

The Influence of Energy Development on the Ecology of the Ferruginous Hawk in the Western Canadian Grassland Ecosystems



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TABLE OF CONTENTS

LIST OF FIGURES	vi
LIST OF TABLES	ix
GLOSSARY OF TERMS	1
1. EXECUTIVE SUMMARY	3
2. PROJECT INTRODUCTION	5
3. LIFE HISTORY	6
Habitat	6
Breeding	6
Diet	6
Territory.....	7
Geographic range and populations trends	7
Limiting factors and threats.....	8
4. FEHA AND HUMAN DEVELOPMENT OF PRAIRIE LANDSCAPES	8
5. REPORT AND DATA COLLECTION OVERVIEW	9
6. ABUNDANCE	11
OBJECTIVE.....	11
INTRODUCTION.....	11
METHODS.....	11
Sampling design	11
Survey protocol	12
Variables that predict FEHA nest abundance.....	12
Statistical analyses.....	13
RESULTS.....	14
DISCUSSION	18
RECOMENDATIONS	18
7. NEST SUCCESS.....	20
OBJECTIVE.....	20
INTRODUCTION.....	20
METHODS.....	20
Sampling Design	20
Nest monitoring protocol.....	21
Variables to predict FEHA nest success.....	22

Statistical analyses.....	22
RESULTS.....	24
DISCUSSION	25
RECOMMENDATIONS	25
8. NEST REOCCUPANCY	26
OBJECTIVE.....	26
INTRODUCTION.....	26
METHODS.....	26
Sampling design	26
Survey protocol	27
Variables to predict nest reoccupancy.....	27
Statistical analyses.....	27
RESULTS.....	29
DISCUSSION	32
RECOMMENDATIONS	32
9. NEST BEHAVIOR.....	34
OBJECTIVE.....	34
INTRODUCTION.....	34
METHODS.....	34
Statistical Analysis	35
RESULTS.....	35
DISCUSSION	38
RECOMMENDATIONS	39
10. NEST ATTENDANCE BEHAVIOUR.....	40
OBJECTIVE.....	40
INTRODUCTION.....	40
METHODS.....	41
Statistical Analysis	42
RESULTS.....	42
Daily Nest Attendance.....	42
Hourly Nest Attendance	47
DISCUSSION	48

RECOMMENDATIONS	49
11. PREY DELIVERY RATES.....	50
OBJECTIVE.....	50
INTRODUCTION.....	50
METHODS.....	50
Statistical Analysis	51
RESULTS.....	52
Daily Prey Deliveries	52
DISCUSSION	54
RECOMMENDATIONS	54
12. COMPARISON OF TREE VS PLATFORM NEST SUCCESS	55
OBJECTIVE.....	55
INTRODUCTION.....	55
METHODS.....	55
Sampling design	55
Nest monitoring protocol.....	55
Statistical analyses.....	56
RESULTS.....	57
DISCUSSION	59
RECOMENDATIONS	59
13. NEST PLATFORM DESIGN	61
OBJECTIVE.....	61
INTRODUCTION.....	61
METHODS.....	61
Sampling Design	61
Statistical Analyses.....	61
RESULTS.....	61
DISCUSSION	63
RECOMENDATIONS	64
14. JUVENILE SURVIVAL & MOVEMENT	65
OBJECTIVE.....	65
INTRODUCTION.....	65

METHODS.....	65
Statistical analysis	66
DISCUSSION	69
RECOMENDATIONS	70
15. ADULT PERCH USE	71
OBJECTIVE.....	71
INTRODUCTION.....	71
METHODS.....	71
Hawk Capture and Telemetry.....	71
Sampling Design	71
Home Range and Perch Characterization.....	71
Statistical Analysis	72
RESULTS.....	72
DISCUSSION	74
RECOMMENDATIONS	74
16. CONCLUSIONS.....	75
17. LITERATURE CITED.....	77

LIST OF FIGURES

Figure 1. Distribution of FEHA in North America showing breeding, wintering, and year-round grounds (from Downey 2006).....	7
Figure 2. REACT’s study area across Alberta and Saskatchewan, showing the distribution of FEHA nests monitored (black triangles) from 2010 to 2013.	10
Figure 3. Examples of survey blocks, including the route driven and stick nests detected along the survey. Survey blocks with transmission lines had survey routes both parallel and perpendicular to the line. The shaded portion reflects the route driven and the estimated area surveyed, as seen from the road.	12
Figure 4. Study area map of southern Alberta and Saskatchewan, including survey blocks completed in 2012 and 2013. Survey blocks were placed across a gradient of land-cover composition and industrial development intensity.	14
Figure 5. Proportion of grass was an important non-linear predictor of FEHA abundance. Hawk abundance peaks in landscapes with approximately 50% native grass.	15
Figure 6. Gas well density was positively associated with FEHA nest abundance. Gas well density may be an important predictor of hawk abundance.	16
Figure 7. A weak synergistic effect between the amount of grassland and total edge density was observed, where FEHA densities were highest in areas with high edge density and moderate amounts of grassland.....	17
Figure 8. A weak synergistic effect between amount of grass and gas well density whereby the increase in FEHA density with gas well density depends on the amount of grass in the block.	17
Figure 9. Study area map of southern Alberta and Saskatchewan. Black triangles are monitored FEHA nests.....	21
Figure 10. Left: Nest monitoring a nest supported by an artificial nest platform. Right: the nest contents as seen while nest monitoring.	22
Figure 11. Map of study area located in southern Alberta and Saskatchewan, depicting the spread of nests where reoccupancy surveys were conducted. Nests were selected based on landscape characteristics and geographic spread, where nests were located across a gradient of landcover composition and industrial development intensity.....	30
Figure 12. Predicted probability of FEHA nest reoccupancy. Years occupied by FEHA increased with greater amounts of native prairie within 2.5 km of the nest (n=600), shown with 95% confidence intervals.....	31
Figure 13. Predicted probability of FEHA nest reoccupancy. Of years occupied by FEHA decreased with fewer active oil wells within 2.5 km of the nest (n=600), shown with 95% confidence intervals.....	31
Figure 14. The predicted probability of witnessing FEHA adults and Fledglings at nest sites during nest monitoring from April through August from 2010 through 2014. Predicted probabilities were generated using logistic regression.	36
Figure 15. Boxplot showing the flight initiation distances (FID) in meters by FEHA adults when approached by an observer by date. Dates below boxes indicate interval boundaries over which the data is summarized. Box edges indicate the 25th and 75th percentiles, horizontal lines indicate	

median values and whiskers indicate 5th and 95th percentiles. Black markers indicate values outside the 95th percentile. Numbers within boxes indicate number of documented FIDs. The short-dash and long-dash horizontal lines indicate 500 meter and 1000 m setback distances used for current management of low disturbance events in Saskatchewan and Alberta, respectively. .. 36

Figure 16. The predicted probability of FEHA adults presence on the nest throughout the nesting season compared to the predicted probability of FEHA adults initiating flight from the nest when Visited, maintaining a 150 m buffer and maintaining at 500 m buffer. Vertical bars are 95 % confidence intervals. 37

Figure 17. Boxplots demonstrating variation in FID between 19 nesting pairs of FEHA adults that were documented to initiate flight from the nest in response to observers at least 5 times in a nesting season. Box edges indicate the 25th and 75th percentiles, horizontal lines indicate median values and whiskers indicate 5th and 95th percentiles. Black markers indicate outlier values outside the 95th percentile. 38

Figure 18. Marginal effects plot showing (A) change in predicted proportion of day spent on the nest by the female FEHA with 95 % confidence intervals with an increase in nestling age and (B) change in predicted count of FEHA female departures from the nest per hour present with 95 % confidence intervals with an increase nestling age while all other model parameters are held constant at their means. 43

Figure 19. The addition of distance to road improved the model that predicted the proportion of time the female spent on the nest (Table 10). Distance to road also influenced how often females left the nest (Table 11). Results shown for average number of young and average age of chicks at time of observation. 46

Figure 20. Marginal effects plot showing (A) change in predicted proportion of the hour spent on the nest by the female FEHA at different times of day and (B) change in predicted proportion of the hour spent on the nest by the female FEHA at different times of the day when nestlings are various ages (in days) with 95 % confidence intervals. All other model parameters are held constant at their means. 47

Figure 21. Mean number of prey delivered to the nest per day from 2011 to 2013 FEHA prey deliveries with 95 % confidence intervals 52

Figure 22. Marginal effects plot showing the change in predicted count of prey delivered to the nest per day with an increase Julian date with 95 % confidence intervals while all other model parameters are held constant at their means. 52

Figure 23. Marginal effects plot showing change in predicted count of FEHA prey deliveries with 95 % confidence intervals when an increase in proportion of annual cropland in a 2.5 km buffer around the nest while all other model parameters are held constant at their means. The overlap of confidence intervals indicates no strong effect of landcover type. 53

Figure 24. Marginal effects plot showing change in predicted count of FEHA prey deliveries with 95 % confidence intervals with an increasing distance from the nest to the nearest road while all other model parameters are held constant at their means. This figure removes the most distant nest which had the lowest feeding rate. 54

Figure 25. Left: Photo by Ashley Burkatsky. Trees are natural nest substrate found in southern Alberta and Saskatchewan. Right: An ANP with > 40 day old nestlings. 56

Figure 26. Nests on ANPs were three times more likely to be successful compared to nests supported by trees. 58

Figure 27. Nests in trees are more likely to blow out than nests located on ANP. 59

