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Tools and Technology

Shock Collars as a Site-Aversive Conditioning Tool for Wolves

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ABSTRACT Reduction of livestock losses from predators is a complex problem that requires the integration of lethal and nonlethal management tools. During 2005 and 2006, we tested shock collars for conditioning wild wolves (*Canis lupus*) in Wisconsin, USA, to avoid bait sites over an 80-day period. Treatment wolves ($n = 10$) visited shock zones less and spent less time at shock zones compared to control wolves ($n = 4$) during 40-day shock periods and 40-day post-shock periods. Treatment wolves remained away from shock zones for a greater number of days compared to control wolves. A smaller proportion of treatment pack members visited shock zones during shock and post-shock periods compared to control packs. Shock collars conditioned treatment wolves to avoid bait sites for >40 days and reduced visitation by other pack members. We also demonstrated the application of shock collars at the scale of livestock farms. Shock collars could serve as a useful nonlethal tool for managing livestock depredations, particularly in chronic problem areas and with endangered populations. © 2012 The Wildlife Society.

KEY WORDS behavior, *Canis lupus*, depredation, gray wolf, human–wildlife conflict, nonlethal management, shock collars, site-aversive conditioning.

Gray wolf (*Canis lupus*) populations have rebounded in the Upper Great Lakes region of the United States (Refsnider 2009). Greater numbers of wolves on the landscape can lead to an increase in the number of livestock depredations (Mech 1995). Increased levels of depredations and development of chronic depredation areas (i.e., farms that suffer livestock depredations for ≥3 consecutive year) will lead to greater animosity toward wolves, greater economic losses, and increased compensation payments made by state governments (Fritts et al. 1992, Mech et al. 2000, Treves et al. 2002). Thus, effective resolution of livestock depredations is necessary to ensure maintenance of recovered wolf populations and recovery of wolves in additional areas of their historic range.

Wolf managers in the United States primarily use lethal control as a management tool for minimizing conflict between wolves and human economic interests (Mech 1995). Lethal control is a valuable tool for managing wolf–human conflict (Berryman 1972, Archibald et al. 1991, Mech et al. 2000, Harper et al. 2008); however, it typically only reduces depredation for ≤1 yr (Fritts et al. 1992, Shivik et al. 2003, Bradley et al. 2005, Ruid et al. 2009) and may not reduce depredations at a regional scale (Musiani et al. 2005). Integrating lethal and nonlethal management tools would likely further reduce livestock depredations (Gehring et al. 2006, Hawley et al. 2009). Nonlethal management tools are generally more acceptable to the general public compared to lethal control (Reynolds and Tapper 1996, Reiter et al. 1999). Nonlethal management tools also may be the only option available for endangered wolf populations. However, few nonlethal tools have been rigorously tested on free-ranging wolves (Gehring et al. 2006, Hawley et al. 2009, Davidson-Nelson and Gehring 2010, Gehring et al. 2010*a*,*b*).

Shock collars may be a useful nonlethal management tool for depredation management (Andelt et al. 1999, Schultz et al. 2005, Hawley et al. 2009). Andelt et al. (1999) found that shock collars prevented captive coyotes (*C. latrans*) from attacking sheep for >4 months after corrective shocks were given. Shivik et al. (2003) found no evidence that long-term conditioning occurred in trials with captive wolves. Schultz et al. (2005) found shock collars prevented free-ranging wolves in one pack from visiting a study farm, and had no effect on the size of home range or maintenance of rendezvous site behaviors. Hawley et al. (2009) used an experimental design to test shock collars on wild wolves. They found that shock collars restricted wolf access to specific sites but

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did not lead to site-aversive conditioning. Our objectives were to 1) determine the ability of shock collars to reduce use of a specific site and lead to site-aversive conditioning, 2) determine whether avoidance behavior of a site was transferred to uncollared pack members, and 3) apply shock-collar technology to livestock farms in a depredation management scenario.

STUDY AREA

Our study area was located in northwestern Wisconsin, USA, including Ashland, Bayfield, Douglas, Sawyer, and Washburn counties. A majority of the land was publicly accessible and under county, state, federal, or commercial paper company ownership. The study area was comprised of 4 distinct ecological landscapes, as classified by the Wisconsin Department of Natural Resources (WDNR), including northwest lowlands, Superior coastal plains, northwest sands, and north-central forest (WDNR 2000). Agricultural land use did not add significantly to the economy of the 5-county region; however, farm operations that raised cattle, sheep, horses, and hay were dispersed across the landscape and comprised a small percentage of overall land cover (WDNR 2000). Approximately 33 wolf packs were located within the study area. Human density averaged between 7 persons/km^2 and 12 persons/km^2, considerably less than the statewide average of 37 persons/km^2 (WDNR 2000). A more detailed study area description was provided by Rossler (2007).

