detection zone, length of visit, and distance from the center of the zone.

We placed shock towers at the center of each treatment site in close vicinity to the data logger. We mounted shock towers in a 65 cm × 100 cm wooden box containing a deep-cycle marine battery power source and custom shock timer (Schultz et al. 2005). Timers allowed for the shock unit to remain on for 13 seconds, then off for 13 seconds, continuously, which was intended to allow wolves time to react while not being shocked continuously. We removed antennas from shock transmitters to maintain a shock zone with a 30-m radius. Wolves wearing a shock collar would receive a low-impulse shock every 13 seconds, for 13 seconds upon entry into the shock zone. The outer detection zone served as a monitoring zone only; no shock was ever administered (treatments or controls) to wolves in this outer zone. Control animals did not receive a shock collar, yet we still monitored them via data logger in both zones.

As soon as it was established that collared wolves had visited bait sites at least once (which took 2–4 days), we began experimentation. Our experimental design included 1) 14-day before-shock period during which we recorded wolf movements at the site (no shock) for both treatments and controls; 2) 14-day during-shock period during which

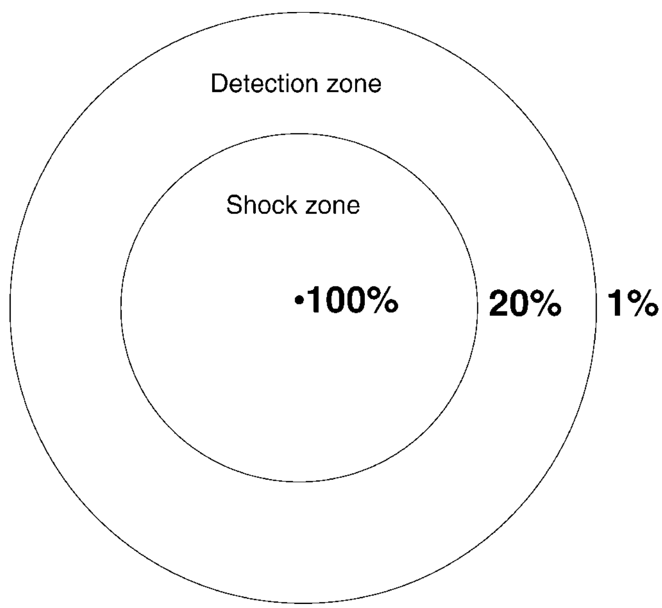

Figure 2. Shock and detection zone percent signal strength of shock collars worn by gray wolves in northern Wisconsin, USA, 2003. Percent signal strength of very high frequency collar beacon detected and recorded by the H.A.B.I.T. Ltd. data loggers (HABIT Research Ltd., Vancouver, BC, Canada) at the center of the zone, edge of the shock zone, and outer edge of the detection zone. We considered recordings between 1% and 20% signal strength in the detection zone. Recordings between 20% and 100 were in the shock zone.

we shocked treatment wolves upon entry into the shock zone; and 3) 14-day after-shock period during which we recorded wolf movements at the site (no shock) for both treatments and controls. The amount and extent of researcher visitations to drop bait and check equipment was consistent between treatments and controls (every 2–3 days).

All wolves were located via aerial telemetry at least once a week by the WDNR. We also located all treatment wolves at least every 2 days via vehicle-mounted ground telemetry. We only located control wolves via ground telemetry 1–2 times per week or when time allowed. Our vehicle-mounted telemetry system consisted of a 5-element yagi VHF antenna mounted 1 m above the roof of a truck. We mounted a compass rosette and marine electronic compass in the interior of the vehicle to provide accurate directional readings (Lovallo et al. 1994). We took $\geq$3 bearings on each animal from established waypoints. We used Locate II to perform triangulations and to gather estimated animal locations (Nams 1990). We used the Maximum Likelihood Estimation (MLE) system within Locate II.