Figure 28. The proportion of successful nests found on each platform type with standard error bars (left). N is the number of nests used to derive the estimate. An ANP with a platform “edge” (right). 62

Figure 29. Post-fledging FEHA movement from nests. Distances greater than 20 km from the nest were excluded. 68

Figure 30. Timing of mortalities of post-fledging FEHA in southern Alberta and Saskatchewan. Most mortalities occurred within two weeks of fledging (2011 mean: August 1, 2012 mean: July 20). 68

Figure 31. Predicted use of distribution poles, gas wells, and oil wells at varying distances from the nest with 95 % confidence intervals. 73

Figure 32. Predicted use of transmission towers at varying distances from the nest with 95% confidence intervals. 73

LIST OF TABLES

Table 1. Top model predictors and standardized coefficients.....	16
Table 2. Apparent nest success from 2010 and 2013, not including nests that were destroyed or damaged by weather. These nests were excluded because we had no <i>a priori</i> reason to believe that land-use would influence the frequency of extreme weather events that damaged nests.....	24
Table 3. Top model predictors and standardized coefficients.....	25
Table 4. Summary of number of nests checked for reoccupancy from 2011 to 2013. FEHA nest monitoring began in 2010, therefore allowing reoccupancy surveys to begin in 2011.	29
Table 5. Species found during reoccupancy surveys in 2011 to 2013.	29
Table 6. Estimated coefficients (β) and standard errors for the final FEHA nest reoccupancy model for 600 nests in southern Alberta and Saskatchewan from 2011 to 2013.	32
Table 7. Provincial setback distances adapted from the Petroleum Industry Activity Guidelines for Wildlife Species at Risk (Environment Canada 2009).	34
Table 8. Adult FEHA behaviours modeled during this analysis.....	41
Table 9. Variables used in quantification of anthropogenic footprint around video recorded FEHA nests.	41
Table 10. The top candidate models for individual human disturbances and their effect on Daily Time On Nest model by the adult female FEHA compared to the base model. Additive cumulative effects models created by adding a single variable at a time to the Base + DistRoad model are also shown.	44
Table 11. The top candidate models for individual human disturbances and their effect on Daily Number of Departures model by the adult female FEHA compared to the base model. Additive cumulative effects models created by adding a single variable at a time to the Base + DistRoad model are also shown.	45
Table 12. The top candidate models for the Hourly Nest Attendance model by the adult female FEHA, compared to the base model.....	48
Table 13. Variables used in quantification of anthropogenic footprint around video recorded FEHA nests.....	51
Table 14. The top candidate anthropogenic model explaining Daily Prey Deliveries by the adult FEHA, compared to the basemodel.....	53
Table 15. Nest success is higher for ANP nests compared to tree nests.	57
Table 16. Top and competing models that predict FEHA abundance. Models within 2 delta Akaike information criterion (Δ AIC) units from the top model, plus null model. (YEAR = year, FIRSTVISIT = date of first monitoring, HATCHDATE = estimated hatch date based, NESTTYPE = nest structure type (1 = tree, 2= platform)).....	57
Table 17. Top model predictors and standardized coefficients.....	58
Table 18. The detected level of significance between the two categories of various structural features when using a t-test.	62
Table 19. The minimum, maximum, and average nest dimensions of 39 platform nests and 161 tree nests quantified during 2012 and 2013.	63

Table 20. The minimum, maximum, and average nest heights of 41 platform nests and 162 tree nests quantified during 2012 and 2013. 63

Table 21. Timing of post-fledging movement from nests in 2011 and 2012. Timing of events varied according to year, with activities occurring approximately two weeks later in 2012 as opposed to 2011. Locations where birds were further from the nest than expected (e.g., carried greater than 2 km from the nest by wind gusts) were excluded from date calculations if they returned to the nest (n=4). 67

Table 22. Summary of nest types and mortality of post fledging FEHA. Transmission Platform nests were attached to 240kV steel lattice structures and located approximately 4 m from the ground. Nest poles were free standing platform nest poles, and Oil and Gas Sheds comprise nests built on oil and gas shacks. Numbers in parentheses indicate mortality rate per nest type. 67

Table 23. Logistic regression coefficient models predicting survival as a function of features measured at nests. None of models were statistically significant predictors of mortality at the nest scale. .. 69

GLOSSARY OF TERMS

(adapted from Steenhof and Newton 2007)

Active: Nests where a minimum of a single adult is associated with a nest structure.

Apparent Nest Success: the proportion of successful nests to the total number of known nest fates, using number of nests that reach minimum acceptable age for assessing success (i.e., 40 days old).

Artificial Nest Platform (ANP): human made structure installed throughout Alberta and Saskatchewan to increase the number of potential available nesting substrates for FEHA. ANPs are typically consist of metal or wooden poles with a nest basket suspended > 3 meters from the ground.

Breeding Season: the period from arrival to a home range to fledgling of young.

Clutch Size: the number of eggs laid in a nest.

Daily Nest Survival: the probability of at least one egg or young in a nest will survive a single day.

Fledging: a fully-feathered juvenile naturally and voluntarily leaving the nest for the first time, although FEHA fledglings will often spend days to weeks at the nest after initial fledging.

Flight Initiation Distance (FID): the distance at which an animal initiates flight in response to human stimulus

Home Range: the area where an animal spends its time to acquire the resources needed for survival.

Incubation Period: the time between the start of incubating an egg until hatch.

Minimum Acceptable Age for Assessing Success: 80% of the age when young normally fledge, which is 40 Days Old for FEHA; this metric is used to estimate nest success, productivity, and survival.

Nest Failure: a nest that does not produce one fledgling, can be terminated in any part of the nesting period.

Nesting Period: the time between laying of the first egg to fledging of first young. FEHA provide parental care to their young for several weeks after fledging, but this period is less dependent on the actual nest structure.

Nestling Period: the time between first hatch and fledging.

Nest Success: Sometimes reported per pair (i.e., Pair #1 was successful) and sometimes used similarly to apparent nest success where a sample of nests is the measure; where at least one young is fledged from the nest.

Territory: similar to a home range, but is defended against competitors.

Nest Survival: the probability of at least one young surviving from nest initiation to fledging (40 days old).

Post-fledging Period: the time between when the young leave the nest and become independent of parental care.

Productivity: the number of young that fledge, where REACT uses the minimum acceptable age of 40 days (see Minimum Acceptable Age for Assessing Success).

Source of nest mortality: the cause of nest failure (i.e., predation, exposure to inclement weather, abandonment, or etc.).

Successful (nest): similar to nest success, but refers to a single nest where at least one young reaches 40 days old.

Nest Visit: An approach by our field staff to a FEHA nest such that they are directly underneath the nest. Often done to record reproductive parameters and maintain video systems.

1. EXECUTIVE SUMMARY

- The Ferruginous Hawk (FEHA) has been listed as an Endangered Species under the Alberta Wildlife Act by the provincial government since 2006 (Alberta FEHA Recovery Team 2009); and were re-listed as a Threatened species under Schedule 1 of the Species at Risk Act (shorthand: SARA) by the federal government in 2010 (Government of Canada 2013).
- Habitat loss and degradation is considered one of the most likely causes of their declines and is one of the highest priority corrective actions listed in the 2009-2014 Alberta Recovery Plan for FEHA. This document summarizes the status of FEHA in Alberta and reports on how the demographic consequences of FEHA living in prairie Canada may be related to energy sector development.
- Four years of data on density, nest success, nest reuse, juvenile survival, and movement of FEHA are described in this report with an emphasis on evaluating how FEHA could potentially react to infrastructure and human activity associated with the energy sector.
- Overall, density of FEHA is similar in areas with high versus low energy development when controlling for other factors such as the amount of grassland and spatial location.
- Reproductive success was the same in areas with high natural gas well density relative to areas with no or low natural gas well density. There was a weak trend towards reduced reproductive success in areas with high oil well density. Overall, reproductive success was at the high end for FEHA with 70% of nesting attempts resulting in young fledging from the nest.
- Reduced reproductive nest success in areas with high oil well density seems to result in slightly less reuse of nests compared to nests in areas with fewer oil wells. However, this pattern is also quite weak. There is no evidence that any changes in nest success are caused by reductions in foraging success or changes in predators.
- The mechanism causing this slight difference in reproductive success in relation to heavy oil is not fully understood but may be caused by human disturbance around nests. There was weak evidence that being near roads resulted in different nesting behaviour than birds far from roads. However, FEHA show large individual variation in their response to disturbance by people. Similarly, habitat selection by hawks is highly variable among individuals, suggesting some are more tolerant of human disturbance than others.
- Current setback distances and timing restrictions are designed to reduce the chance of disturbing a hawk at their nest. If the goal is to reduce the chance of disturbance to close to zero the current distance of 1km is reasonable. However, when we visited nests we typically approach within 500m with a very low probability of FEHA adult flushing. This suggests that low intensity energy sector activities, such as well maintenance, could be done during the breeding season at distances >500 m with a low chance of disturbing the birds.
- There is considerable variation between individuals in their sensitivity to human disturbance however. This potentially provides some flexibility whereby individual hawks could be assessed using protocols used for nest monitoring to determine their sensitivity prior to engaging in

industrial activities around the nest to see what individual birds are willing to tolerate