METHODS

We used WDNR track surveys and conducted our own track and scat surveys along roads and trails within our study area to identify potential study packs. Study packs contained $\geq$3 adult wolves. We randomly assigned each pack to treatment or control, but we prioritized gaining a greater sample of treatment packs. During 15 May–15 June 2005 and 2006, we captured one wolf from each pack using modified, Newhouse number 14 foot-hold traps (Kuehn et al. 1986). We chemically immobilized wolves using an intramuscular injection of 10 mg/kg ketamine hydrochloride and 2 mg/kg xylazine hydrochloride (Wydeven et al. 1995). We targeted adult wolves of either sex. We used tooth eruption patterns, tooth wear, and animal weight to estimate age and social status of captured wolves (Van Ballenberghe and Mech 1975, Gipson et al. 2000). Lactating female, diseased, and/or injured wolves were not included in our study. We fitted treatment wolves with a modified shock collar with an 80-day battery life (Rossler 2007). Shock collars included a 400-g radiocollar (Telonics, Inc., Mesa, AZ), to which we attached an Innotek (Invisible Fence Technologies, Garrett, IN) shock unit (Rossler 2007, Hawley et al. 2009). The total weight of the shock collar did not exceed 4% of body mass of wolves (Kenward 2001). A section of hair (10 cm × 10 cm) was shaved on the back of the neck of treatment wolves to ensure contact between the skin and probes of the shock collar (Andelt et al. 1999, Rossler 2007, Hawley et al. 2009). We fitted control wolves with only a radiocollar. Our research was approved by the Institutional Animal Care and Use Committee at Central Michigan University (IACUC no. 13-04).

Site-Aversive Conditioning to Bait Sites

We established an area known as a bait site within the territory of each study pack. Bait sites were created >1.6 km from where a wolf had been trapped to ensure no aversive conditioning due to trapping and handling near the capture site (Hawley et al. 2009). We located bait sites at the center of a primitive forest road intersection to allow wolves to associate with particular spatial features of the specific site. Similar criteria for bait sites were used to reduce variation between sites, thereby controlling for any confounding factors. We placed one road-killed deer (with minimal decomposition or destruction) at the center of each bait site every 3 days during the 80-day experiment. During each visit to the bait site, we noted whether the deer was consumed before placing a fresh carcass. At each site we defined a shock zone (circular area; Hawley et al. 2009) extending 70 m from the center of the bait site (Fig. 1). We placed radio data-loggers (HABIT Research Ltd., Victoria, BC, Canada) at the center of the bait site to determine the frequency of visitation by wolves and time spent by wolves in the shock zone. We programmed data-loggers to scan for the very high frequency (VHF) of the collared wolf in a study pack, and we included a dummy frequency to ensure that wolf locations (48–51 pulses/min) were legitimate (Hawley et al. 2009). Data-loggers recorded percent signal strength of radiocollars and date and time that wolves spent in the area. We calibrated data-loggers to record signal strength as a function of distance from the center of bait sites (Hawley et al. 2009). Signal strength of 60–100% identified a wolf in the shock zone.

We placed shock towers (Schultz et al. 2005, Hawley et al. 2009) at the center of bait sites (adjacent to data-loggers) in control and treatment packs. A reed switch timer, controlling the shock tower, was placed on a 1-min setting, which

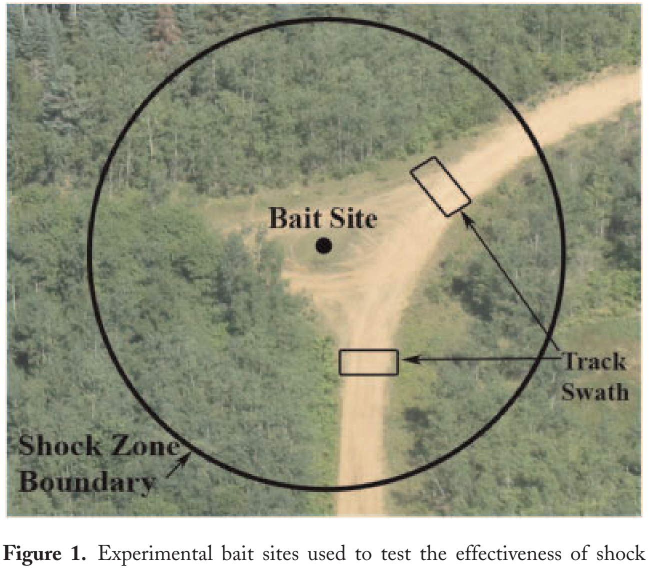

Figure 1. Experimental bait sites used to test the effectiveness of shock collars on gray wolves in northern Wisconsin, USA, May–September 2005 and 2006. The shock zone extended 70 m from the center bait site and track swaths were located 35 m from the center.

signaled the shock tower to emit a low-frequency impulse for 12-s intervals with a 48-s delay prior to the next impulse. Remote triggering of the shock tower allowed shock treatments to be administered to treatment wolves when researchers were not present at the bait site (Schultz et al. 2005, Hawley et al. 2009). We adjusted the shock-tower antenna to create a 70-m shocking radius around the bait site. No wolves received a shock when they were located outside the shock zone. Control wolves did not receive a shock collar, but data-loggers monitored their use of bait site zones, identical to treatment wolves.

