RESOLVING CONFLICTS OF MOUNTAIN PLOVERS (*CHARADRIUS MONTANUS*) BREEDING ON AGRICULTURAL LANDS IN COLORADO

FINAL REPORT
APRIL 29, 2005

Victoria J. Dreitz[1]
Colorado Natural Heritage Program
Colorado State University
Fort Collins, CO 80523
phone: (970) 226-9490

Executive Summary.

The Mountain Plover (*Charadrius montanus*) is a Great Plains species inhabiting agricultural fields and native short-grass prairie. The eastern plains of Colorado are considered the stronghold for Mountain Plovers. The Mountain Plover population has been suggested to be declining over the past century, with a loss of nearly two-thirds of the population (Knopf 1996a). We investigated one factor suggested to be driving population declines on reproduction in eastern Colorado, the impacts of private, agricultural lands on breeding activity.

From 2001 thru 2003 we located Mountain Plover nests throughout known historical areas in eastern Colorado. Our success on accessing private lands was relatively high, covering 100,000 to 220,000 acres throughout the study. The distribution of our study sites for breeding plovers was consistent with the statewide findings of Kuenning and Kingery (1998). The low-density of most breeding plover populations and logistical constraints of cropland fields hindered the use of distance sampling to estimate plover densities on cropland and rangeland. We evaluated a recently new technique, patch occupancy surveys, to estimate abundance of plovers. Our preliminary evaluation suggests that the patch occupancy method is feasible but needs to be further evaluated at a broader scale in eastern Colorado.

We monitored 395 nests during our study, with the majority of nests located on cropland in both idle and wheat fields. Nest success on cropland and rangeland was equivalent: however, the cause of egg mortality differed between the two habitats. Soil compaction practices are the only agricultural practice that totally destroy nests. Because we can not suggest an alternative practice for soil compaction, we proposed a volunteer incentive program. This volunteer incentive program is designed to allow awareness of plover nesting activity by marking nests on croplands prior to any agricultural activity so destruction of nests can be avoided. This program has the potential to "grow" the continental population of Mountain Plovers.

Because Mountain Plover chicks are precocial, mortality of chicks on cropland is seldom the result of agricultural practices. Home range size during brood rearing was similar on cropland and grassland but varied with the size of the prairie-dog habitat in which the adult nested. Daily movements for brood rearing were similar across habitat types. No pattern in movements on or between cropland and grassland existed, however, broods that hatched on prairie-dog habitat stayed on this habitat. Chick survival was similar between cropland in 2002 and prairie-dog habitat in 2003.

---

[1]Current Address: Colorado Division of Wildlife, 317 W. Prospect Road, Fort Collins, CO 80526, (970)-472-4313, Victoria.Dreitz@state.co.us

INTRODUCTION

The Mountain Plover (*Charadrius montanus*) is an endemic species of the Great Plains region (Mengel 1970), with a breeding range that includes short-grass prairies primarily in Colorado, Wyoming, and Montana (Graul and Webster 1976). Colorado is considered the continental stronghold for Mountain Plovers with over 50-70% of the population believed to breed in the eastern half of the state (Graul and Webster 1976, Knopf 1996a, Kuenning and Kingery 1998). Similar to other Great Plains birds, Mountain Plovers have declined over the past century. Annual declines using Breeding Bird Survey data from 1966-1996 are reported to be 2.7%, corresponding to a loss of nearly two-thirds of the population in this time (Knopf 1996a). Factors driving population declines have been suggested to be acting on both reproduction (Knopf 1996a, Dinsmore 2001) and winter stages (Knopf and Rupert 1995, Wunder and Knopf 2003).

The short-grass prairie ecosystem, long considered the primary habitat of Mountain Plovers (Graul 1975), is the most endangered ecosystem in North America (Samson and Knopf 1994, 1996). Historically, short-grass prairie was maintained by a "shifting mosaic" of habitat patches shaped by excessive grazing and fire regimes (Knopf 1996b, Lomolino and Smith 2003, Smith and Lomolino 2004). Today, the short-grass prairie ecosystem is a more stabilized ecological system (Ostlie et al. 1997), one perhaps less capable of renewing itself and adapting to environmental change (Tilman et al. 1996). The conversion of native prairie to agricultural lands, the suppression of fire, and the reduction of grazing guilds have changed the short-grass prairie to its current homogenized state. Some ecological processes may be functionally extinct with the loss of fire and grazing by native herbivores (Knopf 1994, McPherson 1995). The impacts of losing these ecological processes on the wildlife species inhabiting the short-grass prairie ecosystem are unknown.

One factor suggested to be contributing to the decline of Mountain Plovers (USFWS 1999) is the attractiveness of breeding birds to private, agricultural lands (Knopf and Rupert 1999, Shackford et al. 1999). Plovers prefer sites with sparse, short vegetation and bare ground for nesting; often using disturbed sites within grassland (e.g. prairie-dog towns, intensively grazed areas, burns) rather than in the grass landscape specifically (Olson and Edge 1985, Knopf and Miller 1994, Knopf and Rupert 1996). In the southeastern part of their breeding range (Knopf 1996a), particularly eastern Colorado, plovers frequently nest on agricultural fields where mechanical destruction of eggs and young chicks by farm machinery may reduce reproductive success (Knopf and Rupert 1999). Additionally, plovers may re-nest on fields that have recently experienced agricultural activity but are believed to abandon the re-nest effort when the new crop grows to a height that represents a psychological barrier to this bird (Knopf 1996a). However, Shackford et al. (1999) speculated (based on a weak assumption of nest fate) that nest predation rates might be lower on agricultural fields than those on grasslands (Knopf and Miller 1994, Knopf and Rupert 1996), and that there might be a potential trade-off between losses from predation on grasslands and agricultural practices on agricultural lands.

Both Knopf and Rupert (1999) and Shackford et al. (1999) suggested that additional research into plover use of agricultural lands is warranted, especially to quantify how agricultural practices impact nest success of Mountain Plovers. Given the current paucity of scientific data on plover nest success in agricultural fields, we simply do not know if plover reproduction is greater, lesser, or unaffected on agricultural lands. In addition, research to directly compare the density and reproductive success of Mountain Plovers on range and agricultural lands is needed to better quantify the impacts, if any, of different agricultural practices on the continental population.

Herein, we report the findings from our research study aimed at providing scientific information on the relevance of private, agricultural lands used for breeding activity by Mountain Plovers. Information from this study will be used to identify and resolve hypothesized conflicts between Mountain Plover conservation efforts and common agricultural practices; aiding in the recovery of the Mountain Plover population. This research is a cooperative effort of the Colorado Natural Heritage Program (CNHP), Colorado State University (CSU), Colorado Farm Bureau, Colorado Division of Wildlife, U.S. Fish and Wildlife Service (USFWS), and U.S. Geological Survey-Biological Resources Division.

OBJECTIVES

1. Estimate and compare plover densities on agricultural lands, grasslands and prairie-dog towns to determine relative importance of the contiguous landscape on breeding biology of plovers.
2. Identify and compare the relative impacts of agricultural practices on Mountain Plover nest success in eastern Colorado.
    a. Compare plover nest success in agricultural lands to rangeland habitats.
    b. Compare plover nest success within agricultural lands by common agricultural practices, crops, and timing of agricultural practices.
3. Identify farming practices or mechanical equipment that decreases nest success of plovers on agricultural lands.

4. Identify potential conflicts on the landscape between agricultural practices and Mountain Plover reproduction, and where in time and space critical areas of impact are occurring.

METHODS

STUDY AREA

This study encompassed areas on both private and public lands in eastern Colorado where Mountain Plover nesting activity is known to occur (Kuenning and Kingery 1998). Access to private lands was granted with the assistance of the Colorado Farm Bureau and by one-on-one contact with individual producers and CNHP employees. *All information on specific private land locations and individual producers were agreed among the partners to remain confidential to protect private landowner rights in the event Mountain Plovers were listed as "threatened" under the Endangered Species Act*. Areas on public land were mainly located on the Pawnee National Grasslands, Weld County. In 2001, additional data were available for the Comanche National Grasslands (K. Giesen, unpubl. data). During the 2001 and 2002 seasons, we attempted to cover broad areas across eastern Colorado, which resulted in a major component of research funding dedicated to low-returns in number of nests found due to the inclusion of areas of low densities in breeding populations of plovers. In 2003 we concentrated our activities more heavily in areas with higher concentrations of nesting Mountain Plover to increase the quantity of nesting information.

DEFINITIONS

For clarity we provide definitions of habitat terms used throughout this report. Habitat is composed of either cropland or rangeland. Cropland consists of agricultural fields that are managed by individual producers for crop production. The habitat types of cropland are spring idle (hereafter referred to as idle) fields or green wheat (hereafter referred to as wheat). Idle fields consisted of either 1) fields with no crops that may or may not have been treated for weed control or 2) fields that were planted later in the nesting season (after plovers had nested) with warm season crops, such as milo, sorghum, sunflower, or corn. Wheat fields were fields that were planted with wheat the previous winter or early spring prior to Mountain Plover nesting activity. Rangeland habitat consisted of native short-grass prairie vegetation, dominated by buffalo grass (*Buchloë dactyloides*) and/or blue grama (*Bouteloua gracilis*), that may or may not be grazed by domestic herbivores: cattle, sheep and/or horses. Rangeland habitat types are distinguished as 1) grassland, rangeland without black-tailed prairie-dogs (*Cynomys ludovicianus*), and 2) prairie-dog, rangeland with prairie-dogs.