We collected data loggers at each site at the end of the 42-day monitoring period. We downloaded data to a laptop computer via a HABIT Research Ltd. program. We used Excel (Microsoft Corporation, Redmond, WA) to sort out any static recordings such as those caused by lightning, airplanes, or radiotowers (wolf radiocollar recordings were at 50 pulses/min, whereas static recordings were usually >1,000 pulses/min). We also scanned a dummy frequency to ensure that recordings of wolf visitations were legitimate. We included only recordings on the specific VHF collar frequency at or near 50 pulses per minute. We sorted all recordings in Excel by chronological order of each visitation event.

We used data logger recordings for each treatment and control wolf to determine daily visitations. We counted a visitation as an entry into either zone (shock or detection). The animal had to leave the zone for 2 minutes before returning and registering a second visitation. We summed visitation events for each wolf, during each treatment period (before, during, and after), and in each zone (shock and detection).

We estimated mean time study wolves spent in the combined (shock and detection) zone per day, for each of the 3 time periods (before, during, after) from data logger readings. Because it was difficult to determine which zone the wolf was spending time in between data logger recordings (i.e., readings occurred every 3–12 sec), we pooled time spent in the shock zone with time spent in the detection zone. A wolf may simply turn his head, causing the data logger to pick up a weaker signal, thus causing a change in the percent signal strength, which may then be misrepresented as time spent in the wrong zone. We avoided this problem when recording individual visits to separate zones, because the wolf had to leave for an extended period of time and then return before we could consider it a separate visit. We counted each visit as a discrete moment in time, which was not possible when trying to estimate the amount of continuous time the wolf was spending in each zone. Thus, by pooling the 2 zones together for this dataset, we minimized this possible source of error.

We combined flight and ground-telemetry locations and used them as a third dataset. We emphasized treatment animals when obtaining ground telemetry locations; therefore, we did not collect adequate control data for this dataset. We prioritized locating treatment animals, which left little or no time for relocating control animals. We counted animals that we could not locate within 4 km of the bait site as 4.1 km from the site. We used ArcMap to plot all wolf locations on digital orthogonal photographs provided by the WDNR. We then measured distance from the center of the site for each location and calculated mean distance from the center of the zone for each time period.

We conducted statistical analyses using SAS statistical software (SAS Institute, Cary, NC). We examined visitation data using the Shapiro–Wilk test for normality. We log transformed all data and repeated the Shapiro–Wilk test to ensure data were normally distributed ($\alpha = 0.05$).

For visitation and temporal data at bait sites, we used a 2-factor repeated measures analysis of variance (ANOVA; PROC GLM; SAS Institute 1989) to examine between subject effects (i.e., group effects: control and shock collar), within subject effects (i.e, time period: before, during, after), and the interaction of group and time period. We used the univariate tests for within subject effects because we found no violation of Type H covariance after performing sphericity tests ($P = 0.318$ to 0.994; SAS Institute 1989). We used a contrast transformation to treat the first time period (before shocking) as a control level to which we compared the during- and after-shock time periods. We used a one-way ANOVA for correlated samples to detect variation of mean distance from the zone and to measure how wolf movements changed before, during, and after shock treatment. We used the Tukey test to decipher where significant differences occurred, if at all (Zar 1996). To justify pooling data for the 2003 and 2004 field seasons, we used a 2-sample t-test to test for differences between data for the before-, during-, and after-treatment periods.

RESULTS

We captured 17 wolves during the 2003 and 2004 field seasons and excluded 3 treatment wolves from the sample due to failure of GPS collars. We collected data for 5 treatment wolves and 5 control wolves from separate packs (Table 1). Although we used different collar designs for the 2 field seasons, we pooled our results for the seasons after finding no differences between data for the before-treatment ($P = 0.451$), during-treatment ($P = 0.206$), or after-treatment ($P = 0.347$) periods.

We did not find a group effect (i.e., between subjects effect) for wolf visitation to the detection zone ($F_{1,8} = 0.02$, $P = 0.905$). We detected an interaction between time period and group ($F_{2,16} = 4.02$, $P = 0.039$). Visitation to the detection zone during the shocking time period decreased in

Table 1. Capture data, collar information, and status of wolves in shock collar research in northern Wisconsin, USA, from June 2003 to September 2004.