We established track swaths on the primitive roads approaching each bait site by clearing all vegetation and large debris in 5-m-long strips as wide as the forest road. Removal of debris and vegetation created loose dirt where wolf tracks could be distinguished. We placed track swaths on the primitive roads to utilize wolf behavioral tendencies of traveling along paths of least resistance (Mech 1970, Gehring 1995). Track swaths were placed 35 m from center of bait sites and monitored every 3 days, concurrent with baiting the sites (Fig. 1). A single set of tracks entering the site was considered a single visitation. Tracks exiting the site were not recorded to prevent double-counting. Once data were collected, we raked track swaths to remove previous tracks. We used track swaths to record collared and uncollared wolf use of bait sites for treatment and control packs (i.e., proportion of wolf pack visiting bait sites). Wolves may travel as a pack in single-file lines (i.e., walking within each other's tracks; Mech 1970); therefore, our track-swath counts may have underestimated the number of wolves visiting bait sites. However, we assumed this potential bias would be consistent across control and treatment packs.

Radiocollared wolves visited bait sites at least once within 2–4 days of capture (Rossler 2007, Hawley et al. 2009). On the 5th day, post-capture, we began experimentation. Our experimental design included recording treatment and control wolf movements over 1) a 40-day shock period during which we shocked treatment wolves when they entered the shock zone, and 2) a 40-day post-shock period during which no wolves were shocked. This design simulated a depredation management scenario whereby shock-collar technology would immediately be implemented on a farm. The 40-day post-shock period was used to determine whether site-aversive conditioning of the bait sites occurred in treatment packs. We monitored treatment and control packs concurrently throughout the field season in order to decrease experimental bias due to time.

After the 80-day study period, we downloaded data from the data-loggers to a laptop computer using a HABIT Research Ltd. program. We chronologically sorted wolf visitation data from static recordings (pulse rate >1,000 pulses/min) and dummy frequencies (Hawley et al. 2009) using Excel (Microsoft Corporation, Redmond, WA). Data-loggers provided information for treatment and control wolves on 1) amount of time spent in the shock zone, 2) number of visits to the shock zone, and 3) number of days between shock zone visits. We standardized the time spent in the shock zone as mean number of minutes per day spent in the shock zone during the shock and post-shock periods. We counted a visitation to the shock zone when a wolf remained in this zone for ≥48 s because of the delay mechanism (48 s) in our shock-tower timer system. As such, a treatment wolf would need to be in the shock zone ≥48 s to receive a shock. We summed visitations to the shock zone and standardized them as number of visits per day for shock and post-shock periods. To determine site-aversive conditioning, we recorded the number of days between the last visitation to the shock zone during the shock period and the first visitation to the shock zone during the post-shock period for treatment and control packs.

For each check of track swaths, we summed wolf visits and divided total number of visits by estimated wolf pack size, which yielded number of visits proportional to pack size. Wolf pack size was estimated using track evidence from routine scouting of packs and howling surveys conducted at the completion of experimental testing. We conducted howling surveys at the end of experimentation so as to not bias wolf movements. We summed visitation data at track swaths for shock and post-shock periods, respectively. We divided wolf visits for each study period by the number of days track swaths were operational. We excluded days when rain interfered with our ability to accurately record wolf tracks. Standardized wolf visits at track swaths were recorded as number of visits in proportion to pack size per track-swath day.

Treatment and control wolves were located daily using vehicle-mounted ground telemetry. Our vehicle-mounted telemetry system consisted of a 5-element Yagi antenna, electronic compass, and compass rosette to gain accurate locations (Lovallo et al. 1994). We estimated locations with ≥3 bearings and triangulation using Locate 3 (V. O. Nams, Truro, NS, Canada). We used the maximum likelihood estimator to generate error polygons for each location. We used the 100% minimum convex polygon (MCP) method to estimate home-range size of treatment and control wolves over the 80-day study period (Powell 2000). We used ABODE (P. N. Laver, Blacksburg, VA) within ArcGIS and Excel to conduct asymptotic analysis to determine the number of radio locations required to reach a stable home-range size (Harris et al. 1990). We used the MCP estimator for comparison to home-range size of Wisconsin wolves not included in our study (Wydeven et al. 2004). We used the Point Distance Tool within ArcToolbox to calculate the linear distance each telemetry point (for treatment and control wolves) was from the bait site during the shock and post-shock periods. We standardized the distance of locations from the bait site by dividing by the home-range size for each study pack.