DENSITY/ABUNDANCE ESTIMATION

In 2001 and 2002 we attempted to use distance sampling to estimate density of Mountain Plovers and compare differences in plover densities using cropland and rangeland. Habitats were sampled at 0.4 km increments along established field roads and the perimeters of cropland fields when possible. Additionally, systematic transects were established in rangeland at distances > 0.5 km from roads to provide full coverage of the selected survey area. When possible, observers traveled in vehicles along the transects because Mountain Plovers do not perceive motor vehicles as a threat; whereas they are more likely to perceive walking observers as a potential threat and will move away without being detected (Wunder et al. 2003, Plumb et al. 2005). Transects were surveyed three times throughout the breeding season: early May, late May/early June, and late June.

Our findings after the 2001 and 2002 field seasons suggested that using distance sampling to estimate densities of Mountain Plovers is not feasible given the low-density of most populations and between-season distributional shifts of plovers in eastern Colorado. Further, sampling around cropland fields is constrained to the field perimeter when using a vehicle because vehicles cannot be driven across agricultural fields. Results from along roads (or field perimeters) can not be extrapolated to the area (or field) due to the possibility of an underlying pattern associated with the road (or perimeter) coinciding with the detection function (Doherty 2004, Buckland et al. 2001: 295). While walking transects is possible in most cropland fields, plovers would rarely be detected at their initial locations (if detected at all), and logistically, foot surveys are not a cost-effective effort to estimate plover breeding densities.

Patch Occupancy. In 2003 we conducted patch occupancy surveys to estimate abundance, not densities, of Mountain Plovers. Patch occupancy surveys are a type of presence-absence (more properly, detection-nondetection) data (i.e., “occupancy surveys”) that are useful in large-scale surveys (i.e., eastern Colorado) of organisms because of the reduced effort in field sampling (Royle and Nichols 2003). This approach was recently developed and differs from distance sampling by shifting the interest from numbers of animals per area to numbers of sampling units (i.e., patches) occupied by animals. The technique accounts for varying numbers of individuals present per patch. An advantage of the patch occupancy approach is that it looks at extinction and colonization or shifts from one area to the another (i.e., from cropland to rangeland or public to private lands). Patch occupancy may well change over years or between seasons as populations change, new colonies could be formed or colonies could become locally extinct (MacKenzie et al. 2002, Royle and Nichols 2003). Patches (or sites) need to be surveyed on more than one occasion between these periods of change (i.e., annually, monthly, etc.), which is often the case for most monitoring programs. Additionally, patch occupancy surveys can address questions on species co-occurrence (MacKenzie et al. 2002, Royle and Nichols 2003, Bailey et al. 2004).

Field Methods. In 2003 we collected field data to test if patch occupancy methods were feasible for Mountain Plovers throughout our study sites in eastern Colorado. We defined a patch as the area surveyed for presence of Mountain Plovers. Prior to field sampling, we simulated data based on biological information and determined that a minimum of 80 patches needed to be surveyed a minimum of 6 times each throughout the breeding season in order to evaluate the technique.

Patches were established by randomly selecting areas that contained (humanly defined) suitable Mountain Plover habitat in the local study sites. The patches were rectangular in shape ranging from 50 m to 200 m on a side. The lower limit of 50 m was based on crop fields (especially strips of wheat and idle fields), that were not smaller than 50 m in our study sites. The 200 m limit for patch size was based on detection probability is < 20% for Mountain Plovers at distances > 200 m (Wunder et al. 2003). The actual size of each patch was based on as many landscape characteristics as possible. For instance, patch size was established on a crop field that had a width of 150 m, with a rise 100 m from the edge of the field. An example on rangeland would be a historical buffalo wallow that was diagonal from a clump of yuccas. These two points would be used to establish a rectangle, and the patch. If boundaries of the patch could not be established from the landscape features, flagging was used to delineate the patch.

Each survey was $\geq$ 3 min and varied from patch to patch. The observer was allowed to leave the vehicle and walk the edge of the patch, but not into the patch. Surveys were only conducted in weather conditions that were suitable for nest surveys (i.e., no rain or extreme wind). Each survey for a patch was treated as independent. That is, prior information on presence of Mountain Plovers at a patch was not to be considered during a survey. The data collected included: size of patch, habitat, date, duration of survey, time of day survey was conducted, observer, number of adult plovers present, and number of plover chicks present.

Analysis. The abundance estimation model has two types of parameters: 1) r is the probability of detecting each individual Mountain Plover and 2) λ is the mean abundance per patch (Royle and Nichols 2003). Both parameters were modeled as a function of patch and survey specific explanatory variables (or covariates). Detection probability, r, was modeled as a function of observer, habitat, duration of survey, time of day, and time in the breeding season. Mean abundance was modeled as a function of habitat, and patch size. Due to the large number of possible model structures, the structure of r was determined first, then the structure of λ was determined based on the top three modeled structures for r.

Model selection and inference was based on information theoretic methods and scored using Akaike's Information Criterion (AIC) (Akaike 1973, Shibata 1989, Burnham and Anderson 2002) adjusted for small samples sizes (AIC_c) (Hurvich and Tsai 1989). The goal of model selection is to identify a biologically meaningful model that explains much of the observed variability by including enough parameters to avoid substantial bias, but not so many that precision is lost (Lebreton et al. 1992, Burnham and Anderson 2002). We further used a measure of the difference in AIC_c between the best approximating model and all other models (Lebreton et al. 1992, Burnham and Anderson 2002), ΔAIC_c, to provide insight into the amount of uncertainty in model selection. This model selection criterion is also used in our nest success and chick survival analyses (see below).

NEST SUCCESS

We monitored the success of nests to identify and compare the relative impacts of agricultural practices on Mountain Plover nest success in eastern Colorado. On cropland we surveyed field perimeters and vantage points within the field to identify locations of nests by observing adults incubating eggs, shading eggs, or moving from nests. Each nest was marked with 1-2 flags and natural materials (i.e., small pile of crop stubble or rocks found within the field) approximately 1 m from nests in the four cardinal directions. On rangeland sites (both grassland and prairie-dog), we systematically traversed sites in a vehicle to locate nests. Rangeland nests were marked by flagging and stacking 2-3 cow pies or rocks approximately 1 m from the nest.

Egg flotation was used to estimate egg/nest age and proximity to hatching (Dinsmore 2001, FLK unpubl. data). We revisited nests to determine successful hatching by observing chicks or the presence of minute egg-shell fragments in the nest cup to identify nest fate (Mabee 1997). Nests on cropland were revisited < 3 days following agricultural practices to determine mechanical consequences to nest contents.

Analysis. We used an extension of the Mayfield's (1961,1975) nest survival model that allows flexibility in modeling daily nest survival, including the use of individual-, group-, and time-specific explanatory variables (Dinsmore et al. 2002). This recently developed nest survival model permits a more thorough exploration of factors influencing daily nest survival than previous methods. The assumptions of the nest survival model are: 1) nests can be aged when they are first found; 2) nest fates are correctly determined; 3) nest discovery and subsequent nest checks do not influence survival; 4) nest fates are independent; and 5) homogeneity of daily nest survival rates.

Our nest success analysis examined the effects of year, sex, time trends, habitat, and habitat types on daily nest survival of Mountain Plovers in eastern Colorado (Appendix 1). We first modeled the main effects of year, sex, and time trends. We concerned differences in daily nest survival between each year of the study: 2001, 2002, and 2003, *S*(*year*). The weather conditions in 2002 were considered to be "extreme drought" throughout our study sites (National Drought Mitigation Center 2003). The weather conditions in 2001 and 2003 were similar and wet relative to 2002. We included a model with a more specific yearly effect treating 2002 separately from 2001 and 2003, *S*(*2001&2003,2002*). The effect of sex, *S*(*sex*)*,* was simply the sex of the incubating adult. The time trends were either a linear trend (i.e., daily nest survival increasing or decreasing over the nesting period), *S*(*T*)*,* or a quadratic trend (i.e., daily nest survival increasing or decreasing but changes to the opposite trend at a given time during the nesting period), *S*(*TT*). We modeled all possible combinations of our year, sex, and time trend effects (our main effects models). Next, we added the effects of our habitat variables to the set of models containing the best main effects models ($\Delta AIC_c < 2$). In our case the main effect models included: *S*(*T*), *S*(*TT*), *S*(*2001&2003,2002+T*), *S*(*2001&2003,2002+TT*), and *S*(*Sex+T*). Our habitat (*habitat*) and habitat type (*habitat type*) variables are as defined above (see *Definitions*).

Prairie-dog towns have been suggested to be important to Mountain Plover breeding activity, especially in the northern part of their range (Knopf 1996a). We tested nest success of plover within prairie-dog habitat with models that looked at differences in nest success between cropland, grassland, and prairie-dog (*crop,grassland,pdog*). We used AIC_c and ΔAIC_c as our model selection criterion (see above *Patch Occupancy: Analysis* for more detail).