Wolf	Sex	Wt (kg)	Pack	Study yr	Capture date	Date of initiation of preshock period	Collar	Status
M1	M	31	Little Rice River	2003	11 May 2002[a]	9 Aug 2003	Very high frequency (VHF)	Control
M2	M	37	Murray's Landing	2003	7 Jul 2003	9 Jul 2003	VHF + shock[b]	Treatment
F1	F	28	Bootjack Lake	2003	6 May 2003	20 Jul 2003	VHF	Control
M3	M	36	North Willow	2003	10 Jun 2003	14 Jun 2003	VHF + shock[b]	Treatment
M4	M	32	Augustine Lake	2004	29 May 2002[a]	20 Jun 2004	VHF	Control
F2	F	25	Averill Creek	2004	1 Aug 2003	25 May 2004	VHF	Control
F3	F	25	Bootjack Lake[c]	2004	30 May 2004	1 Jun 2004	VHF + shock[d]	Treatment
M5	M	39	Nine Web	2004	15 Jun 2004	19 Jun 2004	VHF	Control
F4	F	27	Pine Lake	2004	12 Jul 2004	15 Jul 2004	VHF + shock[d]	Treatment
F5	F	33	Somo River	2004	3 Aug 2004	7 Aug 2004	VHF + shock[d]	Treatment

[a] Previously collared by Wisconsin Department of Natural Resources personnel.
[b] Original shock collar design (shock collar separate from VHF collar).
[c] We used wolf F1 from this pack as a control during 2003 field season.
[d] New shock collar design (VHF + shock combined).

shock-collared wolves, but not in control wolves ($F_{1,8} = 7.54$, $P = 0.025$; Fig. 3a). We did not detect any decrease in visitation to the detection zone for shock-collared or control wolves in the after-shocking time period ($F_{1,8} = 0.00$, $P = 0.962$; Fig. 3a).

We did not find a group effect for wolf visitation to the shock zone ($F_{1,8} = 0.12$, $P = 0.743$). However, there was interaction between time period and group ($F_{2,16} = 10.65$, $P = 0.001$). Visitation to the shock zone during the shocking time period by shock-collared wolves decreased whereas control wolves did not demonstrate this trend ($F_{1,8} = 23.11$, $P = 0.001$; Fig. 3b). We noted a slight decrease in visitation to the shock zone for shock-collared, but not control wolves, by the after shocking time period ($F_{1,8} = 3.90$, $P = 0.084$; Fig. 3b).

We did not find a group effect for the number of minutes wolves spent in the combined zone ($F_{1,8} = 0.52$, $P = 0.492$). There was an interaction between time period and group ($F_{2,16} = 4.44$, $P = 0.029$). Shocked-collared wolves spent less time in the combined zone during the shocking time period, whereas control wolves did not demonstrate this trend ($F_{1,8} = 8.73$, $P = 0.018$; Fig. 3c). We noted no decrease in time spent in the combined zone for shock-collared or control wolves in the after-shocking time period ($F_{1,8} = 3.00$, $P = 0.122$; Fig. 3c). We commonly recorded false presence indications while data loggers were scanning dummy frequencies, although none of these were at the correct VHF pulse rate. All false positive recordings were $>1{,}000$ pulses per minute, whereas true presence recordings were between 48 pulses and 51 pulses per minute. Thus, we easily screened false positive recordings by pulse rate.