- Many natural nesting sites are being lost each year, mainly due to weather. FEHA nesting efforts are doing very well on platform nests although predation and weather remain issues. Recommendations on how to predator-proof and weather-proof new platforms are discussed.
- Juvenile mortality the first two weeks after leaving the nest is approximately 40%. Most mortalities are caused by predation or starvation. However, about 20% of mortalities can be attributed to human causes, which generally are vehicle collisions and collisions with powerline/transmission line infrastructure.
- Adult hawks prefer to roost on the tallest infrastructure available. There is slightly less use of oil wells relative to natural gas wells and distribution poles.
- Energy sector development through the creation of wells does not seem to affect FEHA ability to find food to raise their young. Nests in areas with significant natural gas development had similar success compared to nests in less disturbed areas.
- Vertical infrastructure creates positive and negative effects for FEHA. There is no evidence that adult FEHA in our study area died from electrocution or collisions (although this did occur on migration and the wintering grounds). Instead, this infrastructure tends to be used as perches and sometimes for nesting. On the other hand, young FEHA learning to fly did die from collisions with power lines.
- Roads and traffic associated with energy sector development are killing young hawks. No adults in prairie Canada were confirmed to be killed by vehicle collisions, but adults on migration and wintering areas were hit and killed by cars. Reducing speeds and travel restrictions post-fledging and pre-migration needs to be investigated as a mitigation option.
- Overall, there is no one factor that is causing the decline of FEHA in prairie Canada. Loss of natural nest sites is occurring as trees age and extreme weather increases, resulting in damaged or fallen trees. Some individuals are being killed by traffic and vertical infrastructure. Whether this mortality is additive or compensatory to that caused by natural processes requires more investigation.
- The final step in this project is to integrate all of this information into a habitat specific demographic model and to assess the sensitivities of each demographic parameter along with estimates of nest site availability and how this is changing over time. Ultimately, this is needed to prioritize recovery actions and to determine if changes made on the breeding grounds will be sufficient to help this species recover.

2. PROJECT INTRODUCTION

The Raptor Ecology and Conservation Team (REACT) is a research group at the University of Alberta that studies raptor ecology in the Canadian Prairies. In 2010, a collaborative project was organized by Dr. Erin Bayne of the University of Alberta and Dr. Troy Wellicome with the Canadian Wildlife Service (Environment Canada) to determine if and how Ferruginous Hawk (*Buteo regalis*, henceforth: FEHA) are affected by human land-use and to develop mitigation strategies to aid in the recovery of this declining species.

This project was undertaken following growing concerns surrounding the sustainability of Canadian FEHA populations. FEHA have been listed as an *Endangered Species* under the *Alberta Wildlife Act* by the provincial government since 2006 (Alberta FEHA Recovery Team 2009); and they were re-listed as a *Threatened species* under Schedule 1 of the *Species at Risk Act* (shorthand: SARA) by the federal government in 2010 (Government of Canada 2013). Habitat loss and degradation is considered one of the most likely causes of their declines and is one of the highest priority corrective actions listed in the 2009-2014 Alberta Recovery Plan for FEHA (Alberta FEHA Recovery Team 2009). Following this recommendation, REACT has been working to identify potential definitions for FEHA critical habitat. We also work alongside industrial partners to assess and minimize the risks of development on FEHA populations, in addition to assessing what can be done to improve habitat conditions.

REACT's FEHA team has consisted of one post-doc, five graduate students, seven undergraduate honours students, as well as numerous field assistants and volunteers. Since 2010, the graduate students have coordinated a dynamic team to collect and analyze FEHA ecological data collected across Alberta and Saskatchewan.

The central goals of this project were to:

- Determine how land-use influences FEHA reproductive success;
- Quantify how much & what types of human disturbance are tolerated by FEHA;
- Evaluate at what distances human activities impact FEHA;
- Determining whether juvenile FEHA survival is negatively influenced by land-use;
- Understanding how adult FEHA use the landscape in their daily movements;
- Assessing how effective artificial nesting platforms (ANPs) are as a mitigation tool.

The results of this study aims to ultimately help regulators and partners define critical habitat for FEHA, evaluate current methods of raptor protection, and to identify which mitigation strategies and future policies will most effectively reduce human disturbances for these threatened birds.

3. LIFE HISTORY

Habitat

FEHA are large, open-habitat raptors that inhabit grasslands, shrub steppes, and deserts of North America (Bechard and Schmutz 1995). Predominantly flat environments provide FEHA foraging habitat and the addition of topographic features and nesting structures create ideal breeding ranges for FEHA (Bechard and Schmutz 1995). Isolated trees to small clusters; sparse forests; or cliffs and rock outcrops are sought for natural nesting sites (Smith and Murphy 1973). The highest nest densities are found in areas with diverse habitats of ~50% native grassland habitat. Nest density generally decreases as cultivation increases (Schmutz 1993). FEHA in Alberta are thought to migrate to more southern grasslands and shrub steppe habitats in the winter in the mid and western United States and Mexico (Bechard and Schmutz 1995).

Breeding

FEHA in Alberta choose their breeding grounds in the early spring, and either build new, or refurbish existing nest sites (Bechard and Schmutz 1995). Primarily a ground-nesting species prior to bison extirpations across North America, they now they use, almost exclusively, elevated nests in trees and man-made structures (Bechard and Schmutz 1995). There is a perception that FEHA will abandon a nest if disturbed while building the nest (Smith and Murphy 1973) or early in incubation. Average clutch sizes estimates range from 2-4 eggs in the late spring to early summer, which are mainly incubated by females for 32-33 days (Palmer 1988). After the nestlings have hatched, the female will brood her young for about three weeks, during which the male is primarily responsible for delivering prey (Palmer 1988). FEHA young typically fledge between 38-50 days old, and will remain within <200 meters of the nest at this age, typically dependent on their parents for feeding up to several weeks after leaving the nest (Blair and Schitoskey 1982). The young disperse and gain independence around one month after fledging (Woffinden and Murphy 1983). Young FEHA have an earlier migration south in August, whereas adults will not migrate until September or early October (Schmutz and Fyfe 1987). Canadian FEHA generally migrate southeast through Montana and North Dakota, then south through the grasslands (Schmutz and Fyfe 1987); although some individuals REACT has monitored migrate along, or across the Rocky Mountains.

Diet

Richardson's ground squirrels are the main prey item of FEHA, followed by pocket gophers and jackrabbits; with other mammals, birds, amphibians, reptiles and insects being occasionally taken (Schmutz et al. 1980). Ground squirrels are the most commonly taken prey item. Lagomorphs provide over two thirds of a FEHA prey biomass, however their reliance on lagomorphs may be lessened in their Canadian range (Bechard and Schmutz 1995). Those pairs that nest near wetlands tend to hunt an above average number of ducks and shorebirds (REACT personal observation). Males handle the majority of the hunting - often perching high up on trees, fence posts, distribution poles, and transmission poles - presumably for the benefit of being able to both look for prey while still being able to engage in nest and territory defence (Palmer 1988).

Territory

The extent of FEHA home range and their movement within that range largely depends on prey availability within that habitat. REACT is the first group to acquire data from which the size of FEHA home ranges in Canada can be determined. The home range size for FEHA in Washington spanned 17-136.4 km² (average 90.3 km²); with males spending the majority of their time in two smaller areas (estimated average of 8.7 km²) within that range: 1) near the nest, and 2) the main hunting grounds (Leary et al. 1998). Nearby conspecifics and competing species may affect where FEHA choose to nest and forage and likely influence estimates of habitat shape and size. Olendorff (1993) found that 11 FEHA across the United States averaged 3.14 km (ranging 0.8-7.2 km) between nests. FEHA habitat often overlaps with other raptors such as Swainson's and Red-tailed hawks (Thurrow and White 1983). Interspecific competition has been shown to lower FEHA reproductive success when FEHA nests are within 300 meters of nests from other species (Schmutz et al. 1980).

Geographic range and populations trends

FEHA are located across the Great Plains of western North America, and in the many river basins along the western side of the Rocky Mountains (COSEWIC 2008). FEHA are considered a native grassland specialist (COSEWIC 2008). The Canadian breeding range stretches across the prairies, from southeast Alberta to southwestern Manitoba (Bechard and Schmutz 1995). Ecosystem changes from agriculture and fire suppression at the northern edge of their Canadian range has forced a southern shift in FEHA breeding range (COSEWIC 2008). FEHA populations have been in a measurable decline since 1992. The most recent estimate comes from 2010, with 643 ± 169 breeding pairs, making it the second lowest estimate to date (Moltzahn 2010).



Figure 1. Distribution of FEHA in North America showing breeding, wintering, and year-round grounds (from Downey 2006).

Limiting factors and threats

FEHA have commonly been described as sensitive to human disturbances (White and Thurow 1985, Oldendorff 1993). COSEWIC (2008) has provided a list of possible contributing factors to the decline of FEHA populations in Canada, including: declining ground squirrel numbers, reductions of non-cultivated grassland habitat, climate change, interspecific competition from other raptors, and increased industrial development. Downey (2006) has noted that breeding success may be limited by human disturbance at the nest. Known threats to FEHA populations have been assessed by the Alberta FEHA Recovery Team (Alberta FEHA Recovery Team 2009) to prioritize imminent threats to FEHA recovery and conservation in Alberta.

4. FEHA AND HUMAN DEVELOPMENT OF PRAIRIE LANDSCAPES

FEHA have commonly been described as sensitive to human disturbances (White and Thurow 1985, Oldendorff 1993), which has stimulated a number of studies that aim to understand the potential impacts of human development on breeding success, behavior, survival and habitat use. Effects range from direct mortality of adults and young, reduced reproductive success, changes to behavior and other indirect effects such as reduction in prey population sizes, noise effects on space use, and pollution changing individual health.