We used the Shapiro–Wilk test within SAS (SAS Institute Inc., Cary, NC) to determine whether data were normally distributed. We log-transformed data that were not normally distributed and checked again for normality. All data analyzed met assumptions for normality and equal variance after transformation. We used Minitab 14 (Minitab Inc., State College, PA) and a paired *t*-test (Zar 1996) to compare shock period and post-shock period data for treatment and control wolves, respectively. We used a 2-sample *t*-test (Zar 1996) to compare treatment and control packs during the shock and post-shock periods, respectively. We used a significance level of $\alpha = 0.05$. All results presented in figures represent non-transformed data for ease of interpretation.

We accounted for cost of use of shock collars in this research so that managers would have these data available for depredation management decisions. We quantified costs into 4 categories: 1) trapping wolves, 2) shock collars, 3) shock towers, and 4) labor for monitoring shock systems. We used WDNR estimates to calculate costs for trapping wolves by combining fuel, equipment, and labor expenses. The cost of shock collars included the shock unit and VHF radiocollar developed by Rossler (2007). We included costs of shock transmitters, batteries, and miscellaneous equipment for construction of shock towers. We estimated labor for monitoring shock systems as monthly cost for one graduate research assistant (stipend and fringe benefits) involved in this study.

Site-Aversive Conditioning to Livestock Farms

During the study, we obtained permission to test shock systems on 2 farms that experienced wolf depredation in 2004. The farms, designated as Farm A and Farm B, allowed us to place data-loggers and shock towers in the center of livestock pastures. We placed data-loggers on fence posts to elevate them 2–3 m off the ground in order to protect them from livestock damage and to maximize the range (800 m) of detection for radiocollared wolves. We used a 45-cm antenna on the shock transmitter to create a 0.8-km-radius shock zone around the shock tower. This distance was adequate to cover all pastures on each of the farms and create a 0.3-km shock-zone buffer on all sides of the pasture, outside the livestock fencing. We walked throughout livestock pastures and the perimeter of each farm with a test shock collar to ensure the shock transmitter and data-logger were communicating with the shock collar. Shock towers were monitored and remained active during 7 June–23 August 2005. Data-loggers remained active on the farms during 7 June–8 October 2005, to determine visitation to the farm after shock collars were no longer functional. Shock-collared wolf visitation to farms was determined using data downloaded from the data-loggers and recorded as number of visits per day.

RESULTS

During 2005 and 2006, we monitored 10 treatment (8 M, 2 F; Table 1) and 4 control wolves (2 M, 2 F; Table 1). One control wolf (W444) was previously trapped and radiocollared by the WDNR. However, during trapping attempts in 2005, she was captured and later pulled out of the trap before immobilization. We considered her to have been retrapped even though she was not immobilized and processed. A female wolf, previously collared by the WDNR in 2005 and not used in previous research, was also used as a control in 2006. We collected 466 ground telemetry locations on treatment wolves ($\bar{x} = 22$ locations/wolf during shock period and $\bar{x} = 23$ locations/wolf during post-shock period). We collected 144 locations on control wolves ($\bar{x} = 23$ locations/wolf during both shock and post-shock periods).

Site-Aversive Conditioning to Bait Sites

Treatment wolves spent an equal amount of time in the shock zone during the shock period ($\bar{x} = 1.1$ min/day, SE $= 0.4$) and post-shock period ($\bar{x} = 1.3$ min/day, SE $= 0.5$; $t = -0.30$, $P = 0.385$). Control wolves spent less time in the shock zone during the shock period ($\bar{x} = 13.6$ min/day, SE $= 3.0$) compared to the post-shock period ($\bar{x} = 21.2$ min/day, SE $= 4.2$; $t = -5.55$, $P = 0.006$). Treatment wolves spent less time in the shock zone during the shock ($t = -4.26$, $P = 0.001$) and post-shock ($t = -5.78$, $P \leq 0.001$) periods compared to control wolves (Fig. 2a).

We found no difference in the number of visits treatment wolves made to the shock zone during the shock period ($\bar{x} = 0.2$ times/day, SE $= 0.06$) and post-shock period ($\bar{x} = 0.2$ times/day, SE $= 0.06$; $t = 0.26$, $P = 0.400$). Control wolves visited the shock zone less during the shock period ($\bar{x} = 0.9$ times/day, SE $= 0.15$) compared to the post-shock period ($\bar{x} = 1.4$ times/day, SE $= 0.25$; $t = -2.55$, $P = 0.042$). Treatment wolves visited the shock zone less than control wolves during the shock ($t = -4.26$,

Table 1. Capture data and status of wolves in shock-collar research in northern Wisconsin, USA, May–September 2005 and 2006.