We detected a shift in mean wolf distance from the center of the site between the before-, during-, and after-treatment periods for treatment animals. The treatment sample size for this dataset was 4 instead of 5, because one treatment animal (Bootjack Lake) did not have sufficient location data to be included. Before treatment, wolves averaged 1.5 km from the center of the bait site (approx. 9 locations/period). During and after treatment, wolves averaged 2.2 km from the center of the bait site, which equaled a shift of 0.7 km or 32%, going from before-treatment to during- and after-treatment (Fig. 4). We found a difference in mean distance from the bait sites in the 3 time periods ($F = 7.29$, $P = 0.02$). A Tukey test detected differences between the before- and during-treatment and between the before- and after-treatment ($HSD_{0.05} = 855.34$, $P < 0.05$). We detected no difference between the during- and after-treatment periods (nonsignificant, $P > 0.05$).

DISCUSSION

Our results demonstrated that shock collars altered free-ranging, wild wolf behavior in and around a specific site. Mean time per day spent in the combined zones by treatment wolves decreased during treatment, which is important because if a wolf is not spending time in an area, then there is less time for a depredation to occur. Our results also documented a change in where wolves were spending their time 14 days after treatment. Treatment that occurred within the shock zone may have indirectly affected behavior of wolves in the detection zone, where no treatment ever occurred, which could be important when considering the idea of a buffer zone around a livestock pasture. By setting up the pasture as the shock zone, it may be possible to create an outer buffer zone (i.e., our detection zone) where wolf activity would decrease as an indirect effect of treatment occurring within the pasture or shock zone.

There is a possibility that mean time spent in the zone per day was directly correlated with mean distance from the zone. Shock-collared wolves shifted 0.7 km further away from the center of the zone during and after treatment occurred. If the animal's mean distance is shifted away from a pasture, there is a good chance it is going to spend less time in and around the pasture. Although 0.7 km may not seem substantial, it could be critical during a sensitive calving season. During shocking trials, shock-collared wolves remained in mostly forested, low-road density areas of their territories. This localization behavior could be important when considering management situations. Localization behavior may be a display of human avoidance by wolves, which could be important in excluding wolves from an area. Similar movement patterns were documented following a shock of a free-ranging wild wolf in Wisconsin