Direct raptor fatalities related to human development include illegal shooting, collisions (with traffic and infrastructure), and electrocution from power lines. While shooting, poisoning, and trapping were historically significant contributors to population declines, they are thought to have been substantially reduced, though present rates are uncertain (Schmutz 1987, Hamata et al. 2001). Presently, raptors in areas with oil and gas development are thought to face increased risk of collisions with associated infrastructure like power lines, fences, and communication towers (Madders and Whitfield 2006). Lehman et al. (2007) showed that the risk of electrocution was greatest for large raptors, and this risk would vary as a function of the size, and age of the birds; and by pole design, habitat, and topography. One study in California showed, for example, adult raptor fatalities around oil and gas development included vehicle strikes (5%), fence collisions (3%), and shooting (2%) (Hunt et al. 2002). The effects on fledgling raptors appears mixed, Van Horn (1993) found no fledgling mortalities in north-central Montana could be directly attributed to oil-field activities, but fledgling raptors with poor control over flight muscles might be especially susceptible to collisions with vehicles, fences and other infrastructure. Most mortality estimates are expected to be underestimating the true rate because they do not account for carcass removal by scavengers and imperfect detection rates of dead birds by observers (Smallwood et al. 2010).

The effect of human development on raptors and FEHA reproduction are mixed. White and Thurow (1985) suggest that FEHA may be especially susceptible to industrial disturbances and abandon areas where development occurs. Conversely, the results of a study by Zelenak and Rotella (1997) showed that petroleum development in breeding areas for FEHA had no negative impacts on their productivity. When comparing disturbed and undisturbed areas of northcentral Montana, it was found that the number of fledglings produced per nest did not differ (Van Horn 1993). Tigner and Call (1996) attributed the success of FEHA in the Rawlin Field Office's (RFO) study area to the inaccessibility of

the nests, minimizing the destruction of nests or young hawks by predators; reductions in nest abandonment (Tigner and Call 1996); and reductions in human activity near nests, which can cause premature fledging (White and Thurow 1985).

FEHA may be vulnerable to behavioural change when faced with chronic disturbance by industrial maintenance or construction. However, it remains unclear what optimal distances should be used to maximize individual success. White and Thurow (1985) found that 90% of hawks flushed if the observer was closer than 250 meters. Conversely, on the wintering grounds in Colorado, Holmes et al. (1993) found mean FIDs of 63 and 195 meters when FEHAs were approached by humans on foot and by vehicle, respectively (n = 40 individuals). Van Horn (1993) found mean FIDs of 205 meters (n = 87 approaches). Keeley and Bechard (2011) found FEHAs initiated flight from the nest at 393 meters on average when approached by humans (n = 50 nests). White and Thurow (1985) had daily treatments on nesting FEHAs, simulating disturbances from oil field development. This study resulted in significantly higher nest abandonment, reduced productivity, and lower rates of territory occupancy the following year.

Wallace (2014) found that FEHA nest density increases with ground squirrel abundance, suggesting that conservation efforts should also consider the protection of ground squirrel and other burrowing mammal populations to prevent indirect negative effects on FEHA. Landscape changes related to oil and gas development may confer an indirect benefit to FEHA populations by improving the habitat for prairie dogs, jackrabbits and cottontails if the associated road systems increase ground squirrel habitat (Zelenak and Rotella 1997). As new substrates (natural-gas infrastructure and ANS) became available, Neal et al. (2010) found a shift in nesting activity to areas favoured for natural-gas development; suggesting these areas provide quality foraging habitat, but previously lacked adequate nesting opportunities (Neal et al. 2010). Other inter-specific interactions could include a change in predator community in industrialized landscapes. FEHA may be susceptible to a number of predators, including raccoons (*Procyon lotor*; Stout et al. 2007) and Great-horned owls (*Bubo virginianus*; Sergio and Hiraldo 2008), which appear to increase with human infrastructure (Sargeant et al. 1993).

5. REPORT AND DATA COLLECTION OVERVIEW

The data collected by REACT provides baseline information for answering a variety of questions about FEHA surrounding industrial and human development on the Canadian prairies. This report uses a series of statistical analyses tailored to address a number of questions pertaining directly to our industrial partners, while statistically controlling for other sources of variation that influence FEHA ecology. REACT has worked with industry, government, and non-government organizations to collect these data on FEHA, and we are happy to share these results and our data for use by regulators and policy makers to inform future FEHA management decisions. The work was supported financially by industry (Altalink, Cenovus Energy, Nexen Inc. Suncor Energy, Climate Change and Emissions Management Corporation, Atco Electric, and Petroleum Technology Alliance Council), government (Environment and Climate Change Canada, Department of National Defense CFB Suffield, Agriculture and Agri-Food Canada, Alberta Environment and Parks, and Saskatchewan Ministry of Environment) and non-government organizations (Alberta Sports, Recreation, Parks & Wildlife Foundation, Alberta

Biodiversity Monitoring Institute and Alberta Conservation Association) In summary, this support has allowed REACT to monitor >1000 nests, track 41 adult male FEHA with microwave GPS transmitters, track 104 juvenile FEHA with VHF transmitters, and to record >1600 hours of nest footage.

The data collected in Canada spans northwards to the towns of Hanna, AB and Kindersley, SK, and reaches eastwards from Pincher Creek, AB to Weyburn, SK (Figure 2). The area is approximately 250,000 km² and is considered representative of the known distribution range of FEHA in Canada. The area studied is predominantly composed of areas with chernozemic soils, mixed and moist mixed grassland ecoregions, and low annual precipitation (Natural Regions Committee 2006, Thorpe 2007). The study area encompasses several major land use developments, including: agriculture, ranching, and oil and gas exploration. Other major land uses in the study area include towns, cities, power line infrastructure, and wind turbines.

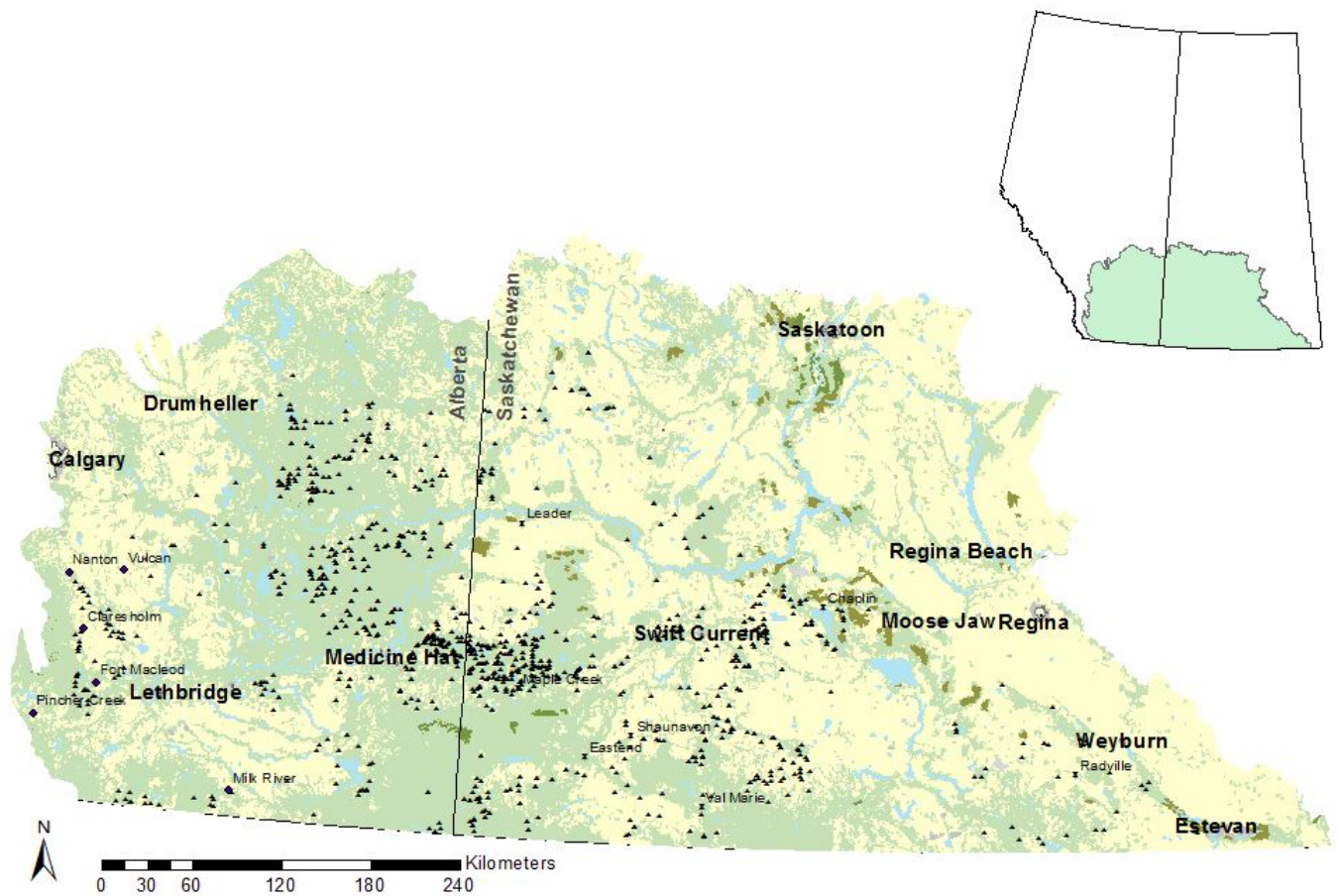


Figure 2. REACT's study area across Alberta and Saskatchewan, showing the distribution of FEHA nests monitored (black triangles) from 2010 to 2013.

