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Are oil and natural gas development sites ecological traps for nesting killdeer?

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Extraction of oil and natural gas is an emerging source of anthropogenic disturbance that threatens wild populations and important wildlife habitats. We compared daily nest survival estimates of killdeer *Charadrius vociferous* at graveled oil pads to those that nested on native grass cover in western Oklahoma, USA in 2015 and 2017. We conducted weekly searches for nesting killdeer around oil pads and in pastures (grass cover) at the Packsaddle Wildlife Management Area April–June. Killdeer showed a strong selection for graveled oil pad over grass fields with 64% of all nest attempts occurring on oil pads. A higher proportion (64%) of the nests we found were in the gravel substrates of oil pads, and daily nest survival estimates for oil pad nests were lower than our estimates for nests in grass substrates. We also identified a difference in edge effects between the two nesting substrates with the probability of nest survival on oil pads highest closer to the edge of the patches and the probability of nest survival in grass cover highest in the interior of the patches. This is an indication that risk of nest failure on oil pads increased towards areas of high human use: Nest failure on oil pads was almost entirely due to destruction by moving vehicles and by oil workers performing routine operations at well sites. Our results demonstrate that modified landscapes attract native species but could function as ecological traps. Management efforts to reduce the effect of oil and natural gas development or similar forms of human land use modifications on co-occurring nesting birds will benefit from reduction in habitat conversion and incorporation of natural gas developments into conservation planning.

Keywords: ecological trap, oil pad, killdeer, nesting selection, nest survival, *Charadrius vociferous*

Organisms are theorized to select ecological space that maximizes individual fitness and avoid space where they are unlikely to be successful (Fretwell and Lucas 1970, Calsbeek and Sinervo 2002). Evolutionary processes have equipped organisms with cognitive clues to discriminate habitat features that might correlate with reduced fitness (Clark and Shutler 1999, Storch and Frynta 1999, Price 2010). The cues used to indicate optimum conditions, however, often do not guarantee the expected fitness (Robertson and Hutto 2006). Habitat selection is typically based on available conditions at the time of selection. Animals are normally unaware of the consequences of habitat selection because the factors that might inhibit reproductive success may not be evident at the time of selection (Battin 2004, Robertson and Hutto 2006). The term 'ecological trap' describes animal selection of areas that appear to be suitable (or even preferred) based on their physical and/or vegetation characteristics but will act as ecological sinks rather than sources (Dwernychuk and Boag 1972, Battin 2004).

Several studies have demonstrated the consequences of ecological traps for species conservation within modified habitat (e.g. agricultural fields, airports, reservoirs and urban areas (Gates and Gysel 1978, Best 1986, Marini et al. 1995, Li et al. 2015). Yet oil wells have received relatively less attention as a potential ecological trap for wild species in disturbed landscapes (Ludlow and Davis 2018). Since the 1930s, natural gas and oil development has increased across all of North America (Lyon and Anderson 2003). With global demand for energy projected to increase more than 28% by 2040 (International Energy Agency 2017), we expect to see continuous increase in oil explorations in the coming decades. At least 350 000 km^2 of grassland and deciduous forest are projected to be impacted by energy development in the US by 2030 (McDonald et al. 2009). Such large-scale

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alterations are likely to impact species that depend on these landscapes. Current landscape changes associated with oil well developments impact wildlife in a number of ways (Northrup and Wittemyer 2013): 1) habitat fragmentation by the creation of complex road networks (Ingelfinger and Anderson 2004, Bi et al. 2011, Thompson et al. 2015); 2) direct loss of critical breeding habitat (Christie et al. 2015, Moran et al. 2015); 3) high disturbance from human activity (e.g. construction and anthropogenic noise) (Blickley et al. 2012, Francis and Barber 2013); and 4) direct mortality of wildlife by vehicle, light entrapment and drowning in oil reserve pits (Trail 2006, Ramirez Jr 2009, Boulanger and Stenhouse 2014, Ramirez Jr et al. 2015).