Banding Birds. We banded nesting adults by capturing them with walk-in box traps made of wire mesh. All birds were banded with a USFWS numbered metal band and colored plastic bands. The numbered band allowed us to identify within-year re-nesting attempts by individual birds and between-year movement of birds between cropland and rangeland habitats for nesting. The colored plastic bands allowed identification of birds throughout their continental range as coordinated with concurrent studies from California, Montana, New Mexico, and Wyoming. Because Mountain Plovers do exhibit site fidelity (F. L. Knopf pers. comm.), we hoped to have a large number of banded birds returning to our study sites in subsequent years. When possible, we banded chicks > 10 days old. Additionally, a feather sample from all adult plovers was collected for sex determination by DNA analyses (Avian Biotech, Tallahassee, Florida). We simply report qualitative information on banded birds in this report.

RADIOTELEMETRY

In 2002 and 2003 we examined the use of croplands and prairie-dog habitats for brood rearing activity. Our specific objective was to compare movement patterns, home range size during brood rearing, and chick survival between croplands and rangeland with and without prairie-dogs. We only focused on cropland and prairie-dog habitat during this study because information on rangeland without prairie-dog was already available (Knopf and Rupert 1996) and we wanted to fill in the remaining gaps in this information.

Field Methods. Because of logistical and resource limitations, we were restricted to examining croplands in 2002 and prairie-dog habitat in 2003. Mountain Plover chicks weigh 10-11 g at hatching (Graul 1975) and are precocial--leaving the nest within 3 hours of the last egg hatching (Graul 1973, Knopf 1996a). Chicks move with the adult up to 2 km from the nest in the first 2 days (Knopf 1996a), thus, re-locating chicks and/or adults is difficult. Because chicks stay with adults, we placed radio transmitters on adults to obtain information on brood-rearing activity. A 1.8 g radio transmitter (Advanced Telemetry Systems, Isanti, Minnesota) was placed on the back of a nesting adult plover at, or just before, hatching of the eggs. The transmitters were affixed by applying a light coating of waterproof epoxy and sliding it under the upper back feathers. This procedure enables the transmitters to drop off during molting. The battery life of the transmitters averaged 56 days. Broods were located with a hand-held Yagi antenna every 24 to 48 hours to record habitat location. First, we located birds from distances up to 800 m to avoid forcing brood movements caused by human disturbance. From this distance, we recorded observer coordinates and distance and bearing to each adult with a brood. Secondly, we decreased our distance (usually by walking) to the adults with broods to confirm the number of chicks present via visual observation. Adults with broods were thus relocated until chicks fledge at ~36 days post-hatch (Miller and Knopf 1993).

Analysis: Movement and Home Range. We used the fixed kernel method (Worton 1995, Seaman and Powell 1996) to calculate brood home ranges with a smoothing parameter chosen by least squares cross validation. This method is a nonparametric technique that depicts irregular distributions more accurately and produces home range estimates with less bias relative to other home range estimators (Seamen and Powell 1996). Home range values are based on 50 and 95% contour intervals, hereafter referred to as "core area" and "home range," respectively (Bogner and Baldassarre 2002, Vega Rivera et al. 2003). Movement, the mean distance moved between two consecutive locations, was calculated for each bird. We also calculated minimum convex polygon home ranges for comparison with an earlier study (Knopf and Rupert 1996).

Analysis: Chick Survival. We estimated chick survival on cropland and prairie-dog towns using analytical methods that allow for individual chicks within a brood not to be detected at every sampling period (Lukacs et al. 2004). This method is very useful for species, such as Mountain Plovers, where the chicks hide when alerted by the adult (Sordahl 1991). The method was specifically developed for this study and has implications to many species with precocial chicks. Broods can be added to or removed from the data set at any sampling period. Adults attending chicks must be uniquely marked (e.g., radio transmitters or leg bands), and that mark must be read without error each time the adult is resighted. Chicks do not need any type of individual marking. The statistical approach is an extension of the Cormack-Jolly-Seber model that allows a form of individual heterogeneity in survival to be modeled. The model estimates: the probability of survival of an individual chick given the chick is alive and remains in the study area, ϕ, and the probability that a chick will be resighted given it is alive and the adult was resighted, p. For more details see Lukacs et al. (2004).

We constructed models to examine several hypotheses about chick survival. Detection probability, p, was held constant in our suite of models. Our data set is relatively small, therefore, not much information about p is available to inform model selection and the chance of spurious results is high. We modeled survival, ϕ, as a constant (.), ϕ at the first day after hatching different from subsequent day (*H1*), ϕ at the first two days after hatching equal but different from subsequent days (*H2*), and ϕ at the first three days after hatching equal but different from subsequent days (*H3*). We also examined yearly effects on chick survival, ϕ(*year*), and included an additive yearly effect in models ϕ(*H1*), ϕ(*H2*), and ϕ(*H3*). We used AIC_c and ΔAIC_c as our model selection criterion (see above *Patch Occupancy: Analysis* for more detail).

RESULTS

The counties that we surveyed for nesting Mountain Plovers included: in 2001 - Baca, Lincoln, Morgan, Pueblo, Washington, and Weld; in 2002 - Baca, Cheyenne, Crowley, El Paso, Lincoln, Logan, Kiowa, Kit Carson, Morgan, Pueblo, Washington, and Weld; and in 2003 - Crowley, El Paso, Lincoln, Logan, Pueblo, and Weld (Fig. 1). We do not report results at the county level. County-level information invites county-by-county comparisons, which infer such things as equal sampling effort and equal percentage of suitable plover habitat between counties during the duration of this study, and thus would be misleading.

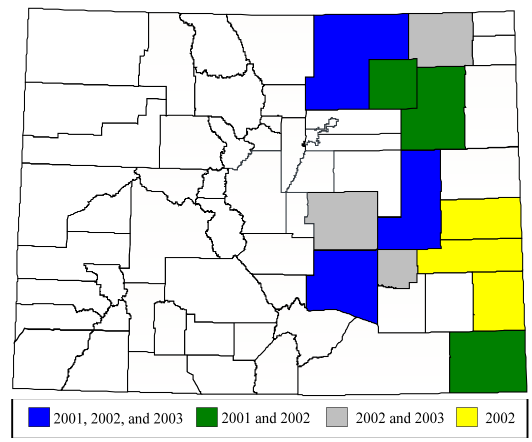

Figure 1. The counties in eastern Colorado that were sampled from 2001-2003 for Mountain Plover breeding activity.

The total acreage we surveyed for all aspects of this study on private land increased throughout the study: 2001 - 100,000 acres, 2002 - 140,000, and 2003 - 220,000 (Fig. 2). During the study we were only denied access by 2 of 24 private individual producers in 2001, 1 of 32 in 2002, and 2 of 32 in 2003 (Fig. 2). In addition, we surveyed across 193,000 acres on public land, the Pawnee National Grasslands.

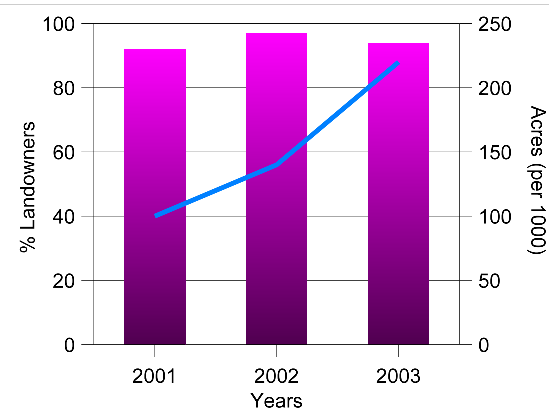

Figure 2. The percentage of individual producers allowing access to their lands to survey for nesting Mountain Plovers from 2001-2003 and the number of acres their lands represent. (Bars represents percentage of landowners, blue line represents acres per thousand).

DENSITY/ABUNDANCE ESTIMATES

The data we collected using distance sampling methods of Mountain Plovers was insufficient to obtain densities estimates on cropland and rangelands in 2001 and 2002. In 2003 we evaluated the use of what we term patch occupancy surveys to estimate abundance of Mountain Plovers on habitat patches (i.e., cropland and rangeland). We surveyed 82 patches: 26 on cropland, 26 on grassland, and 30 on prairie-dog ($\geq$50% of the patch had the presence of prairie-dogs), to estimate abundance of breeding Mountain Plovers throughout our study areas in 2003. The average number of times we surveyed each of the 82 patches was 9.89 ± 1.59 SD.

The selected best model suggests mean abundance per patch varies between cropland, grassland, and prairie-dog habitats, and the probability of detecting a plover varies by the amount of time the patch is searched, the time of the breeding season, and the observer (Appendix 2). The data suggest that Mountain Plover abundance on prairie-dog was about the same on cropland (Fig. 3). The probability of detecting a plover on a patch increased with the amount of time spent searching for plovers, varied among observers, and decreased towards the end of the breeding season.

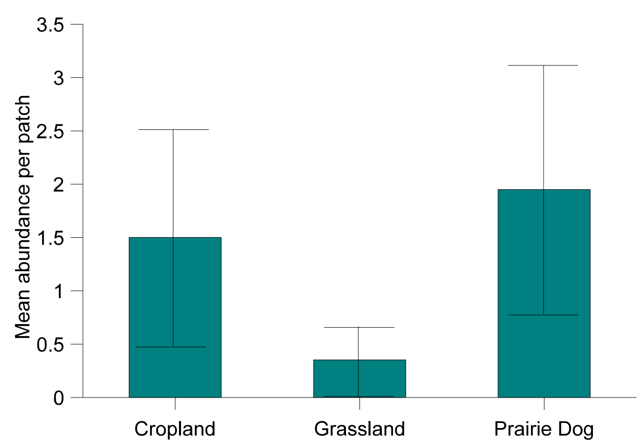

Figure 3. Mean abundance per patch by habitats of Mountain Plovers in eastern Colorado during 2003. The 95% confidence interval is represented by the error bars.