6. ABUNDANCE

OBJECTIVE

Determine if energy development is correlated with FEHA nest abundance.

INTRODUCTION

Expansion and increased density of oil and gas development has changed the landscape in parts of southern Alberta and Saskatchewan. This change comes in the form of wells, roads, power lines, and human activity such as increased traffic that is related to this new infrastructure. These new features and potential sources of disturbance may result in habitat loss and/or degradation for some species, resulting in population decline; while for others they may provide a benefit via new foraging opportunities and potential nest sites.

Addressing this concern for large-ranging species, such as the FEHA requires widespread surveys using a dose-response study design to be effective. The dose-response approach, where the number of animals (response) is correlated via regression analysis with the intensity of one or more human impacts (dose), is important because large-ranging species may have individual home ranges that encompass multiple landcover types and varying densities of industrial features.

FEHA are known to exist in landscapes with various compositions and configurations of grassland, and in landscapes with low to high densities of industrial development. While they do not completely avoid these areas, we have observed different nest densities in different landscapes. Our objective was to determine if FEHA nest abundance is correlated with amount of grassland, presence of transmission lines, density of oil and gas infrastructure, and road density. We also evaluated if there was evidence of additive and synergistic cumulative effects between grassland composition (i.e. native grassland versus tame grass) and energy development.

METHODS

Sampling design

Survey sites were selected using a stratified random sampling design, where sites were distributed across the moist-mixed and mixed grasslands of Alberta and Saskatchewan. The entire study area was delineated into 9.6 km by 9.6 km survey blocks (hereafter block). In each block we measured the amount of cropland, density of transmission lines, road density, and oil & gas well density in each block using GIS layers. This was done *a priori* to create an optimized sampling design. The study area was also stratified to ensure surveys were distributed geographically across the FEHA range in Canada. We then randomly selected blocks within each strata so that we had a balanced randomized design (~equal number of blocks within high versus low levels of each landscape characteristic).

Within each block, survey routes were selected ahead of time. Routes were restricted to roads and were selected to survey through all available land cover types within each block, as well as to cover the maximum area within the block. Survey blocks that were intersected by one or more transmission lines had routes selected to run parallel to the line and at least once perpendicular to the line to achieve a

survey gradient that was near to far from a transmission line within a block (Figure 3). Survey blocks were only surveyed once and different blocks were sampled each year.

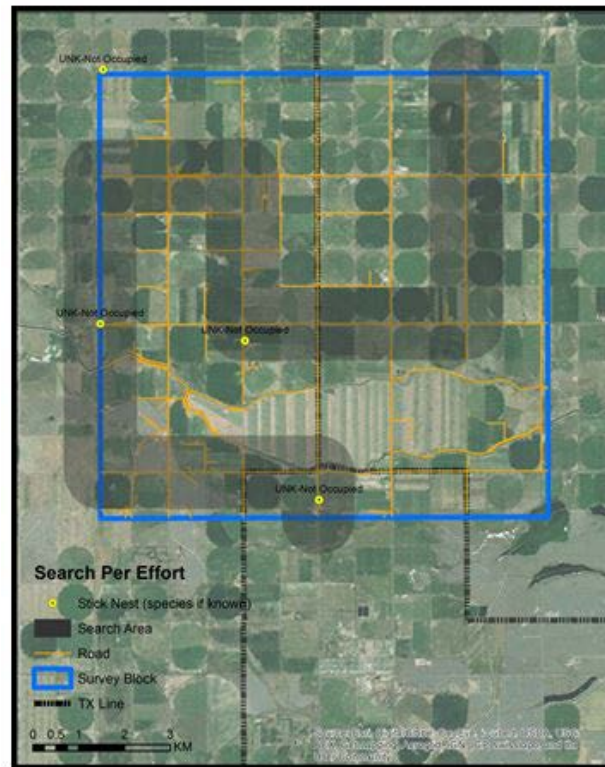


Figure 3. Examples of survey blocks, including the route driven and stick nests detected along the survey. Survey blocks with transmission lines had survey routes both parallel and perpendicular to the line. The shaded portion reflects the route driven and the estimated area surveyed, as seen from the road.

Survey protocol

We conducted surveys by vehicle, driving between 30 and 50 km/hr. A minimum of 20 km to a maximum of 30 km was surveyed in each block. We recorded the total distance surveyed and the time spent surveying. Surveys were conducted in fair to good weather conditions where visibility and therefore detection of FEHA and nests were not affected. For example, surveys could be conducted during low to high winds, but ceased during rain or snow when visibility was compromised. Nest status (i.e., active or empty), date, and evidence of occupancy were recorded for each nest.

Variables that predict FEHA nest abundance

Landscape and human features were grouped into five disturbance variable sets and measured in each block using ArcGIS 10.1 (ESRI 2012). (1) The proportion of native grass in a block is referred to as GRASS. We only included grass because the proportion of a block used for agricultural crops is inversely correlated with proportion of grass. (2) Edge density was calculated by adding the amount of grass/crop interface, water body and wetland edge, and road density to act as an index of landscape heterogeneity, hereafter EDGE. (3) Transmission lines were uncommon throughout the study area,

therefore density was reduced to presence/absence within a block, hereafter TX. (4) Road density that included all surface types of roads (asphalt, gravel, and dirt), hereafter ROADS. (5) Energy sector infrastructure was described by the total number of active surface wells, hereafter WELLS, OIL, and GAS. Land cover spatial data was developed from Agriculture and Agri-Food Canada's Land Cover for Agricultural Regions of Canada, circa 2000. Human infrastructure spatial data was developed from data provided by IHS Energy (March 2012).

Statistical analyses

STATA 12.0 (Statacorp 2011) was used for statistical analyses. Data was explored for outliers, homogeneity of variances, normality, excess zeros, collinearity, model structure, and overdispersion (Zuur et al. 2010). Prior to analysis, all predictor variables were standardized to zero mean and unit variance. This was done to allow direct comparison of the magnitude of each type of human disturbance as the data is scaled the same. Thus, variables with more extreme coefficients have a greater effect on FEHA abundance than those with coefficients closer to zero.

Models were developed in six stages:

- 1) We controlled for space and other intrinsic factors by creating a base model consisting of spatial descriptors, survey effort, and date/year. We created a second-order trend surface to explain large-scale spatial patterns in FEHA abundance. This model was statistically different from the null model ($\chi^2 = 51.38$, $df = 6$, $p = 0.000$). The reason we controlled for spatial pattern was to account for unmeasured environmental factors that might influence the spatial distribution of FEHA for which we do not yet have data (e.g., ground squirrel abundance, nest tree abundance, etc.). We also included year, Julian date of survey, total distance surveyed, and total number of nests found during survey. Total number of stick nests was included to assess if potential nest site availability influenced FEHA nest abundance. Alternatively, a landscape with more stick nests may indicate that more individuals can be supported because prey availability may be higher.
- 2) Terms that improved the model performance (i.e. decreased Akaike Information Criteria (AIC) values) were included in the base model. The base model was treated as our null model to which all other human impacts were compared.
- 3) Controlling for the space and intrinsic factors, we then evaluated whether each predictor variable was best described by a linear or quadratic term. A linear response would indicate that FEHA abundance increases or decreases with a particular human impact. A quadratic response would indicate that FEHA abundance increases to level X and decreases thereafter. Finding support for a quadratic model could also indicate some type of threshold response by FEHA to that particular variable. For density variables, we also tested if categorizing values into low/medium/high or low/high categories improved model performance. Data was categorized using natural breaks in histograms. Whether a linear, quadratic, or categorical model provided a better fit was evaluated by comparing AIC and evaluating the coefficients and confidence intervals for each term.
- 4) Using the base model to control for space and intrinsic factors, we then added landcover to the model and compared the impact using AIC. The proportion of a block that was grassland showed a very strong quadratic effect and resulted in a dramatic increase in model fit. Given the

FEHA nest abundance was predicted highest in the centre of the study area, with lower abundances near the foothills. Total number of stick nests found on a block was positively associated with FEHA nest abundance. While not statistically significant, total distance surveyed was weakly negatively associated with number of FEHA nests found on blocks. Year did not improve models, but more FEHA nests were detected on blocks as Julian date increased. Controlling for spatial pattern and intrinsic factors, we found that the proportion of grass was the single most important land-cover predictor of FEHA abundance. There was a strong quadratic relationship with proportion grass, with FEHA predicted to be most abundant in blocks with 49% grass (Figure 5).