To accommodate heavy machinery required for drilling and well maintenance, a drilling site is cleared of vegetation, graded, and topped with a layer of crushed stone. The area of crushed stone substrate is often referred to as a well pad or oil pad. This substrate generally represents a novel feature of the land cover in which it has been created. Well pads can also vary in size from several hectares for a site with multiple horizontal wells drilled from a centralized location, to vertical wells that individually occupy a smaller land area but require a larger number of disturbed sites for a comparable amount of production to horizontal drilling. For example, in the Allegheny National Forest of northwestern Pennsylvania, USA, individual vertical wells were located on well pads that averaged 1600 m^2 plus an associated 400 m of access road (ANF 2007).

The introduction of a novel land cover can lead to a cascade of changes for biotic communities. Thomas et al. (2014) found that road and well pad construction in contiguous forest was associated with reduction in canopy cover and tree basal area sufficient to induce compositional changes in entire guilds of breeding birds. For multiple species of ground-nesting birds, however, the gravel well pads themselves could serve as an attractant. Many ground-nesting birds that seek beaches or other barren substrate for nest placement are known to make use of gravel in parking lots, roof tops, and industrial sites. Across temperate North America, the widespread and abundant killdeer *Charadrius vociferous*, a plover that frequents both uplands and wetlands, is perhaps the best known ground nesting species attracted to anthropogenic cover types. Killdeer are often encountered nesting in pastures, parking lots and on gravel roadsides. They are also highly likely to make use of graveled well pads for oil and gas drilling but little is known of their nest success in such areas. Other plovers have been shown to be susceptible to nest disturbance from human activity. For example, trampling from human foot traffic is cited as an important factor in the decline of snowy plover *C. nivosus* nesting on beaches (Lafferty et al. 2006). At the eastern edge of its range in western Oklahoma, the mountain plover *C. montanus* has largely abandoned typical nesting substrate in closely cropped grasses and bare soil of prairie dog *Cynomys ludovicianus* towns for the bare soil of plowed fields in areas of intense cultivation (McConnell et al. 2009). Nest destruction from farm machinery in plowed fields approached caused 70% nest failure in at least one study (Shackford et al. 1999) but the plovers persist in their selection of these fields for nesting. On a far larger (near continental) scale, a similar phenomenon could be taking place with killdeer. Especially as well construction continues at a rapid pace, it is important to understand both the degree of selection for gravel well pads by nesting killdeer and the nest success of the birds that use that habitat.

In this study, we assessed killdeer reproductive success in a landscape of oil and gas drilling by comparing daily nest survival between birds that nested on oil pads and those that nested on traditional substrates of short grass cover. In addition, we evaluated daily nest survival in relation to environmental features in our study system to quantify their potential impact on killdeer nest survival.

Methods

We conducted this study at the Oklahoma Dept of Wildlife Conservation's (ODWC) Packsaddle Wildlife Management Area (WMA) in northwestern Oklahoma, USA. Packsaddle WMA covers ~6475 ha of mixed-grass prairie supporting abundant grasses, forbs and extensive cover in a the dwarf shinnery oak *Quercus havardii* on rolling terrain ranging approximately 579–762 m a.s.l. Average annual precipitation is 53 cm, with the majority occurring during spring and summer (DeMaso et al. 1997). Detailed vegetation and landscape characteristics of the area are described by DeMaso et al. (1997) and Hall (2015). The WMA is managed with a combination of leased cattle grazing and prescribed fire to provide hunting opportunities for general game with a particular emphasis on northern bobwhite *Colinus virginianus*. Oil and gas extraction is permitted on the WMA and by 2017 it hosted >40 active, gravel oil pads (Atuo and O'Connell 2018). The substrate of oil pads consists of graded gravel supporting well heads and other infrastructure (Supplementary material Appendix 1 Fig. A1). Pads are visited regularly year-round for maintenance by workers.