Wolf	Sex	Weight (kg)	Capture date	Pack	Study year	Status
W523	M	32	27 May 2005	Bearsdale	2005	Treatment
W518	M	36	31 May 2005	Smokey Hill	2005	Treatment
W519	M	45	3 Jun 2005	Bibon Swamp	2005	Treatment
W556	M	nw[a]	26 May 2005	Moreland Lake	2005	Treatment
W498	F	nw[a]	9 Jun 2005	Shoberg Lake	2005	Treatment
W522	M	35	27 May 2005	Rainbow Lake	2005	Control
W444	F	nw[a]	13 Jun 2005	Hellhole Creek	2005	Control
W524	M	34	24 May 2006	Casey Creek	2006	Treatment
W526	F	nw[a]	10 Aug 2005[b]	Lake Nebagamon	2006	Control
W565	M	34	5 May 2006	Bird Sanctuary	2006	Control
W520	F	30	13 Jun 2006	Foxboro	2006	Treatment
W517	M	32	16 May 2006	North Empire	2006	Treatment
W473	M	42	23 May 2006	Moose Lake	2006	Treatment
W552	M	29	18 May 2006	Moose Road	2006	Treatment

[a] No wt recorded at capture.

[b] Previously captured by Wisconsin Department of Natural Resources personnel.

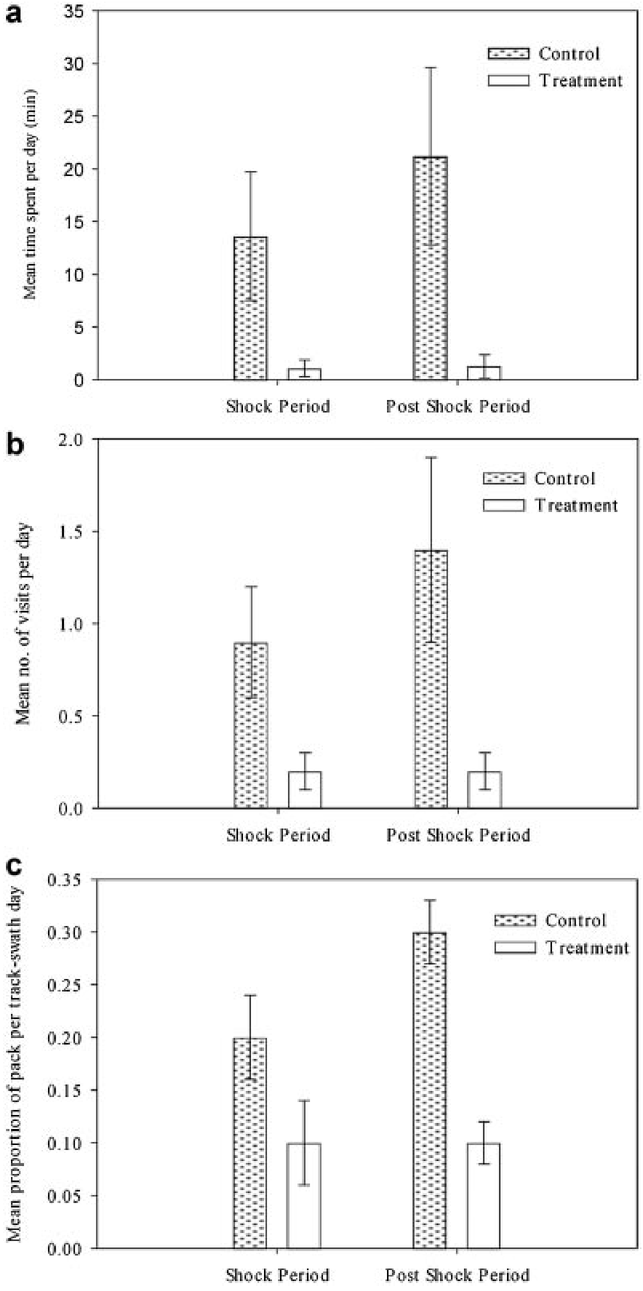

Figure 2. Mean minutes per day (a), mean visits per day (b), and mean proportion of pack visits per track-swath day (c) by treatment and control wolves during shock and post-shock periods in northern Wisconsin, USA, May–September 2005 and 2006. Error bars are ±2 standard errors.

$P = 0.001$) and post-shock ($t = -5.78$, $P \leq 0.001$) periods (Fig. 2b). We also found that a greater number of days elapsed between visits to the shock zone for treatment wolves ($\bar{x} = 41.5$days, SE $= 4.5$) compared to control wolves ($\bar{x} = 5.8$days, SE $= 2.6$; $t = 4.83$, $P \leq 0.001$).

We found no difference in the proportion of the wolf pack visiting bait sites each day during the shock and post-shock periods for treatment ($t = 1.30$, $P = 0.112$) and control ($t = -1.96$, $P = 0.072$) packs. However, a smaller proportion of treatment pack members visited the shock zone during the shock period ($t = -3.53$, $P = 0.002$) and post-shock period ($t = -9.70$, $P \leq 0.001$) compared to control packs (Fig. 2c). In 7 of 10 treatment packs, no pack members visited bait sites once shocking occurred during the shock period.