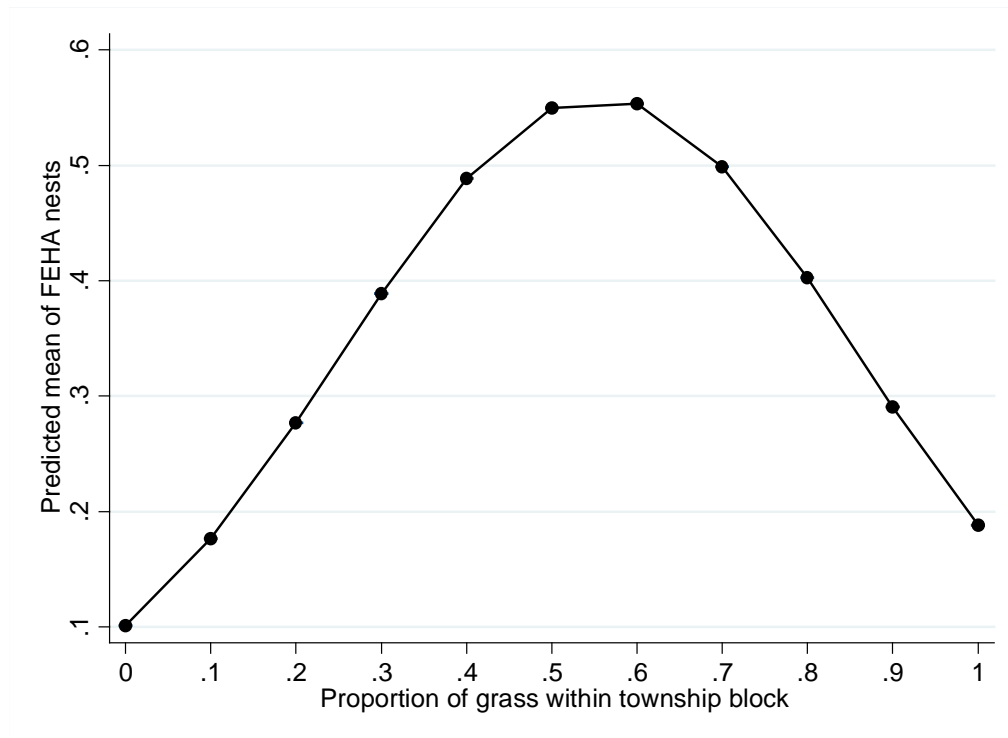


Figure 5. Proportion of grass was an important non-linear predictor of FEHA abundance. Hawk abundance peaks in landscapes with approximately 50% native grass.

There was no strong support for an additive or synergistic influence of EDGE, WELLS, OIL, TX, or ROADS. Models with GAS had better fit, and this term was also statistically significant. Results show that density of active gas wells in a block was associated with higher densities of FEHA nests (Figure 6). The coefficients in Table 6 provide the information needed to predict the mean number of FEHA nests per township.

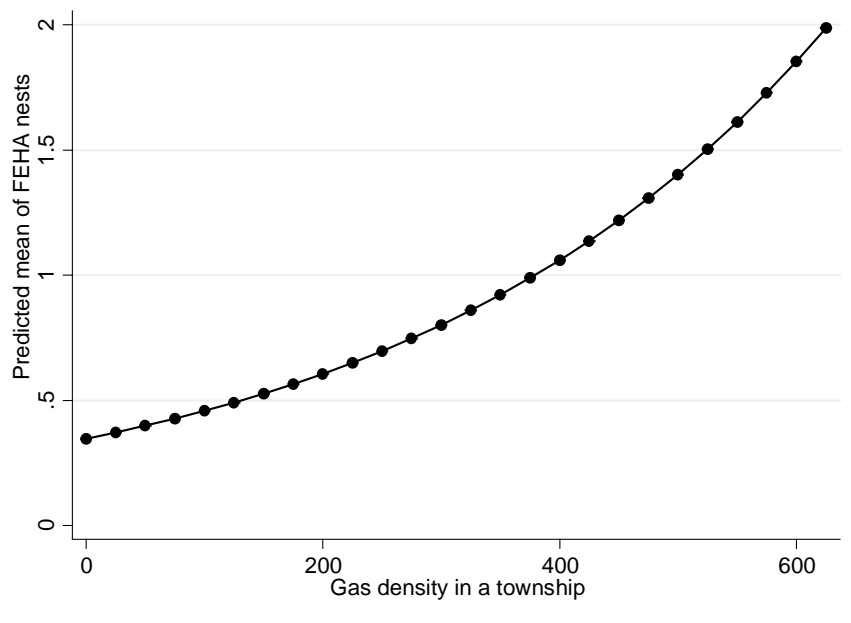


Figure 6. Gas well density was positively associated with FEHA nest abundance. Gas well density may be an important predictor of hawk abundance.

Table 1. Top model predictors and standardized coefficients.

Variable	Beta Coef.	Std. Err.	z	p-value	95% Confidence Interval	
Lat	15.24	23.22	0.66	0.51	-30.28	60.75
LatQ	-15.65	23.24	-0.67	0.50	-61.21	29.90
Long	0.15	0.14	1.06	0.29	-0.13	0.43
NestCount	0.73	0.14	5.14	0.00	0.45	1.01
TotalDistance	-0.12	0.16	-0.73	0.46	-0.44	0.20
JulianDate	0.30	0.16	1.91	0.06	-0.01	0.60
Grass	1.96	0.57	3.43	0.00	0.84	3.08
GrassQ	-1.63	0.57	-2.86	0.00	-2.75	-0.51
Gas	0.38	0.15	2.56	0.01	0.09	0.66
Intercept	-1.38	0.18	-7.83	0.00	-1.72	-1.03

Two interaction models performed better than our top model that only included main effects based on AIC criteria. Total edge density and total gas well densities, when individually interacted with amount of grassland, showed a synergistic positive effect on FEHA density, though neither interaction term was statistically significant. For total edge density, this synergistic effect was strongest when the amount of grass in a block was between 33 – 66% (Figure 7). Increased gas well density with increased amounts of grassland was also positively associated with higher FEHA nest densities (Figure 8). Overall, these interactive effects were very weak and may be spurious.

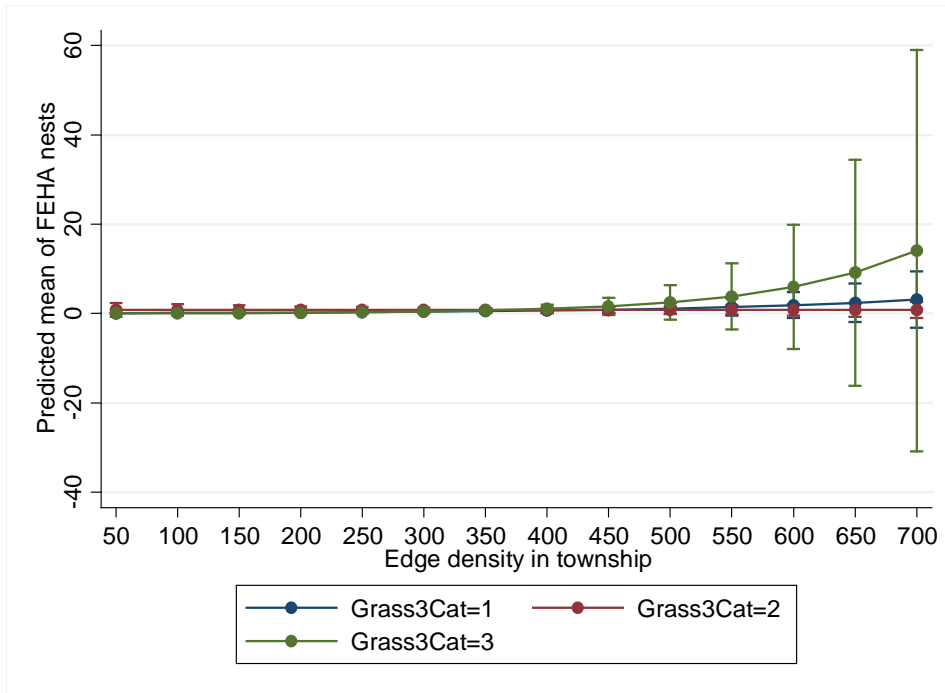


Figure 7. A weak synergistic effect between the amount of grassland and total edge density was observed, where FEHA densities were highest in areas with high edge density and moderate amounts of grassland.

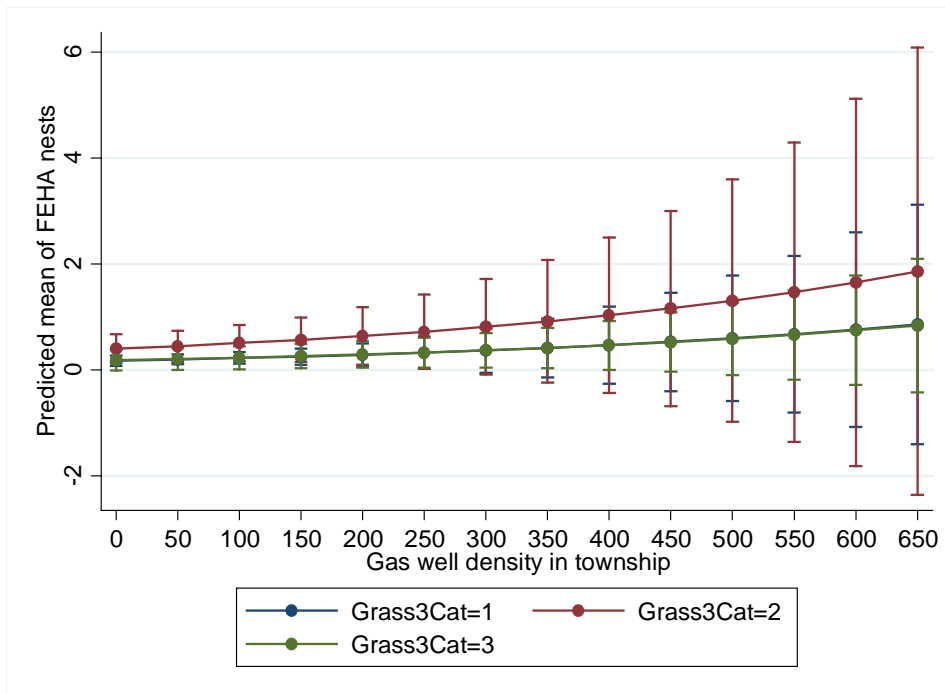


Figure 8. A weak synergistic effect between amount of grass and gas well density whereby the increase in FEHA density with gas well density depends on the amount of grass in the block.