NEST SUCCESS

We monitored 395 Mountain Plover nests during this study (Fig. 4). The 2002 breeding season had the highest number of nests. There are many possible reasons for these differences in nest numbers. We believe weather conditions had the largest influence, especially between 2002 and 2003. In the areas we surveyed in 2002, the weather conditions were considered to be drought (National Drought Mitigation Center 2003.). However, in 2003, the northern portion (north of Interstate 70) of our study area received early spring precipitation and the number of nests we located in this area in 2003 (*n* = 59) was 47% lower than 2002 (*n* = 125). Whereas the southern portion (south of Interstate 70) received none or very little precipitation in both years and we found a similar number of nests.

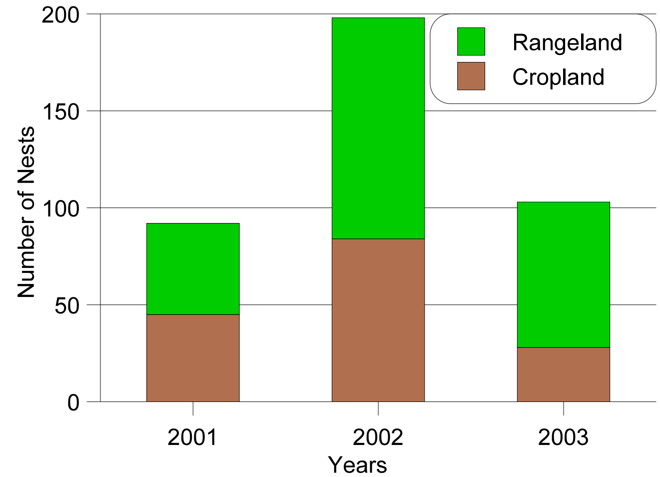

Figure 4. The number of Mountain Plover nests per habitat that were monitored in eastern Colorado from 2001 to 2003.

Mountain Plovers were only reported to nest on idle fields (Knopf and Rupert 1999, Shackford et al. 1999). In 2001 we concentrated most of our efforts to locate nests on cropland in idle fields. Ancedotal observations during 2001 suggested that Mountain Plovers were also using growing wheat fields. In the preceding years of the study, we surveyed wheat fields for Mountain Plover nesting activity. Idle fields were the main cropland habitat type we located Mountain Plover nests, however, wheat fields are used more frequently than previously suggested (Fig. 5). In 2002, we believe the

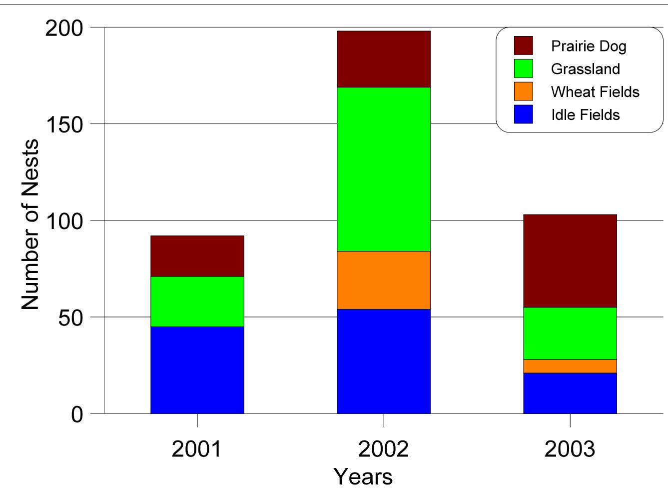

Figure 5. The number of Mountain Plover nests per habitat type that were monitored in eastern Colorado from 2001 to 2003.

higher use of wheat fields was due to the drought conditions. Wheat growth was minimal this year and few (if any) producers harvested a wheat crop. More specifically, wheat germination was patchy within fields and plovers nested in patches of poor or no germination. Weather conditions in 2003 produced growth in wheat during the plover breeding season. Of the nests that were located on cropland in 2003, 25% were on wheat fields, the remaining 75% were found on idle fields.. Differences did exist in the number of nests we found on the rangeland habitat types (Fig. 5). We found similar number of nests on grassland (n = 26) and prairie-dog (n = 21) in 2001, more on grassland (n = 85) than prairie-dog (n = 29) in 2002, and less on grassland (n = 27) than prairie-dog (n = 48) in 2003. Again these differences may be a result of precipitation and vegetation growth.

We monitored Mountain Plover nests across a 111-day breeding season interval (18 April - 6 August) during the three-year study. Nests were initially located from April to June of each year (Fig. 6). A slight peak was observed in mid-May, followed by a lesser peak of new nests in mid-June. Approximately 10% of the nests we monitored in 2002 were located on or after 24 June with < 2% in 2001 and 2003. The results from our analysis of daily nest survival of Mountain Plover suggest a decreasing linear trend during the breeding interval (Fig. 7) (Appendix 1). Based on

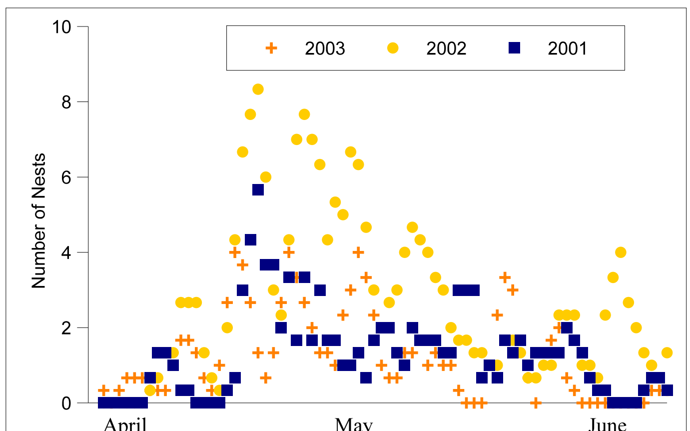

Figure 6. The months in which Mountain Plover nests were initially located in eastern Colorado from 2001 to 2003. Data points based on a moving average for each year.

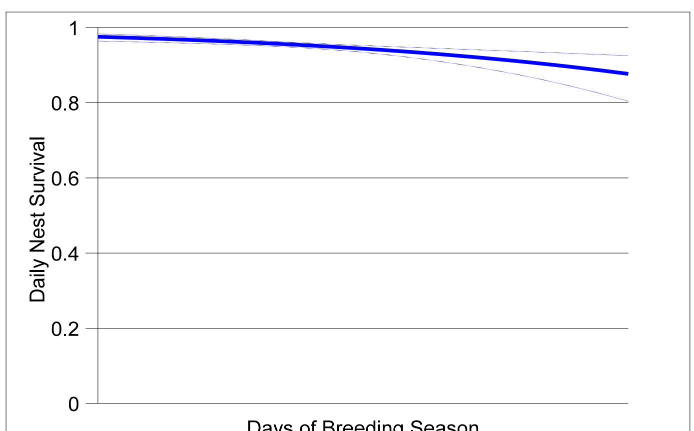

Figure 7. Daily nest survival for Mountain Plovers in eastern Colorado from 2001 to 2003. Point estimate is thick line, 95% confidence intervals are thin lines.

AIC_c, the most parsimonious models that best explained the data ($\Delta AIC_c < 2$) contained this decreasing linear trend on daily nest survival. The inclusion of our habitat variables did not increase the model's ability to approximate data. Whereas models including these habitat variables were included in our set of the most parsimonious models, the coefficients are relatively small and asymmetrically overlap zero suggesting the magnitude of this effect is minimal (Appendix 3). For instance, the model *S(habitat type+T)* suggests that daily nest survival differ by habitat type and decreases through the breeding interval. Wheat fields have the highest daily nest survival, followed by prairie-dog and grassland (which are similar), then idle fields (Fig. 8). The confidence intervals for these nest success estimates all overlap suggesting the differences are biologically meaningless. These findings were similar for our yearly, sex, habitat, and quadratic variables.

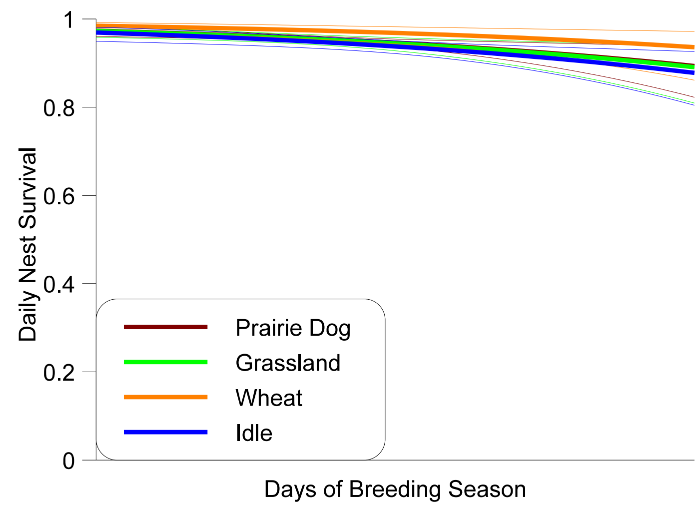

Figure 8. Daily nest survival per habitat type for Mountain Plovers in eastern Colorado from 2001 to 2003. Point estimates are thick lines, 95% confidence intervals are thin lines.