Home-range size was greater for treatment wolves ($\bar{x} = 82\,\text{km}^2$, SE $= 10$) compared to control wolves ($\bar{x} = 35\,\text{km}^2$, SE $= 6$) for the 80-day monitoring period ($t = 2.91$, $P = 0.013$; Fig. 3). Treatment wolves were located closer to bait sites during the shock period ($\bar{x} = 3.5$ km, SE $= 0.5$) compared to the post-shock period ($\bar{x} = 4.5$ km, SE $= 0.4$; $t = -2.03$, $P = 0.037$). We found no difference in the distance control wolves were located from bait sites between the shock and post-shock periods ($t = -0.14$, $P = 0.551$). Treatment wolves were located farther from bait sites during the shock period ($t = -2.46$, $P = 0.030$), and the same distance during the post-shock monitoring period ($t = -0.49$, $P = 0.631$) compared to control wolves.

Wolf trapping costs ranged from US$ 1,000–1,500/wolf (A. P. Wydeven, unpublished data). Our shock-collar design incorporating a modified Innotek shock unit (US$ 145/unit) and Telonics radiocollar (US$ 280/unit) was an estimated US$ 425/collar. We constructed shock towers at an estimated cost of US$ 300/tower. Graduate research assistant costs were US$ 1,579/month. Total costs to trap and establish the shock-collar system ranged from US$ 1,725 to US$ 2,225/wolf, excluding labor costs for monitoring. Shock-collar equipment cost (i.e., shock collar and shock tower) was US$ 725/site.

Site-Aversive Conditioning to Livestock Farms

We recorded 2 visits on Farm A by a shock-collared wolf during the shock period (4 Jul and 20 Aug 2005; Fig. 4). No other visitations were recorded on Farm A during the monitoring period. We recorded zero visitations on Farm B. However, U.S. Department of Agriculture Animal and Plant Health Inspection Service-Wildlife Services (USDA APHIS-WS) confirmed a depredation of a pony foal on Farm B on 12 August 2005. We suspect this was caused by members of an adjacent pack. Farm B was located near the eastern edge of the treatment pack and proximate to 3 known neighboring wolf packs. U.S. Department of Agriculture

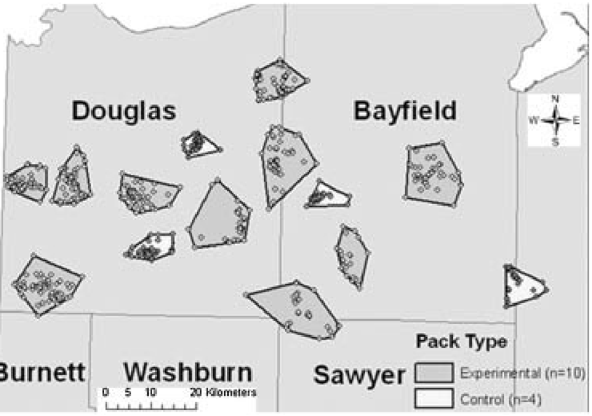

Figure 3. Minimum convex polygon home ranges for shock-collared and control wolves in northern Wisconsin, USA, May–September 2005 and 2006.

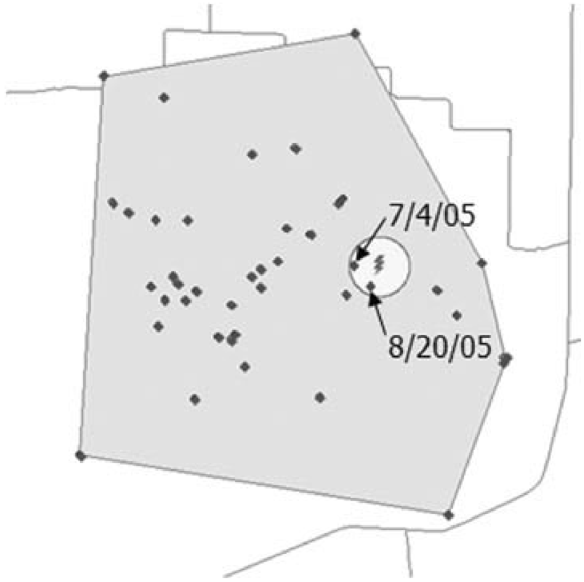

Figure 4. Minimum convex polygon home range and radio locations for shock-collared wolf and test farm (Farm A) in northern Wisconsin, USA, 7 June–23 August 2005. The test farm and shock zone is shown by the light gray circle with lightning bolt in center. The shock tower was active throughout this time period.