Study species

The killdeer (Fig. 1) is the most common and widely distributed plover in North America. Its breeding distribution extends from the Arctic Circle to the southern US, Mexico and Caribbean islands (Sanzenbacher and Haig 2001). Killdeer use a wide variety of open cover types providing sparse or short vegetation and exposed soil. These include sandbars, mudflats, grazed fields, and other barren lands (Jackson and Jackson 2000). The species tolerates areas highly disturbed by humans such as agricultural fields and urban areas (e.g. athletic fields, parking lots, airports and golf courses) where it typically nests and forages in vegetation no taller than 3 cm (Jackson and Jackson 2000, Jorgensen et al. 2009). The killdeer nest is a shallow depression on the ground 7–9 cm wide and surrounded with small stones that provide cryptic protection to the egg (Jackson and Jackson 2000, Jorgensen et al. 2009). Shortly after hatching, young killdeer are mobile and leave the immediate area of the nest under parental supervision.

Figure 1. Adult killdeer on a nest on a gravel oil pad (above); newly hatched killdeer chicks (below).

Nest searches

We included killdeer nests in our study that were discovered incidentally or located through area searches of select oil pads and heavily grazed patches within pastures, 2015 and 2017. To coincide with peak nesting of killdeer in the southern Great Plains, field work took place April–June (Conway et al. 2005a). A team of three independently searched oil pads that were in proximity (< 2000 m) to the Canadian River at the low land zone of the Packsaddle WMA. We selected 2000 m cutoff distance to maximize the chance of finding nests. We also searched other potentially suitable killdeer nesting habitats with short vegetation height (Conway et al. 2005b). Killdeer typically nest in areas with short vegetation (<10 cm) where they can sight predators from a distance (Long and Ralph 2001). Thus, we systematically searched all areas with grass height < 10 cm for killdeer nest. We used adult behavior such as the characteristic 'broken wing' behavior consistent with nest defense as a cue for finding nests. Upon arriving at an oil pad or open field, we observed killdeer movements and identified the point where an adult killdeer was first detected on the ground. We then conducted a careful and systematic search of the area until a nest was found. Once an active nest was discovered, we recorded a GPS point to later relocate the nest.

For each nest, we recorded the clutch size and estimated nest age based on the number of eggs and when clutch was complete. Killdeer incubate their eggs for 24–28 days (Phillips 1972, Lenington 1980), and we estimated the potential hatch date by adding the difference between 24 to the age (in days) of the clutch estimated at discovery. Because these estimates were open to errors, we revisited each nest at least once every two days during incubation but intensified our visit to once per day during the last five days prior to the estimated hatch date. During each visit, we recorded nest fate and classified the nest as 'active' if there was at least one egg in the nest, and 'failed' if the nest became empty prior to producing hatchlings. For failed nests, we identified the cause of nest failure as human (if the nest was crushed by vehicles as identified by tire marks- and egg remains), predation (if the clutch was reduced but incubation continued) or unknown (if neither eggs, chicks, nor adult birds were seen). We estimated Euclidian distance from each nest to the river and edge using the near tool in ArcGIS 10.3. We defined edge as the habitat boundaries in the immediate vicinity of a killdeer nest.

Habitat preference

To asses habitat preference, we used a 2 m resolution Geo-Eye imagery of Packsaddle WMA acquired 6 July 2014 through the NASA Scientific Data Purchase. A supervised classification of the image was completed as part of a collaborating project (Atuo 2017). Using the classified imagery, we computed the proportion of oil pads and grass cover in a subset of the WMA searched for killdeer nests. We calculated habitat preference for each habitat type given its availability using the Jacobs' index of selection (Jacobs 1974):

$$D = \frac{(r - p)}{(r + p - 2rp)}$$

where r is the proportion of use habitat, and p is the proportion of available habitat. Jacobs' index varies between –1 and +1. Positive values indicate a preference for a certain habitat, while negative values indicate avoidance.