The causes of nest failure were different between cropland and rangeland (Fig. 9). This result was expected since rangeland nests are seldom (if at all) influenced by private, agricultural practices.

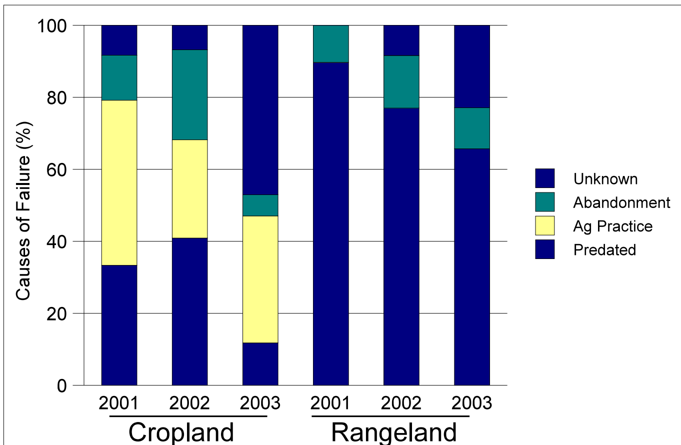

Figure 9. The causes of nest failure for Mountain Plovers from 2001 to 2003.

Nest failures were grouped into four categories. “Predated” included nests that had apparent evidence that a predator destroyed the nest attempt, or no sign of disturbance was associated with egg disappearance. “Ag Practice” included destruction of nests by any private agricultural practice. “Abandoned” included nests that contained eggs for > 6 weeks past initiation of nests and never hatched. “Unknown” included nests that failed but we could not determine the cause because not only did the eggs disappear, but the nest material or entire nest cup disappeared as well. The highest percentage of nest failures on cropland was attributed to ag practices in 2001 and 2003 and predation in 2002. Rangeland nest failures were attributed to predation for all years of the study. We were unable to determine the cause of failure for 47% of the failed nests on cropland and 23% on rangeland in 2003. We believe most of the “unknown”-fate nests did not survive rainfall events and were flooded away from the nest site.

The terminology for specific agricultural practices and the agricultural implement used for an agricultural practice are not standard throughout our study site. We defined agricultural practices as 1) “tillage”: soil surface which was broken up by machinery such as disks, mulchers, harrows, rippers, cultivators, sweeps, plows, and any mechanical weed control machinery; 2) “drilling”: the placement of crop seed into the ground by drills and planters; and 3) “compacting”: soil is packed around a crop seed by a culti-packer or roller packer (Fig. 10) which may or may not follow or be attached to machinery used for drilling; or the

Figure 10. Examples of soil compacting machinery used in private, agricultural practices in eastern Colorado.

top soil layer is a hard crust, and thus roller-packed so plants can grow through the top crust. Of the nests that experienced a tillage event, 17 of 35 (46%) survived this practice. Drilling only occurred at 10 nests during our study, and 4 nests survived this practice (Fig. 11). We were unable to find any nests that survived a compacting practice. We believe that compacting results in the complete loss of a plover nest, even those surviving tillage and seed drilling.

Figure 11. An example of a Mountain Plover nest that survived tillage. The top photo has an individual (T. McCoy) pointing out the nest in the cropland field, the lower photo is the nest after drilling.

Banding Birds. We banded a total of 559 (96, 252, and 291 in 2001, 2002, and 2003, respectively) Mountain Plover adults and chicks during our study. During the 2002 breeding season, we observed 30 birds that were banded on our study sites prior to 2002 and 5 birds that were banded in Imperial Valley, California. One banded bird re-nested after its first attempt failed, and that bird was originally banded as an adult on one of our study areas. In 2003, we observed 29 banded birds that were banded on our study sites and 3 birds that were banded in Imperial Valley, California. We observed no re-nesting attempts in 2003. Further, all of our resightings of banded birds that were banded in our study area, were in the same general area (i.e., north of I-70 vs. south of I-70) where each bird was originally banded.

RADIOTELEMETRY

Home range. We monitored 13 broods on cropland fields in 2002 and 10 broods on prairie-dog towns in 2003. Home range estimates for the two habitats were relatively comparable: cropland

(131.6 ha ± 74.4 SD) and prairie-dog towns (243.3 ha ± 366.3 SD). The mean point estimates of the core area on prairie-dog towns was 44% larger than on cropland, however confidence intervals between the two habitat types overlapped (Appendix 4).

The insignificantly larger point estimates in home range and core area on prairie-dog towns can be attributed to two birds, one with an estimated home range of 1156.5 ha and core area of 210.8 ha, and another with a home range of 630.0 ha and core area of 114.4 ha. Removing these two birds gives a home range of 80.8 ha ± 42.8 SD and core area of 15.4 ha ± 10.7 SD on prairie-dog towns. The two outlier birds raised their broods on a large prairie-dog complex (>10,000 ha), a mosaic of small, active prairie-dog towns within 800 m of each other, and moved freely within the complex. The other eight transmittered birds and their broods were located on smaller, isolated prairie-dog towns ranging from 1-320 ha surrounded by short-grass prairie that was not, or only lightly, grazed by cattle.

Based on minimum convex polygon (MCP), home ranges on cropland, and prairie-dog habitat are comparable to rangeland habitat (56.6 ha ± 21.5 SD, CI: 39.4-73.8) reported by Knopf and Rupert (1996). Whereas there are inherent biases such as inclusion of large exploited areas within MCP (Kenward 1987), the overlapping confidence intervals in home ranges among habitat types suggests that Mountain Plovers use comparably sized patches within highly different landscapes when raising a brood (Dreitz et al. 2005).

Movements. Movement, defined as the distance between locations of adults with broods on consecutive observation days, differed across habitats. Adults that nested on cropland showed no pattern in brood movements. Some individuals stayed on cropland, others moved to nearby rangeland, and others moved back and forth between cropland and rangeland. Adults that nested on prairie-dog habitat were always re-located with their broods on prairie-dog towns.

The daily movement distance was similar across years and among habitats (Appendix 4). The movement distance for the two adults with broods on prairie-dog town complexes was 690.7 m and 589.9 m, respectively, within the average range for all habitats (175.6-800.1 m). Additionally, these movement distances were not related to home range or core area size. For example, one adult nested on a prairie-dog town approximately 200 ha in size. Its home range (132.4 ha) and core area (34.9 ha) were substantially smaller, despite movement distance (604.2 m) similar to other adults with broods.

*Surviva*l. We estimated chick survival of Mountain Plovers from 19 and 11 transmittered adults in 2002 and 2003, respectively. Model $\phi(H3)p(.)$ was selected as the best model by our model selection criterion (Appendix 5). The inclusion of year, or differences between habitats (cropland and prairie-dog), did not improve this model. The estimates of survival probability for the first three days after hatching was 0.92 ± 0.02 SE. Survival was modeled as constant from day 4 to day 36 and equaled 0.99 ± 0.01 SE. Detection probability was estimated as 0.34 ± 0.02 SE.

DISCUSSION

In eastern Colorado where much of the land is privately owned, approaches to species conservation require first identifying intrinsic values of wildlife habitats without assuming negative impact resulting from private land practices. In this landscape, breeding activity of Mountain Plovers is closely associated with agricultural fields and short grass prairie pastures. During our study on Mountain Plovers we had excellent success in gaining access to privately owned land; including rangelands used for grazing by domestic herbivores and cropland fields. Our success can be attributed to at least three reasons. First was the collaboration with the

Colorado Farm Bureau. Secondly, one of the most important factors in the success or failure of private landowner conservation efforts is the person tasked with contacting the landowner (Wilcove and Lee 2004). Thirdly, using a non-regulatory agency to conduct this research, such as CNHP/CSU, likely reduced skepticism from landowners that regulatory agencies would be immediately confrontational. Our study was presented as seeking technical guidance and Wilcove and Lee (2004) have noted that technical guidance on species and their habitats appears to be more important than either regulator relief or financial assistance in securing cooperation of landowners for species conservation.

We recognize the inconsistency of changing specific study sites between years of this study. However, we feel our results adequately represent breeding activity of Mountain Plovers at the level of eastern Colorado. In 2001 and 2002 we spent a large component of our efforts in finding concentrations of breeding plovers on private lands. In many areas we found breeding activity but at very low densities. In 2003 we focused on increasing our quantity of nest data at sites where we had observed high concentrations of breeding plovers in 2002. The total number of nests we found in 2003 was lower than 2002. We believe this decline was due to decreases in breeding activity because of weather conditions. The distribution of our study sites for breeding plovers in eastern Colorado was consistent with the statewide survey findings of Kuenning and Kingery (1998).