DISCUSSION

Our model attempts to control for geographic factors, survey effort, date and year, and other intrinsic factors that naturally vary throughout our study area. Our space model shows a strong degree of spatial clustering of higher FEHA nest abundance in the centre of the range. Why this pattern occurs is not clear but suggests some environmental variables are missing from our model. This could include factors like ground squirrel abundance, climate, and ecosystem productivity metrics which are variables we are currently investigating.

Once we developed a base model to control for space, date and year effects, survey effort, and total stick nests, we found that landcover composition and edge density were strong predictors of FEHA nest abundance. One of the limitations of dose-response variable models is that the mechanism causing the observed patterns is not always clear. For example, whether FEHA truly do prefer landscapes with 50% crop and 50% agriculture or if there is some other variable that is correlated with this proportion grassland is possible. A plausible scenario is that landscapes with high grass cover are in more extreme soil and climate conditions and thus have lower system productivity (i.e., fewer prey resources) whereas the blocks completely converted to agriculture are the most productive but do not support the vegetation conditions where FEHA prey do well. Thus, the higher abundance of FEHA in mixed landscapes may reflect them making the best of the existing situation. Understanding how prey abundance varies at this spatial scale across the same gradient would help separate these hypotheses and is something we are currently investigating.

By controlling for the above variables, we were able to evaluate the influence of different industrial developments on FEHA nest density. We found a positive association between gas well density and FEHA nest abundance. It is possible that FEHA nest abundance may be positively related to gas well density because hawks select elevated perches for hunting and vigilance; therefore landscapes with gas wells may be selected for their perch availability. We found no evidence in section 8 that more gas wells leads to higher reproductive success which would typically be associated with higher abundance if gas wells were causing FEHA to preferentially select to nest in landscapes with more wells. Importantly, there is no strong evidence the gas wells negatively impact FEHA nest abundance.

Our results show that FEHA nest abundance can increase when landscapes have multiple land uses present. Where grassland and cropland create a mosaic composed of 50% grassland, FEHA nest abundance was highest. Natural gas wells on a landscape were also correlated with FEHA nest abundance, suggesting gas development does not deter FEHA from settling in such areas. We did not find a threshold of oil or gas well densities where FEHA nest abundance was negatively influenced. However our analyses were limited to the existing industrial infrastructure in the FEHA range. Oil and gas well development should proceed with caution if well density surpasses the densities examined in our study.

RECOMENDATIONS

- Grassland patches in landscape mosaics support the highest number of FEHA nests. Thus, agricultural conversion beyond a 50% threshold should be avoided.

- Detailed monitoring of any townships currently dominated by native grassland that undergo conversion to crop production should be monitored in detail to assess if mosaic landscapes maintain the same or higher abundance of FEHA over time to determine the mechanisms behind this clear and consistent grass threshold.
- No evidence of negative effects of gas or oil wells on current abundance or distribution, but caution should be used and FEHA ecology monitored/evaluated for oil and gas developments that exceed the densities included in this study.

7. NEST SUCCESS

OBJECTIVE

Determine if oil and gas infrastructure is associated with FEHA nest success.

INTRODUCTION

Assessing reproductive success is crucial for evaluating how populations change in response to anthropogenic development. In the previous section, we demonstrated that FEHA nest density was highest in areas with intermediate levels of grassland and increased with active gas well density. High FEHA abundance may be indicative of high quality habitat but could also exist because the birds are suffering from an ecological trap. An ecological trap occurs where abundance is high but reproductive success is low because the birds have made a selection decision that puts them in a habitat where they have lower reproductive success than areas with fewer birds. This can occur when a cue used to assess habitat quality in the early spring upon the birds arrival does not honestly signal what the bird will experience later in the breeding season (i.e. a series of nest platforms may look like good nesting sites but be placed in areas with insufficient food). Thus, evaluating the reproductive success of FEHA in varying amounts of agricultural land and intensities of industrial development is important to identify if ecological traps are occurring.

As demonstrated in section 7, FEHA can be found nesting in cropland and in areas with high densities of industrial development. Human infrastructure and associated activity may be a disturbance to nesting FEHA and could disrupt activities such as foraging or nest attendance resulting in such areas having low reproductive success but high density. Sources of nest mortality may also be correlated with human land uses. Our video monitoring indicates the Great Horned Owls and racoons might be two important predators of FEHA nestlings. Great Horned Owls and racoons are associated with agriculture and abandoned farms and may be influenced by industrial activity as well. In this analysis, we compared FEHA nest success in areas with different land use and industrial intensities to determine if ecological traps from industrial and agricultural development exist. Specifically, our objective was to examine the influence of land-cover, transmission line infrastructure, and energy sector development on FEHA reproductive outcomes.

METHODS

Sampling Design

We surveyed for FEHA nests across southern Alberta and Saskatchewan in 2010 through 2013. We limited surveys to the fescue, moist-mixed, and mixed grassland ecoregions. We used a stratified sampling design, where nests with low to high amounts of grassland and low to high amounts of oil and gas infrastructure were included. As nests were found, we described the landscape around each nest using GIS and quantified proportion of grassland, proximity and density of transmission lines, road density, and oil and gas well density. By quantifying each home range, we were able to select a subsample of FEHA nests that fit into a stratified sampling design. We determined nest outcome for nests in each strata, resulting in a relatively equal number of nests in high to low levels of land use and

industrial intensities. We also specifically monitored nests that were near and far from, and in varying densities of both oil and gas infrastructure (Figure 9).

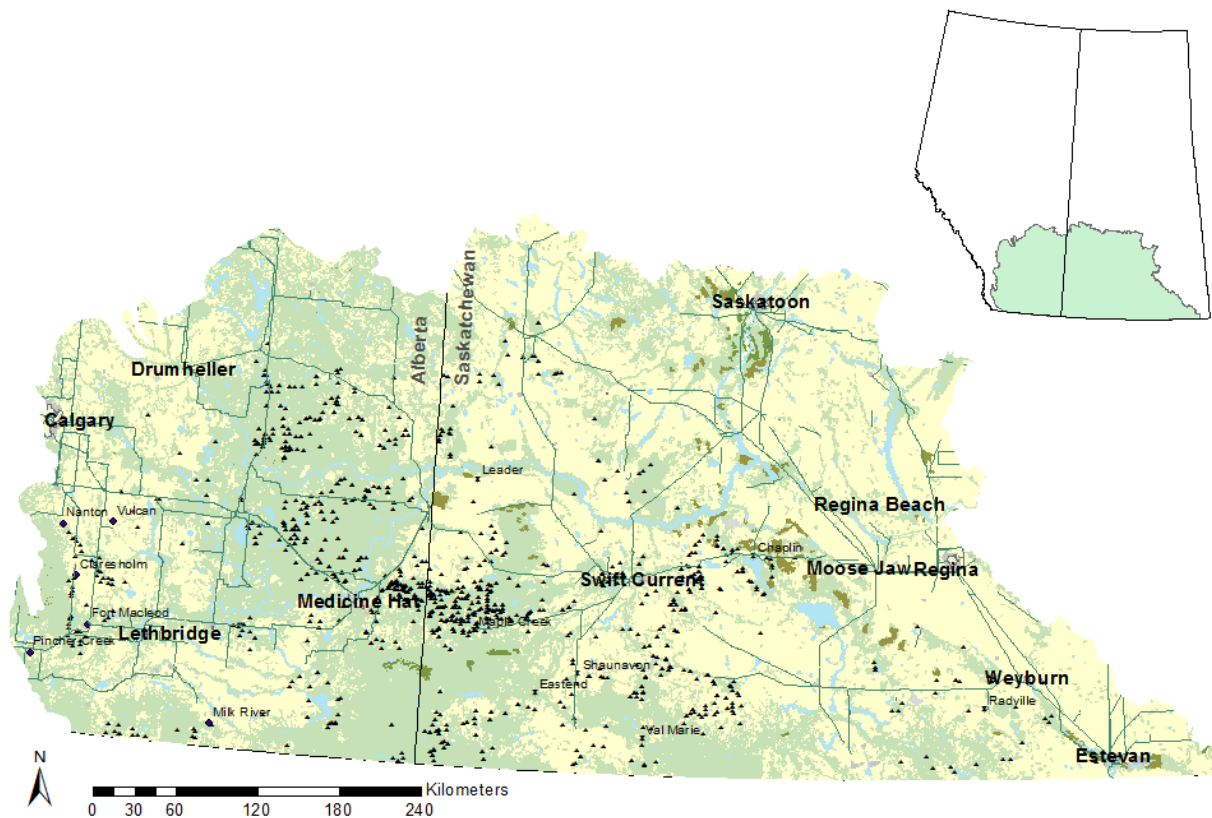


Figure 9. Study area map of southern Alberta and Saskatchewan. Black triangles are monitored FEHA nests.