Data analysis

We located and monitored 13 and 31 killdeer nests in 2015 and 2017, respectively. Killdeer are solitary nesters that occur at relatively low density in the southern Great Plains (Sauer et al. 2017), so we expected nests to be widely dispersed. We pooled the data among years by cover type, i.e. grass cover versus oil pad, to perform descriptive and quantitative statistical analysis irrespective of year of study. We summarized killdeer nest data (i.e. number of nests found, nest success, number of eggs in nests, and number of chicks hatched) into a contingency table and tested the frequencies of nesting activities using χ^2-tests (Agresti 1996) in R ver. 3.4.3 (<www.r-project.org>). Following the independence test, we performed the marginal test of proportion to determine whether the proportion of nests found, number of eggs, hatching success, and nest success differed by nest substrate type. The mean number of eggs found or hatched were tested using t-test and the variance in mean eggs found or hatched were evaluated using two-way analysis of variance (ANOVA) considering habitat types and distance to edge as covariates in the model. Significance for all tests was evaluated at $\alpha = 0.05$. We also performed a Wilcox rank sum test to evaluate the difference in the median distance to the edge for nests in grass versus gravel oil pads.

Nest survival analysis

Each nest has the two possible outcomes of success or failure. We hypothesized that each nest has an equal probability of success following a Bernoulli distribution (Agresti 1996). This formulation helped us to evaluate nest survival in the two habitat conditions and to use three different survival-analysis approaches. The first approach modeled nest survival probability. The second provided the survival probability based on a time-to-event analysis using lifetime data. The third approach provided the risk or hazard rate of a nest surviving based on categorical covariates. To model daily nest survival (DSR) in relation to habitat and distance to edge, we used the package 'RMark' (Laake 2013) in R that estimates survival rate within capture-recapture data framework using logit link function. Daily nest survival is the probability that a nest survives a single day regardless of calendar date or nest age. By raising DSR to the power of nest duration (the number of days from initiation to completion), we can estimate true nest success rate for the entire nesting cycle (i.e. egg laying to fledging; (Mayfield1975).

The RMark package is the extension of Mayfield's approach (Mayfield 1961, 1975) that uses maximum likelihood approach to estimate daily survival probabilities and nesting success rate for data from nests that were visited periodically (Rotella 2012). Mayfield's ad hoc estimator assumes that DSR is the same for all nests on all dates and for all nest ages within the sample, but the RMark package allows us to model DSR as a function of multiple covariates (continuous and discrete) and also helps to compare competing models. The logit link function provides beta (parameter) estimates that is similar to using a logistic regression function for survival analysis. We fitted seven DSR models including additive and interaction effects of a covariate, i.e. distance to the edge with habitat types, and evaluated the best models for DSR based on Akaike information criteria (AIC) weight (Wagenmakers and Farrell 2004).

Next, we used the Kaplan–Meier (KM) survival function, non-parametric approach because it allowed us to analyze time-to-event analysis from lifetime data even for right censored data with respect to one covariate ignoring the impact of other covariates in the model (Allison 2010, Therneau and Grambsch 2013). Our data were right-censored because some nests survived to the end of our study period (Allison 2010). The KM survival function has been used in the other fields to estimate time to failure; this procedure allowed us to examine nest survival based on nest age and distance to edge.

Furthermore, we used the Cox proportional hazard (Cox-PH) model, a semi parametric approach to investigate how habitat type might influence the rate of nest survival at a particular point in time. This rate is commonly referred to as the hazard rate and can be interpreted as the risk of nest not surviving at a given time. Our data were also right-censored for the Cox-PH analysis. At first, we used the Schoenfeld residual test to determine if our data met the assumption of proportional hazard (Allison 2010, Therneau 2015). However, the additive model containing distance to edge and interaction effect models such as two-way habitat and distance to edge did not meet assumptions of proportional hazard. Therefore, we reported hazard rate and plotted cumulative hazard function based on habitat type. Both KM survival and Cox-PH analysis were performed using the *survival* package in R (Therneau and Grambsch 2013, Therneau 2015).