DENSITY/ABUNDANCE

Distance sampling has been used to estimate densities of breeding Mountain Plovers on Pawnee National Grasslands (FLK), in South Park, Colorado (Wunder et al. 2003), in Montana (Knopf 1996a), and in Wyoming (Plumb et al. 2005). Landscape differences throughout the range of

Mountain Plovers and the distribution of plovers define the feasibility of distance sampling in various locales. Long-term distance sampling methods have proven to be problematic (i.e., no estimates) over the last nine years on the Pawnee National Grasslands (Knopf unpubl. data). These data likely reflect the shift of breeding plovers off the Pawnee National Grasslands. The annually shifting mosaic of cropland fields and rangelands used by Mountain Plovers in eastern Colorado also hinder the use of distance sampling, unless substantial funding is provided. Sampling in cropland fields for Mountain Plovers is confined to the perimeter. Density estimates from distance sampling along field perimeters (or roads) only provides estimates of animal density in the vicinity of the field perimeters, under or over representing (dependent on the behavior of a species) the density in the survey region (Buckland et al. 2001). These density estimates along roads do not provide estimates of relative abundance, nor do they allow trends in abundance to be monitored (Buckland et al. 2001:295).

Using patch occupancy surveys we observed more plovers per patch on prairie-dog than any other habitat during the 2003 breeding season. Mountain Plovers selectively nest on black-tailed prairie-dog towns in Montana, especially southern Phillips County (Knowles et al. 1982, Knowles and Knowles 1984, Olson and Edge 1985, Dinsmore 2001). In eastern Colorado, the association between prairie-dogs and plovers is relatively unknown. Even though our results suggest that plovers were observed in higher concentrations on prairie-dog towns than the other habitats, we believe further research needs to be conducted to readily assess our 2003 (one year) findings. Previous studies have suggested that the influence of prairie-dog towns on habitat choice of grassland birds may be related to precipitation (Barko et al. 1999, Winter et al. 1999a, 1999b). Particularly during wet years in short-grass prairie when grasses are taller, prairie-dog towns and their associated communities become more distinctive (Smith and Lomolino 2004) and may serve as refugia habitat.

Estimating abundance of Mountain Plovers from patch occupancy data appears to work well at the patch scale. Field protocols are relatively easy to implement resulting in sample sizes sufficiently large for estimation. Further evaluation of the patch occupancy method needs to be conducted throughout eastern Colorado in all areas that have suitable plover habitat. We only evaluated this method in areas of high plover concentrations. Further advances are being made with patch occupancy surveys in both field protocols and addressing biological questions, such as monitoring population trends (J.A. Royle pers. comm.).

NEST SUCCESS

Nest survival of Mountain Plovers in eastern Colorado followed a general daily decrease throughout the breeding season during our study. Following Dinsmore et al. (2002), we estimated the probability of a Mountain Plover nest surviving the 29 d incubation period using the mean initiation data for eastern Colorado, 9 May. Using our best approximating model, *S(T)*, nest success was 0.37 during our study.

Agricultural practices do not appear to be an additive detriment to nest success of Mountain Plovers. Nest success on cropland and rangeland is equivalent with the cause of nest mortality differing between the two habitats. The major causes of nest failure is agricultural practices and predation on cropland and predation on rangeland. Predation rates on cropland are relatively low, and the rate of nest loss on cropland is compensatory with nest loss on rangelands. Nests do survive tillage and drilling practices. However, all nests in a field are destroyed by soil compaction practices.

Since planting requires soil compaction and we can not suggest an alternative practice for soil compaction that precludes crushing eggs, we proposed a volunteer incentive program. The volunteer incentive program is designed to allow awareness of Mountain Plover nesting activity by marking nests on croplands prior to any agricultural activity so landowners can avoid destruction of nests (Fig. 12). Considering nest failures on croplands are compensatory with failures on rangeland, this conservation program on croplands has the potential to "grow" the continental population of Mountain Plovers. We did not detect a minimum necessary "buffer" by which a nest must be missed; as long as the eggs remained in the nest cup, plovers continued to incubate.


Figure 12. An example of a Mountain Plover nest that is marked with flagging in a cropland field and avoided during agricultural activity.

RE-NESTING

We observed only one re-nesting attempt during our study. Re-nesting has generally been a rare event in other plover studies in Colorado, Montana, and Wyoming also.

BROOD MOVEMENTS

Because Mountain Plover chicks are precocial, leaving the nest within 3 hours of the last egg hatching (Graul 1973, Knopf 1996a) and will move with the adult up to 2 km from the nest in the first 2 days (Knopf and Rupert 1996), the mortality of chicks on cropland fields is seldom the result of agricultural practices. Mountain Plovers do use both rangeland and cropland to raise their chicks. The value of which habitat fosters more success seems influenced by precipitation conditions in a given year as mediated through agricultural practices.

Our results from prairie-dog habitat suggest that home range for brood-rearing of Mountain Plovers may be related to the size of the prairie-dog complex or town but movement distances are not related to size of a prairie-dog town. Whereas some of the prairie-dog towns are isolated, others occur in complexes (groups of prairie-dog towns in close proximity). Adults with broods are not known to move between prairie-dog towns in Montana (Dinsmore et al. 2002) where towns are rarely close together. However, in 2003 we did observe movement of adults with broods between prairie-dog towns (i.e., within a complex) in Colorado. From a biological standpoint, we suggest that among the prairie-dog habitat options, when a prairie-dog complex is available it is likely more favorable than prairie-dog towns for Mountain Plover brood-rearing activity. The supporting habitat being a prairie-dog complex versus a town has also been suggested for another short-grass prairie associated species, the black-footed ferret (*Mustela nigripes*) (Biggins et al. 1993).

CHICK SURVIVAL

During both 2002 and 2003 chick survival of Mountain Plovers was lowest immediately after hatch, and quickly increased within 3 days post-hatch. The trend of increasing survival with age of the chick has also been noted by Knopf and Rupert (1996), Lukacs et al. (2004), and Dinsmore and Knopf (In review). Our study was conducted on agricultural fields in 2002 and prairie-dog towns in 2003. Our approach suggests that chick survival was similar in 2002 and 2003, thus we anecdotally conclude that chick survival did not differ among habitats. However, to evaluate chick survival across habitats, studies should be conducted on each habitat within the same year. Such a study proved too costly to attempt in this study.

SUMMARY

- The Mountain Plover breeding season is at its height in mid-May, but seems to extend later into the summer (July/August) during drought years.
- Nesting success in cropland and rangeland is comparable with the cause of egg losses differing between the two landscapes.
- Agricultural practices do not appear to be an additive detriment to nesting success of Mountain Plovers.
- Soil compaction (roller packer or culti-packer) is likely the only agricultural practice which destroys all Mountain Plover nests encountered, and we proposed the development of a mechanism favoring a volunteer incentive program to mark nests prior to any agricultural practice.
- Estimating density/abundance trends of Mountain Plovers may be possible using patch occupancy methods, if appropriately stratified across landscapes.
- Preliminary data suggests that home range size for brood rearing of Mountain Plovers is similar on cropland and grassland but vary with the size of the prairie-dog town or complex in which an adult nests.
- Preliminary data suggests that daily movement distances for Mountain Plover brood rearing are similar across cropland, grassland, and prairie-dog habitats.

- Preliminary data suggests that there is no directional pattern in movements on or between cropland and grassland for Mountain Plover brood rearing. However, broods that hatched on prairie-dog towns (or complexes) never left this habitat.
- Preliminary data suggests that the critical period for Mountain Plover chick survival is 3 days post-hatch. If chicks survive this 3-day period, survival rate increases to 0.99. Chick survival could not be compared across years or habitats, these variables were confounded in our study.

ACKNOWLEDGMENTS

I sincerely thank the landowners throughout eastern Colorado who provided access to their lands. I acknowledge T. McCoy who initiated the first field season. I thank T. Allen, L. Blackburn, C. Cook, R. Magill, C. Mettenbrink, M. Margulies, S. Musgrave, P. Osterle, and L. Smythe for field assistance. I am very grateful for the many people who helped throughout the duration of this study, including: K. Morgan (Colorado Farm Bureau, now with Colorado Division of Wildlife (CDOW)), L. Nelson (CDOW, now with Minnesota DNR), W. Graul (CDOW, now retired), Francie Pusateri (CDOW), R. Morganweck, T. Sexson, C. Davis, B. Leachman and Pat Mehlhop (all of U.S. Fish and Wildlife Service (USFWS)), P. Stevens (USFWS, now with U.S. Geological Survey), John Sovell, B. Drummond, Renee Rondeau, and R. Schorr (all with CNHP). Finally, I especially thank F. L. Knopf (USGS) and M. B. Wunder (CNHP, now with CSU) for their continued biological, technical, and administrative assistance and support throughout the duration of this study. K. Morgan, T. Sexson, P. F. Doherty, Jr., K. P. Burnham, and F. L. Knopf made helpful suggestions to earlier drafts of this report. Financial and logistical support was provided by the Colorado Farm Bureau, Colorado Division of Wildlife, U.S. Fish and Wildlife Service, and U.S. Geological Survey. The Lois Webster Fund of the Audubon Society of Greater Denver and the Colorado Field Ornithologists provided funding for radio transmitters.

LITERATURE CITED

AKAIKE, H. 1973. Information theory and an extension of the maximum likelihood principle, p. 267-281. *In* B. Petrov and F. Csaki, [EDS.], Proceedings of the 2nd International Symposium on Information Theory. Akademiai Kiado, Budapest.