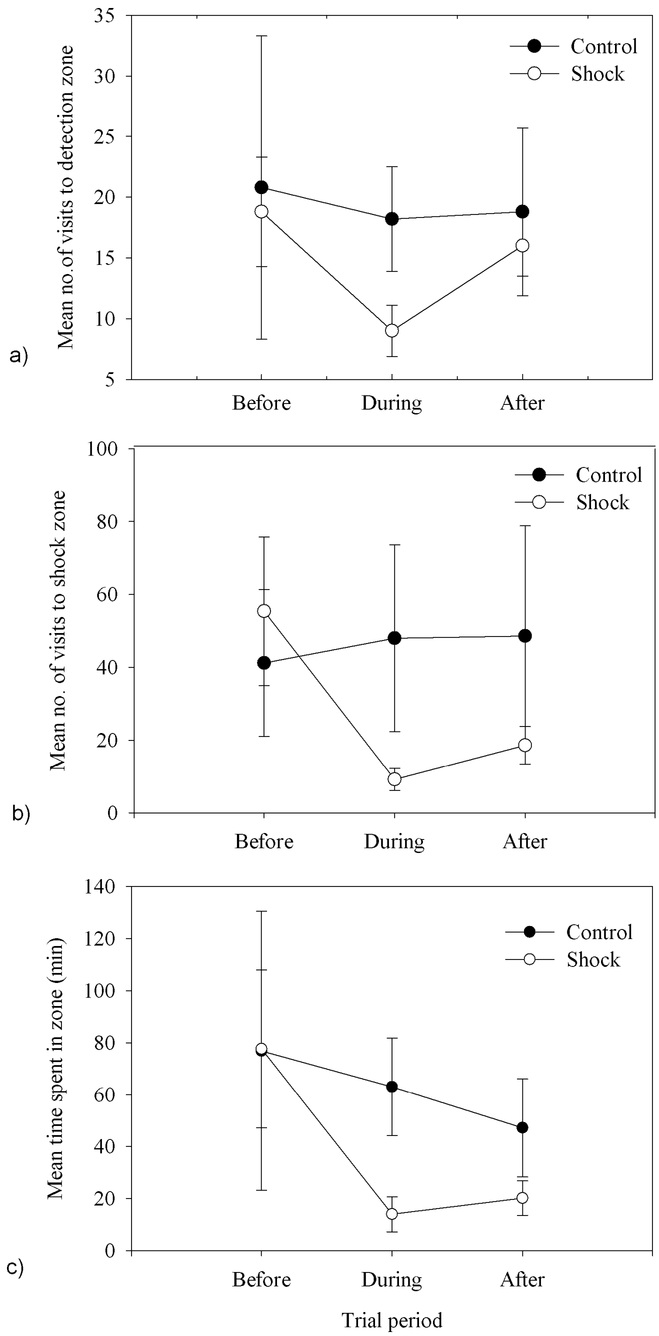

Figure 3. Mean number of visits to the detection zone (a) and shock zone (b), and mean minutes spent in the combined zones (c) by control and shock-collared wolves during the before-, during, and after-treatment periods in northern Wisconsin from June 2003 to September 2004. Standard error bars are included.

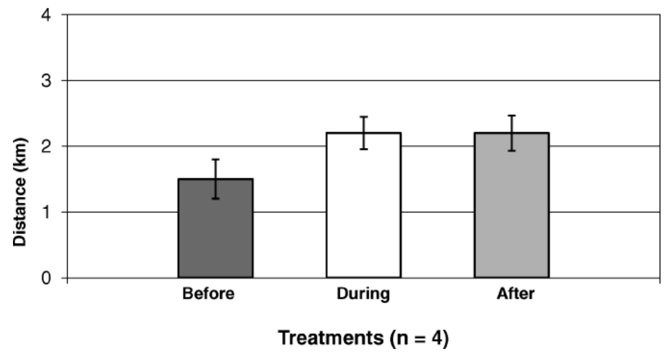

Figure 4. Mean distance of wolf locations from the center of the zone (km) before, during, and after treatment in northern Wisconsin from June 2003 to September 2004. We detected a significant change between the before- and during-treatment, as well as the before- and after-treatment periods with a one-way analysis of variance for correlated samples.

(Schultz et al. 2005). In 1998, the WDNR captured, shock-collared, and released a depredating wolf on a livestock operation. The wolf was monitored via radiotelemetry while receiving a shock and each time moved farther away from the farm. These movements demonstrated a large initial response to the shock and apparent disruption in wolf movements. The WDNR reported a decrease in depredations on the farm, but could not determine if any conditioning occurred (Schultz et al. 2005).

If we extrapolated our results to a management situation, we would consider a depredating wolf 80% less likely to even enter a livestock pasture while being treated with a shock collar for 14 days. If the wolf did enter the pasture after having received a shock, there would be a strong chance it would be much more wary than before (Andelt et al. 1999). So although there is an 80% reduction in visits to the area, there could be an even higher reduction in attempts to harass or kill livestock.

Although attack and kill behaviors are separate from consumption behaviors in wolves, presence of a dead deer (which we used for bait) in a wolf's home territory is more easily accessible than is a domestic cow in a human settlement (Shivik et al. 2003). In fact, most of our study packs remained in proximity to the baited sites in the pretreatment period and would consume each deer within 2–3 days. The length of our before-treatment monitoring period gave wolves 14 days to become comfortable feeding within the shock zone.

In a management situation, wolves would not be given this acclimation period, as the shock would be turned on immediately. In most cases, livestock pastures will occur on the edge of a wolf's territory, or at least a less familiar part of their territory (Fritts et al. 1992). It is possible that most free-ranging wild wolves will never feel completely confident around a human settlement. Furthermore wolves will in most cases have been trapped on or near the pasture in question before being fitted with the shock collar. This increased level of fear and awareness of humans could potentially increase efficacy of shock collars within a livestock pasture (Fritts et al. 1992). Because we observed few non-wolf tracks at either treatment or control bait sites other than the occasional coyote, interaction with other animals was not a factor in our study.