Results

To assess if killdeer selection of oil pads and grass cover represent habitat preference, Jacobs' index values were calculated for 16 nests on oil pads and 28 nests on grass cover. Killdeer showed strong disproportional preference for oil pads relative to its availability in the landscape (D = 0.98). Jacobs' index for selection on grass cover was negative (D = –0.97) indicating a strong avoidance. Summaries of the killdeer nests are shown in Table 1. Observed frequency of nests found on oil pads was not significantly different ($\chi^2 = 3.27$, p-value = 0.07) from nest found in grass cover. However, we observed high frequency of nest success on grass cover than we did on oil pads ($\chi^2 = 4.56$, p-value = 0.03) indicating that apparent nest success was high in grass cover than on oil pads (Table 1). Similarly, the frequency of eggs found and proportion of eggs hatched were significantly higher on oil pads than on grass cover ($\chi^2 = 14.88$, p-value <0.001; $\chi^2 = 27.08$, p-value <0.001). Although the mean number of eggs founds did not differ between habitat types (t = –1.54, p-value = 0.14; Table 1), the mean number of eggs that survived to hatch was significantly higher on grass cover (t = 2.89, p-value = 0.007; Table 1). Furthermore, the two-way analysis of variance indicated that variance in the observed mean number of eggs was neither due to the main effect nor the interaction effects of habitat types and distance to edge. Nevertheless, the mean number of eggs that survived to hatching varied due to the effect of habitat types (two-way ANOVA, F = 9.15; p-value = 0.004) but not due to main or interaction effects of distance. Wilcox sign rank sum test indicated that the median distance to edge grass cover (50.6 m) was significantly (W = 447, p-value <0.001) high than distance to the edge on oil pads (5.5 m) indicating that the nest on oil pads are likely more vulnerable to the extrinsic factors than nest on grass cover.

Table 1. Summary of killdeer nests, eggs found, and eggs hatched at the Packsaddle Wildlife Management Area in western Oklahoma during, 2015 and 2017. SD = standard deviation; ANS = apparent nest success.

	Nests			Eggs found		Eggs hatched	
Habitat	Found	Success	ANS	Total	Mean ± SD	Total	Mean ± SD
Grass cover	16	10	0.63	59	3.7 ± 0.5	37	2.3 ± 1.7
Oil pads	28	7	0.25	109	3.9 ± 0.3	23	0.8 ± 1.5
Total	44	17	0.39	168	3.8 ± 0.4	45	1.4 ± 1.7

Table 2. Constant daily survival rate (DSR) (mean ± standard error) and survival probability of killdeer nests at the Packsaddle Wildlife Management Area in western Oklahoma, 2015 and 2017. Estimates represent analysis of pooled data using a logit link function within a capture–recapture data framework in the RMark program in R.

	Real function parameter		Survival probability during study period	
Factors	Constant DSR	95% CI	Exposure DSR	95% CI
Grass cover	0.979 ± 0.008	(0.954–0.990)	0.540 ± 0.136	(0.284–0.773)
Oil pads	0.920 ± 0.017	(0.891–0.947)	0.089 ± 0.047	(0.031–0.235)
Distance to edge	0.950 ± 0.010	(0.927–0.966)	0.226 ± 0.066	(0.120–0.378)

Nest survival

Estimated constant daily survival rate (DSR) for killdeer nest was similar among habitat types (Table 2). Nonetheless, exposure DSR (i.e. survival over a 30-day exposure period) on grass cover (0.54) was six times higher than on oil habitat (0.09). Exposure DSR increased with decreasing distance to the edge at a faster rate for nest on oil pads compared to nests on grass cover indicating that nests that were nearer to edge on oil pads were more likely to survive (Fig. 2).

We considered a model important for explaining daily survival rate if it fell within ΔAICc < 4 and did not contain uninformative variables (Arnold 2010). Hence, we interpreted two models containing time (nest age) and habitat types, as the most parsimonious models explaining killdeer DSR (Supplementary material Appendix 2 Table A1). We excluded the model containing distance to edge because parameter estimates were neither significant in the additive nor in the interaction model containing habitat types (Supplementary material Appendix 3 Table A2). In both models, the negative parameter estimates of oil pads indicated a decreasing nest survival probability with nest age on oil pads, but high survival probability for nests on grass cover (Supplementary material Appendix 3 Table A2). The negative coefficient of time (nest age) also point to the decreasing survival probability with nesting period.