BAILEY, L. L., T. R. SIMONS, AND K. H. POLLOCK. 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. Ecological Applications 14:692-702.

BARKO, V. A., J. H. SHAW, AND D. M. LESLIE, JR. 1999. Birds associated with black-tailed prairie dog colonies in southern shortgrass prairie. Southwestern Naturalist 44:484-489.

BIGGINS, D. E., B. J. MILLER, L. R. HANEBURY, B. OAKLEAF, A. H. FARMER, R. CRETE, AND A. DOOD. 1993. A technique for evaluating black-footed ferret habitat. Pages 73-88. *In* J. L. Oldemeyer, D. E. Biggins, B. J. Miller, and R. Crete [eds.]. Proceedings of the Symposium on the Management of Prairie Dog Complexes for the Reintroduction of the black-footed ferret). U.S. Fish and Wildlife Service Biological Report 13:1-96.

BOGNER, H. E., AND G. A. BALDASSARRE. 2002. Home range, movement, and nesting of least bitterns in western New York. Wilson Bulletin 114:297-308.

BUCKLAND, S. T., D. R. ANDERSON, K. P. BURNHAM, AND J. L. LAAKE, D. L. BORCHERS, AND L. THOMAS. 2001. Introduction to distance sampling: estimating the abundance of biological populations. Oxford University Press, Oxford, UK.

BURNHAM, K. P., AND D. R. ANDERSON. 2002. Model selection and inference, 2nd ed. Springer-Verlag, New York.

DINSMORE, S. J. 2001. Population biology of Mountain Plovers in southern Phillips County, Montana. Ph.D. dissertation. Colorado State University, Fort Collins, Colorado.

DINSMORE, S. J., G. C. WHITE, AND F. L. KNOPF. 2002. Advanced techniques for modeling avian nest survival. Ecology 83:3476-3488.

DINSMORE, S.J., AND F. L. KNOPF. *In review*. Differential parental care by adult Mountain Plovers. Canadian Field Naturalist.

DOHERTY, P. F., JR. 2004. Conceptual and practical issues in monitoring animals: a review and recommendations. Technical Report. Colorado Division of Wildlife, Fort Collins, Colorado.

DREITZ, V. J., M. B. WUNDER, AND F. L. KNOPF. 2005. Movement and home ranges of Mountain Plovers raising broods in three Colorado landscapes. Wilson Bulletin: *In press*.

GRAUL, W. D. 1973. Adaptive aspects of the Mountain Plover social system. Living Birds 12:69-94.

GRAUL W. D. 1975. Breeding biology of the Mountain Plover. Wilson Bulletin 87:6-31.

GRAUL, W. D., AND L. E. WEBSTER. 1976. Breeding status of the Mountain Plover. Condor 78:265-267.

HURVICH, C. M., AND C. -L. TSAI. 1989. Regression and time series model selection in small samples. Biometrika 76:297-307.

KNOPF. F. L. 1994. Avian assemblages on altered grasslands. Studies in Avian Biology 15:247-257.

KNOPF, F. L. 1996a. Mountain Plover (*Charadrius montanus*). *In* A. Poole and F. Gill [EDS.], The birds of North America, no. 211. Academy of Natural Sciences, Philadelphia, Pennsylvania, and American Ornithologists' Union, Washington D.C.

KNOPF, F. L. 1996b. Prairie legacies-birds. 1996. In F. B. Samson and F. L. Knopf [EDS.], Prairie conservation: preserving North American's most endangered ecosystem. Island Press, Covelo, California.

KNOPF, F. L. AND B. J. MILLER. 1994. Charadrius montanus–montane, grassland, or bare-ground plover. Auk 111:504-506.

KNOPF, F. L., AND J. R. RUPERT. 1995. Habits and habitats of Mountain Plovers in California. Condor 97:743-751.

KNOPF, F. L., AND J. R. RUPERT. 1996. Reproduction and movements of Mountain Plovers breeding in Colorado. Wilson Bulletin 108:28-35.

KNOPF, F. L., AND J. R. RUPERT. 1999. Use of cultivated fields by breeding Mountain Plovers in Colorado. Studies in Avian Biology 19:81-86.

KNOWLES, C. J., C. J. STONER, AND S. P. GIEB. 1982. Selective use of black-tailed prairie dog towns by Mountain Plovers. Condor 84:71-74.

KNOWLES, C. J., AND P. R. KNOWLES. 1984. Additional records of Mountain Plovers using prairie dog towns in Montana. Prairie Naturalist 16:183-186.

KUENNING, R. R., AND H. E. KINGERY. 1998. Mountain Plover, p. 170-171. *In* H. E. Kingery [ed.], Colorado breeding bird atlas. Colorado Bird Atlas Partnership and Colorado Division of Wildlife, Colorado.

LEBRETON, J. -D., K. P. BURNHAM, J. CLOBERT, AND D. R. ANDERSON. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62:67-118.

LOMOLINO, M. V., AND G. A. SMITH. 2003. Terrestrial vertebrate communities at black-tailed prairie dog (*Cynomys ludovicianus*) towns. Biological Conservation 115:89-100.

LUKACS, P. M., V. J. DREITZ, F. L. KNOPF, AND K. P. BURNHAM. 2004. Estimating survival probabilities of unmarked dependent young when detection is imperfect. Condor 106:927-932.

MABEE, T. J. 1997. Using eggshell evidence to determine nest fate of shorebirds. Wilson Bulletin 109:307-313.

MACKENZIE, D. I., J. D. NICHOLS, G. B. LACHMAN, S. DROEGE, J. A. ROYLE, AND C. A. LANGTIMM. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248-2255.

MAYFIELD, H. R. 1961. Nesting success calculated from exposure. Wilson Bulletin 73:255-261.

MAYFIELD, H. R. 1975. Suggestions for calculating nest success. Wilson Bulletin 87:456-466.

MCPHERSON, G. R. 1995. The role of fire in the desert grasslands, p 130-151. *In* M.P. McClaran, T.R Van Devender [EDS.], The desert grassland. University of Arizona Press, Tucson.

MENGEL, R. M. 1970. The North American Central Plains as an isolating agent in bird speciation, p. 280-340. *In* W. Dort and J. K. Jones [EDS.], Pleistocene and recent environments of the central Great Plains. University of Kansas Press, Lawrence.

MILLER, B. J., AND F. L. KNOPF. 1993. Growth and survival of Mountain Plovers. Journal of Field Ornithology 64:500-506.

NATIONAL DROUGHT MITIGATION CENTER. 2003. The Drought Monitor. http://drought.unl.edu

OLSON, S. L., AND D. EDGE. 1985. Nest site selection by Mountain Plovers in northcentral Montana. Journal of Range Management 38:280-282.

OSTLIE, W. R., R. E. SCHNEIDER, J. M. ALDRICH, T. M. FAUST, R. L. B. MCKIM, AND S. J. CHAPLIN. 1997. The status of biodiversity in the Great Plains. The Nature Conservancy, Arlington, Virginia.

PLUMB, R. E., F. L. KNOPF, AND S. H. ANDERSON. 2005. Minimum population size of Mountain Plovers breeding in Wyoming. Wilson Bulletin 117:15-22.

ROYLE, J. A., AND J. D. NICHOLS. 2003. Estimating abundance from repeated presence-absence data or point counts. Ecology 84: 777-790.

SAMSON, F.B., AND F.L. KNOPF. 1994. Prairie conservation in North American. BioScience 44:418-421.

SAMSON, F.B., AND F.L. KNOPF, [EDS.]. 1996. Prairie conservation: preserving North America's most endangered ecosystem. Island Press. Covelo, California.

SEAMAN, D. E., AND R. A. POWELL. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075-2085.

SHACKFORD, J. S., D. M. LESLIE, JR., AND W. D. HARDEN. 1999. Range-wide use of cultivated fields by Mountain Plovers during the breeding season. Journal of Field Ornithology 70:114-120.

SHIBATA, R. 1989. Statistical aspects of model selection, p. 215-240. *In* J. C. Williams [ED.], From data to model. Springer-Verlag, New York.

SMITH, G. A., AND M. V. LOMOLINO. 2004. Black-tailed prairie dogs and the structure of avian communities on the shortgrass prairie. Oecologia 138:592-602.

SORDAHL, T. 1991. Antipredator behavior of Mountain Plover chicks. Prairie Naturalist 23: 109-115.

TILMAN, D., W. WEDIN, AND J. KNOPS. 1996. Productivity and sustainability influences by biodiversity in grassland ecosystems. Nature 379:718-720.

U.S. FISH AND WILDLIFE SERVICE. 1999. Endangered and threatened wildlife and plants: proposed threatened status for the Mountain Plover. Federal Register 64:7587-7601.

VEGA RIVERA, J. H., W. J. MCSHEA, AND J. H. RAPPOLE. 2003. Comparison of breeding and postbreeding movements and habitat requirements for the Scarlet Tanager (*Piranga olivacea*) in Virginia. Auk 120:632-644.

WILCOVE, D. S., AND J. LEE. 2004. Using economic and regulatory incentives to restore endangered species: lessons learned from three new programs. Conservation Biology 18:639-645.