Prior to our research, no experimental assessment had been done on the possible use of existing shock collar technology as a nonlethal management method for free-ranging wolves. Thus, it is difficult to compare our research with past research, because only captive or observational studies of free-ranging wolves have been published. Andelt et al. (1999) and other studies demonstrated shock collars effectively deterring attacks on sheep by captive coyotes, yet research results on captive wolves have been mixed (Andelt 1999; Shivik et al. 2002, 2003). It is unclear why these 2 closely related species in captivity have shown such variation in their reaction to shock collars. Similar to Shivik et al. (2003), we found variability in wolf response to shock units during captive trials (Hawley 2005). We believe that much of the variability was attributable to technological variation within the shock collars (e.g., variable pulsing of shocks), rather than behavioral differences (Hawley 2005). It is possible that Shivik et al. (2003) incorrectly attributed variability in performance of shock collars to variability in animal response.

When shocking ceased, some of our treatment wolves slowly resumed normal movement behavior and began moving back to the shock site. Inconsistency in shock delivery may have played a role in the inability of shock collars to condition wolves to avoid the shock site long term. During the first field season with the original collar design, based on manufacturer specifications, we assumed that battery life would extend >2 months. However, we performed extensive field tests and discovered that batteries began to expire halfway through the treatment period, approximately 20–22 days. Although this may add more support to the effectiveness of the collars, because the wolves were only being shocked for an average of 7 days for the first field season, it is also a possible source of inconsistency in delivery of treatment. Shock collar battery life was extended to 50 days for the new collar design we used during the 2004 season.

The new design also had sources of inconsistency (Hawley 2005). During captive trials, we noted that collars would frequently shift or even flip completely, before correcting themselves upon further wolf movement (Hawley 2005). We believe that if a shock collar with a higher degree of consistency is developed and tested, results could show a long-term conditioning effect and a greater reduction in or complete elimination of both wolf visits and time spent in an area.

If shock collar battery life could be extended from 50 days to 100 days, reduction in visitations and time spent in the zone during treatment could prove highly significant in protecting livestock during the growing season. Treves et al. (2002) reported that 83% of all verified wolf depredations in Minnesota and 61% of all verified wolf depredations in Wisconsin occurred between the months of May and September. If wolves were excluded from livestock pastures during that period, we predict that most wolf depredations could be avoided (Gehring et al. 1996, 2006). Conditioning may not be necessary if shock collars could actively exclude wolves from a pasture for an extended period of time. Any long-term conditioning would then be considered additional protection. In chronic problem areas, 1 year of protection could be considered just as effective as lethal control (Fritts et al. 1992, Bradley et al. 2005). If there is any aversive conditioning carrying over to the following year, it could potentially save agencies the time and money of implementing lethal control measures on an annual basis. However, within nonlethal wolf management it should be a priority to develop and test new shock collar designs. With consistent, long-term correction ($\geq$14 days), the animal may learn a site-specific avoidance behavior.

MANAGEMENT IMPLICATIONS

Our results suggest that shock collars hold potential value for use as nonlethal control for free-ranging wild wolves in certain depredation management situations. However, additional research should focus on measuring the ability of shock collars to provide long-term conditioning by administering treatment for the full extent of the battery life and on improvement of collar design for shock consistency. Future research should also attempt to quantify effects shock-collared wolves may have on other pack members. We suggest the new shock collar design we used should be further developed and tested to extend battery life, consistent shock probe contact with the neck, and audible shock warnings.

ACKNOWLEDGMENTS

Our study was funded by Central Michigan University (Research Excellence Fund Award), Central Michigan University College of Graduate Studies, Defenders of Wildlife, and CITGO Petroleum, Inc. We are grateful for major logistical support provided by the WDNR. Additional logistical support was provided by HABIT Research Ltd., Innotek, and the Wildlife Science Center, Forest Lake, Minnesota. We also thank R. Clark, D. Murphy, and D. Hawley for their help.

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Associate Editor: Messmer.