APHIS-WS trapped and euthanized 2 adult male wolves within 0.8 km of Farm B. Neither of the 2 adult wolves trapped by USDA APHIS-WS had been radiocollared or fitted with a shock collar. Track evidence before the 2 adult wolves were euthanized, and howling surveys conducted afterward, indicated there were 4 adult wolves and 1–3 pups in the treatment pack. We found no evidence that the size of the treatment pack decreased after removal of the 2 adult males by USDA APHIS-WS. Of the 4 adult wolves in the treatment pack, 2 were radiocollared adult males. The presence of pups indicated ≥1 of the other 2 wolves to be a female.

DISCUSSION

Shock collars appear to be effective in modifying foraging behaviors and/or movements in captive coyotes (Linhart et al. 1976, Andelt et al. 1999), captive wolves (Shivik et al. 2003), island foxes (*Urocyon littoralis*; Cooper et al. 2005), and wild wolves (Schultz et al. 2005, Hawley et al. 2009; this study). Similar to Hawley et al. (2009), we found that shock collars reduced the amount of time and the number of visits by wolves to specific sites. We found a 12- to 16-fold reduction in amount of time at sites and 4- to 7-fold reduction in visitation by shock-collared wolves compared to control wolves. During active shocking, treatment wolves also were displaced a greater distance away from bait sites compared to control wolves. We found shock collars aversively conditioned wolves to avoid bait sites for ≥1 month, whereas control wolves visited bait sites approximately weekly. Further, with only 1 member of a wolf pack shock-collared, we reduced the use of bait sites by other pack members compared to control packs. We also successfully used shock-collar systems on livestock farms as a demonstration of a depredation management scenario similar to Schultz et al. (2005).

Operant conditioning is applicable to our results. Operant conditioning is characterized by a response to a stimulus becoming more frequent if followed by positive consequences but less frequent if followed by negative consequences (Skinner 1981). Aversive conditioning is learning in which a punishment or other unpleasant stimulation is used to associate negative consequences with an undesirable response, therefore reducing the frequency of that response. Our design relied on a shock (negative consequence) received by wolves when visiting the bait site (undesirable response). Our design used free-operant avoidance learning, whereby no discrete stimulus was used to signal a subsequent consequence (Sidman 1953). Often psychological studies incorporate a signal stimulus with an unpleasant stimulus to condition test animals to avoid undesirable responses (Olton 1973). Schultz et al. (2005) relied on an auditory, beeper system as a signal stimulus to aversive shock stimuli. We relied on the specific site where the road-killed deer was placed to act as the signal stimulus.

Many animals are capable of spatial learning and use cognitive maps for travel and habitat use (Bell 1991). Wolves are intelligent, territorial animals with the ability to learn readily and retain what is learned for extended lengths of time (Mech 1970). We suggest avoidance of bait sites by treatment wolves was due to their ability to learn and associate the negative stimulus (shock) with the location (signal stimulus) in which the shock was administered. Denny et al. (1959) found lab rats preferentially associated a shock with a given location rather than with coextensive auditory stimuli. All treatment wolves were shocked more than one time at the same bait site, and bait sites remained consistent throughout the entire 80-day study period. Biegler and Morris (1996) found that consistency in environmental features increased the potential for spatial learning. We suggest that reinforcement of negative shock stimuli with the signal stimulus and environmental features of the bait site allowed wolves to associate the shock with the bait site and use cognitive mapping and spatial learning to associate negative consequences with the bait site. Treatment wolves likely associated negative stimuli with bait site locations and not road-killed deer placed at sites. Wolves were shocked when they entered the shock zone surrounding bait sites, but not shocked coincident with consuming deer. If wolves were shocked instantaneously with consumption of deer, it is likely aversive conditioning would occur to the deer bait. For example, Andelt et al. (1999) conditioned coyotes to avoid attacking sheep via shocking coyotes immediately during their attempted attacks on sheep. Treatment wolves remained within their home ranges and none died of starvation throughout the course of the study or after the research was completed.

Coppinger and Coppinger (2001) found most domestic dogs would not learn to avoid a specific behavior after only one correction. Shivik et al. (2003) noted high variability in the response of captive wolves to corrective shocks, which likely leads to the lack of aversive conditioning.

Hawley et al. (2009) suggested that variability in the pulsing of shock in collars was a likely explanation for variation in response of wolves to shock collars. Similar to Hawley et al. (2009) we removed this technological variation in shock collars via testing of individual collars. The short duration of the shock trial (14 days) in the Hawley et al. (2009) study likely reduced the probability of long-term aversive conditioning. We used a 40-day shocking period to allow treatment wolves to be shocked at least once, with time for additional shocking treatments to reinforce the negative stimulus upon return to bait sites. Our study suggests that shock collars influenced behavior of wolves around bait sites and wolves developed avoidance learning and aversion to specific areas for >40 days after 40 days of shock treatment. Control wolves, experiencing no shock stimulus, increased time spent at and visitation rates to bait sites by 56%. Control wolves had a positive association or conditioning (Bell 1991) to bait sites (i.e., repeated positive, food stimulus with no negative stimuli). Hawley et al. (2009) also found similar results with control wolves, which increased visitation 18% during trial periods.