Kaplan–Meier (KM) analysis indicated a median killdeer nest survival period of 24 days (Fig. 3a). The distance from edge at which 50% of the nests survived to hatch was 79 m for grass fields and 6 m for oil pads (Fig. 3b). Also, 50% of the nests survived to day 27 on grass fields, but only to day 21 on oil pads. Nest survival probability on grass cover was 52%, twice as high as nests on oil pads (25%: Fig. 3c).

Cox-proportional hazard model using the pooled data showed that the model with habitat types was significant at $\alpha = 0.05$ level. The model also revealed that survival rate was

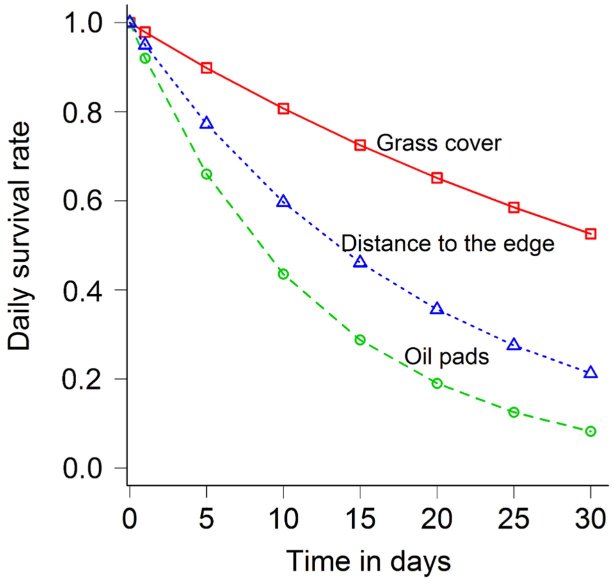

Figure 2. Daily survival rate of killdeer nests based on pooled data for habitat types and distance to edge.

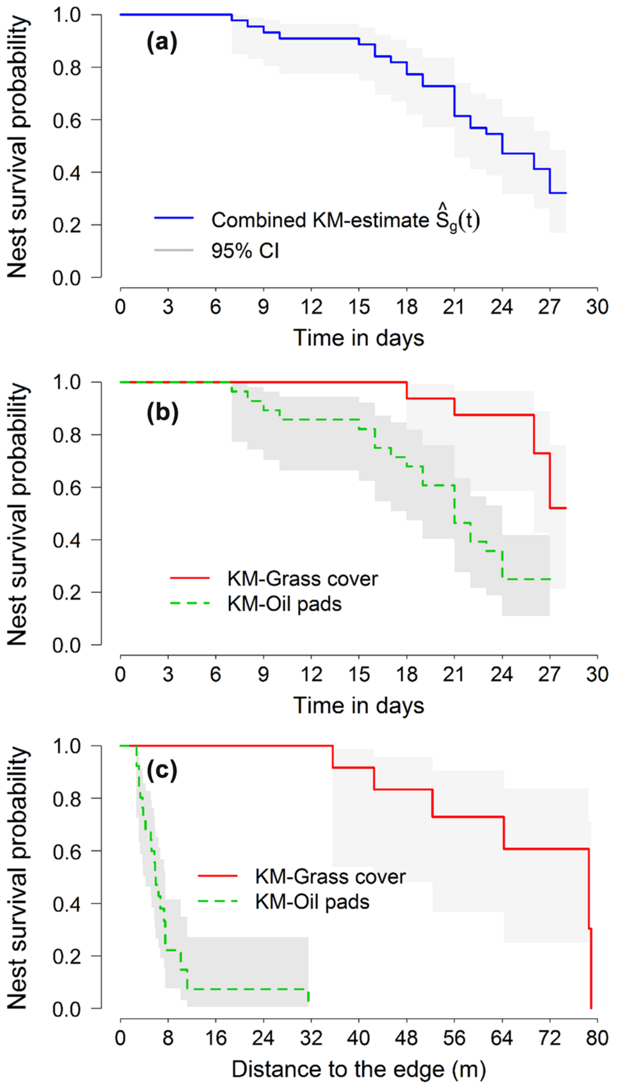

Figure 3. Kaplan–Meier (KM) plots showing nest survival probability of killdeer at the Packsaddle Wildlife Management Area in western Oklahoma: (a) pooled survival probablity over the time (days), (b) survival probablity by habitat type (grass cover and oil pads) with respect to time, and (c) survival probability by habitat type with respect to distance to the edge (m).