WINTER, S. L., J. F. CULLY, JR., AND J. S. PONTIUS. 1999a. Influence of prairie dog colonies and climatic variation on bird communities in Kansas shortgrass prairie, p. 379. *In* J. Thorpe, T.A. Steves, and M. Gollop [EDS.], Proceedings of the fifth prairie conservation and endangered species conference. Provincial Museum of Alberta, Edmonton, Alberta.

WINTER, S. L., J. F. CULLY, JR., AND J. S. PONTIUS. 1999b. Influence of prairie dog colonies on vegetation in Kansas shortgrass prairie, p. 375-379. *In* J. Thorpe, T.A. Steves, and M. Gollop [EDS.], Proceedings of the fifth prairie conservation and endangered species conference. Provincial Museum of Alberta, Edmonton, Alberta.

WORTON, B. J. 1995. Using Monte Carlo simulation to evaluate kernel-based home range estimators. Journal of Wildlife Management 59:794-800.

WUNDER, M.B., AND F. L. KNOPF. 2003. The imperial valley of California is critical to wintering Mountain Plovers. Journal of Field Ornithology 74:74-80.

WUNDER, M. B., F. L. KNOPF, AND C. A. PAGUE. 2003. The high-elevation of Mountain Plovers in Colorado. Condor 105:654-662.

Recommended Citation: Dreitz, V. J. 2005. Resolving Conflicts of Mountain Plovers (*Charadrius montanus*) Breeding on Agricultural Lands in Colorado. Final Report to Colorado Division of Wildlife, Colorado Farm Bureau, U.S. Fish and Wildlife Service and U.S. Geological Survey by Colorado Natural Heritage Program, Colorado State University, 42 pages.

Appendix 1. Nest survival models and their corresponding Akaike Information Criterion (AIC_c) scores for nesting success of Mountain Plovers in eastern Colorado. Models are listed in ascending order of AIC_c with ΔAIC_c indicating the difference between each model and the model with the lowest AIC_c value (i.e., the best model).

Model	K[1]	AIC_c	ΔAIC_c
S(*T*)	2	855.1891	0.0000
S(habitat type+T)	5	855.7397	0.5506
S(*TT*)	3	855.9376	0.7485
S(*2001&2003,2002+T*)	3	856.1546	0.9655
S(*habitat type+TT*)	6	856.9511	1.7620
S(*sex+T*)	3	857.0375	1.8484
S(*habitat+T*)	3	857.1383	1.9492
S(*2001&2003,2002+TT*)	4	857.1489	1.9598
S(*year+T*)	4	857.7194	2.5303
S(*sex+TT*)	4	857.7895	2.6004
S(*habitat+TT*)	4	857.8350	2.6459
S(*year+TT*)	5	858.5679	3.3788
S(*2001&2003,2002+sex+T*)	5	858.6151	3.4260
S(*crop,grassland,pdog+T*)	4	859.1291	3.9400
S(*2001&2003,2002+habitat type+T*)	7	859.4275	4.2384
S(*sex+habitat type+T*)	7	859.5820	4.3929
S(*crop,grassland,pdog+TT*)	5	859.8401	4.6510
S(*2001&2003,2002+sex+TT*)	6	859.8487	4.6596
S(*2001&2003,2002+habitat+T*)	5	859.9117	4.7226
S(*year+sex+T*)	6	860.1137	4.9246
S(*2001&2003,2002+habitat type+TT*)	8	860.7664	5.5773
S(*sex+habitat+T*)	5	860.8117	5.6226
S(*2001&2003,2002+habitat+TT*)	6	860.8793	5.6902
S(*year+sex+TT*)	7	861.2232	6.0341
S(*2001&2003,2002+crop,grassland,pdog+T*)	6	861.6877	6.4986
S(*2001&2003,2002+crop,grassland,pdog+TT*)	7	862.7603	7.5712
S(*sex+crop,grassland,pdog+T*)	6	862.8022	7.6131
S(.)	1	866.8006	11.6115
S(*2001&2003,2002*)	2	868.1344	12.9453
S(*sex*)	2	868.7368	13.5477
S(*year*)	3	870.0886	14.8995
S(*2001&2003,2002+sex*)	4	871.9451	16.7560
S(*year+sex*)	5	873.8765	18.6874

[1] Number of parameters in the model.

Appendix 2. Patch occupancy models and their corresponding Akaike Information Criterion (AIC_c) scores for nesting success of Mountain Plovers in eastern Colorado. Models are listed in ascending order of AIC_c with ΔAIC_c indicating the difference between each model and the model with the lowest AIC_c value (i.e., the best model). Detection probability, *r*, is modeled as a function of search time (*st*), time of the breeding season (*brd*), observers (*obs*) and if the patch was known to have a plover present prior to the first survey (*plover*). Mean abundance per patch, λ, is modeled as a function of habitat, patch size and if the patch was known to have a plover present prior to the first survey.

Model	*K*[1]	AIC_c	ΔAIC_c
r(*st*+*brd*+*obs*) (*habitat*)	9	506.45	0.00
r(*st*+*brd*) (*habitat*)	6	508.71	2.26
r(*st*+*brd*+*obs*) (*habitat*+*size*)	10	508.96	2.51
r(*st*+*brd*+*obs*) (*habitat*+*plover*)	10	508.99	2.54
r(*st*+*habitat*) (.)	5	509.28	2.83
r(*st*+*brd*+*obs*) (.)	6	510.87	4.42
r(*st*+*brd*+*obs*) (*habitat*)	7	510.90	4.45

[1] Number of parameters in the model.

Appendix 3. Logistic coefficients for models examining various effects on daily nest survival of Mountain Plovers in eastern Colorado from 2001 to 2003. Models with a $\Delta AIC_c < 2$ are presented (see Appendix 1).

				Confidence Intervals	
Model	Coefficient	Estimate	SE	Lower	Upper
S(*T*)	Intercept	2.8375	0.0851	2.6706	3.0044
	T	-0.0159	0.0042	-0.0242	-0.0077
S(*habitat type+T*)	Intercept	2.8709	0.0892	2.6961	3.0457
	Idle Fields	-0.0738	0.0939	-0.2578	0.1103
	Wheat Fields	0.1599	0.0971	-0.0305	0.3502
	Grassland	0.0173	0.0969	-0.2072	0.1726
	T	-0.0132	0.0045	-0.0223	-0.0048
S(*TT*)	Intercept	2.7618	0.1082	2.5497	2.9739
	T	-0.0143	0.0047	-0.0235	-0.0051
	TT	0.0002	0.0002	-0.0002	0.0006
S(*2001&2003,2002+T*)	Intercept	2.7578	0.1142	2.5340	2.9816
	2002	0.1542	0.1514	-0.1426	0.4509
	T	-0.0162	0.0042	-0.0246	-0.0079
S(*habitat type+TT*)	Intercept	2.8066	0.1144	2.5823	3.0308
	Idle Fields	-0.0568	0.0956	-0.2442	0.1305
	Wheat Fields	0.1626	0.0972	-0.0280	0.3531
	Grassland	-0.0080	0.0975	-0.1991	0.1831
	T	-0.0125	0.0048	-0.0219	-0.0030
	TT	0.0002	0.0002	-0.0002	0.0006
S(*sex+T*)	Intercept	2.8313	0.0865	2.6619	3.0008
	Male	-0.0321	0.0811	-0.1911	0.1269
	T	-0.0162	0.0043	-0.0247	-0.0078
S(*habitat+T*)	Intercept	2.8331	0.0870	2.6625	3.0038
	Crop	0.0179	0.0770	-0.1330	0.1688
	T	-0.0162	0.0044	-0.0247	-0.0076
S(*2001&2003,2002+TT*)	Intercept	2.6993	0.1277	2.4490	2.9496
	2002	0.1355	0.1523	-0.1630	0.4341
	T	-0.0147	0.0047	-0.0240	-0.0055
	TT	0.0002	0.0002	-0.0002	0.0006

Appendix 4. Mean home range size (hectares) and movement of Mountain Plover broods on cropland and prairie-dog habitats in 2002 and 2003. Home range size was based on 50% and 95% fixed kernel (FK) home range estimates and Minimum Convex Polygon (MCP), respectively.

	50% FK		95% FK		MCP		Movement (m)	
Habitat	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Cropland	19.86	14.20	131.56	74.37	90.3	53.6	411.26	131.11
Prairie-Dog	44.83	66.76	243.28	366.30	115.5	169.23	422.86	174.93

Appendix 5. Mountain Plover chick survival models and their corresponding Akaike Information Criterion (AIC_c) scores in eastern Colorado for 2002 and 2003. Models are listed in ascending order of AIC_c with ΔAIC_c indicating the difference between each model and the model with the lowest AIC_c value (i.e., the best model).

Model	*K*[1]	AIC_c	ΔAIC_c
$\phi(H3)$ $p(.)$	3	1114.13	0.00
$\phi(year)$ $p(.)$	3	1121.92	7.80
$\phi(.)$ $p(.)$	2	1127.87	13.75
$\phi(H1)$ $p(.)$	3	1159.01	44.88
$\phi(H1+year)$ $p(.)$	4	1160.41	46.28
$\phi(H2)$ $p(.)$	3	1161.60	47.47
$\phi(H2+year)$ $p(.)$	4	1163.42	49.39
$\phi(H3+year)$ $p(.)$	4	1164.14	50.01

[1] Number of parameters in the model.