No previous study has addressed questions dealing with behavior of uncollared wolf-pack members in relation to a wolf fitted with a shock collar. We found uncollared wolves in treatment packs visited bait sites less than uncollared wolves in control packs. Wolves are social animals and there is continuous information transfer and communication between pack members related to social hierarchy—dominance, temperament, injury, and hunting strategy (Mech 1970). Information transfer between pack members occurs directly via physical contact, eye contact, and body postures (Mech 1970). Weingrill et al. (2005) suggested direct visual contact during shocking was necessary for social learning to occur in vervet monkeys (*Chlorocebus aethiops*). Thus, if a treatment wolf entered a bait site and received a shock, but no other members of the pack were with that wolf, it is unlikely that information transfer would occur. Transfer of information may occur later upon subsequent visits. Direct transfer of information is more likely to occur when members of a pack are together while visiting a specific site and a shock-collared wolf receives a shock and then proceeds to retreat from the site. Indirect communication is also an important part of wolf social interaction, particularly during denning and rendezvous periods when pack cohesion is reduced (Mech 1970). Avoidance of bait sites could be communicated through scent marking in the form of defecation, urination, scratching, and/or gland secretion (Mech and Boitani 2003). Other wolves visiting the site may smell these secretions associated with distress and avoid the site. However, washing away of scent or diminished concentration over time may occur before other pack members visit the site, thus prohibiting indirect communication. The loss or decreased effectiveness of scent and lack of direct communication may account for continued visitation by some nonshock-collared pack members in 3 of 10 treatment packs.

Although shock-collared wolves were displaced from specific locations within their home range, the size of their summer home ranges was the same as summer home ranges for Wisconsin wolf packs not included in our study (Wydeven et al. 2004, WDNR 2006). Schultz et al. (2005) found shock collars did not negatively impact movement behavior, with regard to home range, of treatment wolves. In our study, shock-collared wolves did not disperse outside their home range after receiving a shock at bait sites. Home-range size for control wolves was less than half the size of summer home ranges for Wisconsin wolf packs not included in our study (Wydeven et al. 2004, WDNR 2006). Localized feeding of wolves (i.e., at bait sites) on a consistent schedule was likely the reason for reduced home-range size. Control wolves likely regarded bait sites as a regular source of food resources, without a negative consequence. We also found that control wolves shifted their movements and spent more time proximal to bait sites. Hawley et al. (2009) suggested the localized feeding of wolves, which were not subjected to a negative stimulus, influenced the distribution of wolves upon the landscape. Fritts et al. (1992) suggested that carcass disposal sites (i.e., localized areas where dead livestock are disposed by farmers) could increase wolf use of agricultural areas. We suggest that localized feeding could be used as a possible nonlethal depredation-management tool by diverting wolf use away from livestock areas. Diversionary feeding (as shown in our study) could constrict home-range size and shift wolf movements away from livestock. Boertje et al. (2010) demonstrated that diversionary feeding could reduce predation on moose calves in Alaska, USA. Further research should investigate the use of diversionary feeding as a nonlethal management tool.

Schultz et al. (2005) and our tests on livestock farms demonstrate the application of shock collars for depredation management. However, our sample size was low and we lacked control farms in this portion of our study to gauge overall effectiveness of shock collars in a depredation-management scenario. An understanding of where historical home-range boundaries are located is a major issue that must be addressed before implementing shock collars. Schultz et al. (2005) found shock collars can shift an individual wolf away from an agricultural area. If a farm resides on the boundary of 2 or more wolf packs, shifting the movements of only 1 pack may leave the territory around the farm vacant for other wolves to occupy. A nonshock-collared pack shifting its territory to encompass the farm may continue with depredation behavior. We believe this may have happened on 1 of our farms. Treves et al. (2002) reported that 61% of all verified wolf depredations in Wisconsin and 83% of verified wolf depredations in Minnesota, USA, occurred during May–September. Our current shock-collar design, with an 80-day battery life, would provide 2.6 months of reduced visitation by a shock-collared wolf to a farm. Based on our results, we predict additional avoidance of farms by wolves after expiration of the batteries via aversive conditioning. Thus, a significant portion of the season when depredations occur could be addressed with shock collars. Increasing shock-collar battery life could extend the shocking period and likely enhance aversive conditioning.

MANAGEMENT IMPLICATIONS

Shock collars could serve as an important management tool in chronic depredation areas and/or where wolves are endangered (e.g., southwestern United States). The use of shock collars on farms experiencing chronic depredation activity that is not alleviated through other control measures is an appropriate wolf management consideration. Shock collars may also be appropriate when wolf depredations occur on isolated farms in the midst or edge of a large protected area where lethal control is undesirable or prohibited. Future research should examine long-term avoidance patterns of wolves fitted with shock collars and the influence shock collars have on pack dynamics and social learning.

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