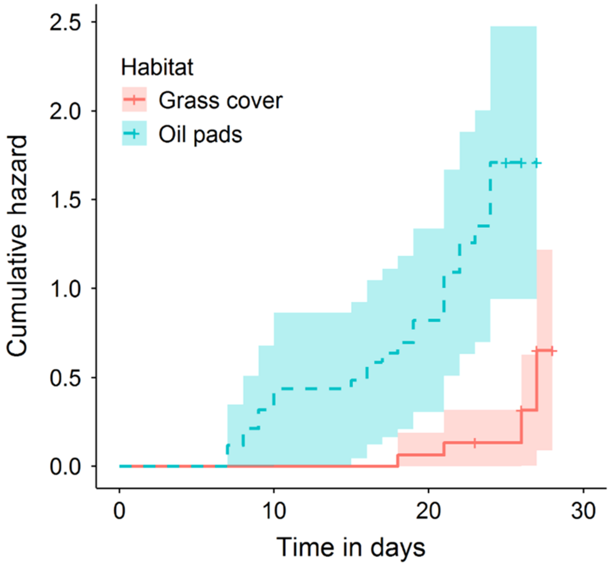

Figure 4. Cumulative hazards function for killdeer nest survival on grass cover (solid line) and oil pads (dashed line) at the Packsaddle Wildlife Management Area in western Oklahoma.

poor on oil pads than on grass cover since the hazard rate was higher on oil pads (Fig. 4). The other models that included distance to edge, and two-way interactions of habitat types and distance to edge did not have any significant effect (Supplementary material Appendix 4 Table A3). The model with distance to edge as its only covariate showed significant decreasing hazards (hazard rate = –0.02, z = –2.23, p = 0.02) on killdeer nest survival with minimal effects.

Discussion

Knowledge of reproductive success of an organism derived from nest survivorship is often used to understand the source-sink dynamics of wildlife populations (Dwernychuk and Boag 1972, Anteau et al. 2012). Our study demonstrates that while oil pads provides good nesting option for killdeer, they may act like traps for the killdeer that nest in them. During this study, we observed a disproportionately high nest failure for killdeer nesting on oil pads in contrast to those that selected natural fields for nesting. Seventy-seven percent of all nest attempts on oil pads were destroyed before the eggs reached hatch date. Despite this relatively high nest failure, killdeer in our study area showed strong selection for oil pads. All oil pads that were selected for nesting by killdeer shared a common attribute of graveled surface. It is therefore plausible that killdeer attraction to oil pads is mainly driven by the presence of gravels that provide a cryptic environment for their eggs (Fig. 5). Wass (1974) reported a killdeer nest on a graveled roof, an indication that the bird has an unusual affinity for pebbles that blends with its eggs. Nest failure from factors other than human related nest destruction was low. Except for two nests on grass field that we believe were destroyed by grazing cattle, nest failure on oil pads was almost entirely due to anthropogenic destruction involving moving vehicles by workers performing routine operations at well sites. All successful nests on oil pads were located away from tire trails but <6 m away from the edge. Nest loss on grass cover was low and majorly attributed to predation likely from racoons and crows (Brunton 1990). Compare to oil pads, it was more difficult to find nests in grasslands which may have bias our data in 2015. Nonetheless, nest searching on grassland greatly improved in 2017 with the location of 13 nests. Overall, our sample size across years provided 44 nests robust enough to provide reliable results.

Our results indicated nest survival declines with distance from edge in both habitat types, although at substantially different rates. Nest survival decline much more quickly on oil pads than in grass fields (Fig. 3b). Nests that were placed close to the edge of oil pads had higher chances of survival whereas survival probability was highest for birds that nested away from edge on grassland. This was not surprising because for nests on oil pads, proximity to edge implies safety from areas with high human related activities whereas it may imply risky habitat for nests on grass cover. Edge habitat is often portrayed as dangerous areas that adversely affect reproductive success in several species by increasing the rate of nest depredation and parasitism (Paton 1994, Shipley et al. 2013). This was true for nests on grass cover. However, higher survival in edges of oil pads suggest that risk associated with anthropogenic nest loss might be greater than predation risk in this system. Nests at the edge of oil pads are less likely to be trampled by moving vehicles or oil workers.

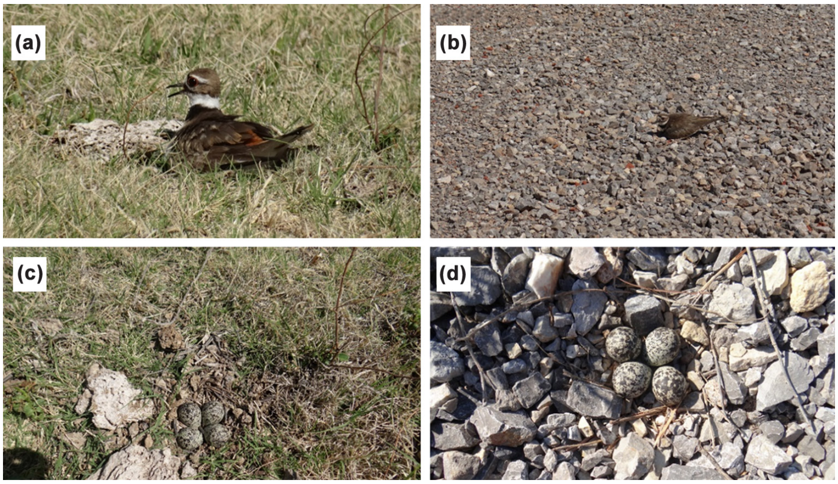

Figure 5. Killdeer incubating eggs in grass cover (a) on an oil pad (b); killdeer clutches of four eggs on grass cover (c) and on an oil pad (d).

Overall, our study demonstrated the mismatch between cues that are used by a ground nesting bird to select nesting habitat, and actual nest success. In the face of viable alternatives, killdeer appeared to select for areas where they are vulnerable to nest destructions, and the chance for reproductive success is low. A major component of ecological trap is the idea that evolutionary cues of habitat selection can be misjudged and poorly matched with novel conditions (Robertson and Hutto 2006). We acknowledged that our studied species is an r-selected species and are less likely to demonstrate significant changes in population size or growth rate in the short term. Nonetheless, when conditions that create ecological traps are left unchecked, even rapidly reproductive species are likely to suffer sustained population decline in the long term (Robertson and Hutto 2006).

Several studies have demonstrated the effects of oil and gas pads on bird's abundances both in grasslands and forested landscapes (Van Wilgenburg et al. 2013, Thomas et al. 2014, Thompson et al. 2015, Loss 2016). These studies are mostly based on bird's abundances in relation to well sites. However, to the best of our knowledge, our study represents the first attempt to investigate the potential role of oil and gas wells as possible ecological traps for a nesting bird in the central Great Plains bioregion. The results from our study together with other studies are indications that the growing threats of energy development on wildlife cut across different ecological systems and threatens several wild species.

Educational enlightenment program for oil workers and other non-wildlife related workers that emphasize respect for wildlife in disturbed landscapes might benefit species that thrive in them. Given that killdeer attraction to oil pads appears to be influenced by the presence of gravel, it will be important to further investigate the amount and characteristics of gravel that that enhances killdeer nest site selection. Also, given the high summer temperature in this region (up to 40°C), and possibility of heat absorption and retention, it will be important to investigate thermoregulation of eggs that are laid and incubated on pebbles. Finally, our study provides relevant baseline information on the potential effects of oil and gas wells construction as a possible ecological trap for nesting killdeer.

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Supplementary material (available online as Appendix wlb-00476 at <www.wildlifebiology.org/appendix/wlb-00476>). Appendix 1.