Nest monitoring protocol

Nest location and type of structure supporting the nest (i.e. tree, artificial nest platform (ANP), transmission tower, and etc.) were recorded. We monitored nests throughout the breeding season and recorded their fate (i.e., successful when naturally fledged at least one young), source of nest mortality, date of nest outcome, and other reproduction parameters (Figure 10). Hatch dates were estimated from nestling age.



Figure 10. Left: Nest monitoring a nest supported by an artificial nest platform. Right: the nest contents as seen while nest monitoring.

Variables to predict FEHA nest success

We used ArcGIS 10.1 (ERSI 2012) to quantify the surrounding landscape within 2.5 km radius of each nest. We used landcover spatial data developed by Agriculture and Agri-Food Canada's Land Cover for Agricultural Regions of Canada, circa 2000. Human infrastructure spatial data was developed from data provided by IHS Energy (March 2012). Using these products, we quantified 1) proportion of grass (hereafter referred to as GRASS), 2) energy sector footprint as total number of oil wells (OIL) and gas wells (GAS), 3) road density (ROAD), and 4) presence or absence of transmission line (TX within a 2.5 km radius around each nest.

Statistical analyses

STATA 12.0 (Statacorp 2011) was used for statistical analyses. Data was explored for outliers, homogeneity of variances, normality, excess zeroes, collinearity, model structure, and overdispersion (Zuur et al. 2010). We standardized disturbance variables to zero mean and unit variance before analyses to allow for direct comparison of the magnitude of effects. We excluded nests with unknown fates and included only nests that fledged at least one young naturally (successful) and failed nests that were not blown out by wind or rain. We excluded weather-related failures because they are more likely influenced by weather and nest structures, rather than land use.

We developed the model in 6 stages:

1) We created two sets of baseline models to explain 1) large-scale spatial patterns and 2) intrinsic biological patterns in FEHA nest outcome. First, we created a third-order spatial trend surface to account for unmeasured, but influential, environmental factors that explain variation in our nest outcome data. Second, we created a biological null model to account for intrinsic biological factors that influence nest outcome. We included year, date nest monitoring started, hatch date and a dummy variable to account for unknown hatch dates, and nest structure type (i.e., tree vs. man-made platforms). We controlled for date of first visit to account for nests that were found later in the nesting season and therefore were more likely to be successful. For each baseline set, we used backwards stepwise elimination to remove non-significant terms. The biological baseline model performed better than the

spatial baseline model. Combining the spatial baseline with biological baseline did not improve model fit, so only variables significant in the biological baseline model were included at the start of our model building process.

2) Including the biological null model, we then compared the performance of linear, quadratic, and categorical forms of each human impact variable with univariate tests. A linear response would indicate that FEHA nest success increases or decreases with a particular human impact. A quadratic response would indicate that FEHA nest success increases to level X and decreases thereafter. We also tested the natural log form of oil well density to transform a zero-inflated distribution. We compared Akaike Information Criterion (AIC) values, coefficients, and confidence intervals between the linear and quadratic terms and the model with best fit was included in the next stage of model selection. A pairwise correlation was used to test for collinearity among the final variables and only GAS and ROAD were highly correlated ($R= 67\%$). Univariate models with GAS had a lower AIC value than ROAD, therefore ROAD was excluded from later models.

3) We then used a forward stepwise approach to add each disturbance variable to the model and compared the performance of each added variable using AIC. Variables were added as either linear or non-linear as modeled in Stage 2. LNOIL improved the model and as each disturbance variable was added, the model did not further improve. The final model included the biological null model plus LNOIL.

4) While we designed this study to cover as broad a range of human disturbances as possible, more nests were found in areas with no disturbance than with disturbance. Our first approach to modelling included all nests. However, when there are many nests with no disturbance at all, the statistical relationship between nest success and human disturbances can be strongly influenced by the “zero” nests more than is warranted. Thus, we also ran the models excluding those nests that had no features for each type of human disturbance (i.e., we tested GAS by running the model with a reduced sample size where only those nests with one or more gas wells within 2.5 km of the nest were used. We then compared changes in beta coefficients and p-values from the two model types. By only including nests with these features within the core home range, we expected to see the same relationship as was observed when nests with zero disturbance was included. Our expectation was that a regression from 1 to the maximum number of wells would result in an effect that was similar to that observed when using a range from 0 to the maximum.

5) We tested whether including the spatial model with the above model at this later stage would improve model performance and it did not.

6) Lastly, we evaluated the influence of interactions based *a priori* hypotheses. We included interactions between GRASS, because of its strong effect on habitat selection and density, and each disturbance parameter to evaluate whether any synergistic cumulative effects were present. The final additive model from above was still the best model after evaluating interactions, therefore there is no evidence for any synergistic cumulative effects.

All of the models were created with random effects logistic regression with individual nest as random effect. This was required because we revisited the same nest in multiple years. Models were compared

using AIC to determine model fit. We also evaluated the statistical significance of each term and checked how coefficients changed as terms were added or removed from the model.

RESULTS

From 2010 to 2013, we observed nest outcomes for 936 FEHA nesting attempts for 643 individual nests across our study area (**Error! Reference source not found.**). See section 9 for a more detailed description of reproductive metrics.

Our spatial model explained little variation in our nest outcome data, despite adding it to our disturbance model at different points in the model selection procedure. Hatch date was the most influential biological predictor for nest outcome and year, monitoring start date, and nest structure type were also predictors. Nests with earlier estimated hatch dates and nests found later in the season were more likely to be successful. This is a commonly found phenomenon that can partially be attributed to nests that have survived for longer periods, and therefore are likely to be found active and thus have a higher likelihood to survive longer, and through to fledging. Year was also influential and nest success was lower in 2010 and 2013. Platform nests were also more likely to be successful than nests in trees, despite excluding weather-related nest failures (i.e., blow-outs).

Our top model based on AIC was an additive model with the biological model terms and the natural log of oil density. Oil wells were negatively associated with nest success, but the relationship was weak and not supported in models where nests with zero oil wells were removed (Table 3).

Table 2. Apparent nest success from 2010 and 2013, not including nests that were destroyed or damaged by weather. These nests were excluded because we had no *a priori* reason to believe that land-use would influence the frequency of extreme weather events that damaged nests.

Year	Successful		Failed		Total
	n	%	n	%	
2010	81	66%	41	33%	123
2011	186	74%	67	26%	253
2012	186	73%	68	27%	254
2013	191	62%	115	38%	306
Total	645	69%	291	31%	936

Table 3. Top model predictors and standardized coefficients.

Variable	Std. β	Std. Err.	z	p-value	95% Confidence Interval	
Year						
2011	0.67	0.78	0.86	0.39	-0.86	2.20
2012	0.90	0.79	1.14	0.25	-0.64	2.44
2013	0.58	0.75	0.77	0.44	-0.90	2.05
DateOfFirstVisit	0.19	0.22	0.86	0.39	-0.24	0.63
NestStructureType	1.11	0.59	1.88	0.06	-0.04	2.26
DummyHatch	10.65	6.73	1.58	0.11	-2.54	23.84
FixedHatch	-0.04	0.04	-1.00	0.32	-0.13	0.04
lnOil	-0.23	0.19	-1.23	0.22	-0.59	0.14
Intercept	-2.97	1.19	-2.50	0.01	-5.30	-0.64

DISCUSSION

Intrinsic factors such as year, nest structure type, and hatch date were the best predictors of FEHA nest fate. Relative to these intrinsic factors, human infrastructure had little influence on nest outcome. Our results indicate that there is weak evidence that density of active oil wells may be negatively related to nest outcome. However, this effect is very weak and potentially spurious because the effect was no longer evident when we removed nests with no oil wells at all.

Our models of reproductive success had limited predictive accuracy suggesting either: A) crucial environmental covariates were missing from our model; or 2) there is a large component to FEHA nest success that is relatively random (i.e. timing of when predator arrives at nest and where parents are at that time). To date, we have not been able to include factors such as prey availability or predation risk because of the costs involved in collecting this data. It is possible that human development interacts with environmental factors not included in our model.

RECOMMENDATIONS

- High oil well density was slightly associated with lower nest success. The relationship is weak however and depended highly on which nests we chose to include in the analysis. The results provide a warning that oil field development should proceed with caution to reduce potential negative effects on FEHA nest success. Enhanced monitoring of FEHA nests within current and future oil fields should be a priority and should be compared to nests in the same general vicinity of the oil fields to determine the mechanisms causing this pattern.
- Further analyses are needed to explore the effect of spatial scale and annual variation on the potential effects of human development on nest success, but suggest that nest success is mainly driven by intrinsic biological processes related to weather, food, and predation.

8. NEST REOCCUPANCY

OBJECTIVE

Determine if oil and gas infrastructure is correlated to nest reoccupancy by FEHA.

INTRODUCTION

Understanding factors that influence nest reoccupancy is important to understanding if the current protections around nest sites are protecting future reproductive efforts. Current mitigation is focused on restricting industrial development and human activities within a setback distance of 1000 m from a FEHA nest. The goal of setback distances is to reduce the amount of landscape change around the nest and potential disturbance by people during any year's breeding attempt. In addition, a FEHA nest is protected for two years after it was last used by FEHA. However, both efforts focus on short term protection of a nest site, rather than long term protection of nests and home ranges from decreasing suitability caused by land-use change. Not enough is known as to whether either measure is effective for either short or long term protection of habitat suitability.

Agriculture and energy sector development can change the landscape around a FEHA nest, potentially changing its quality for FEHA. Decreasing habitat quality is particularly a risk when human development occurs near or in species at risk habitat. FEHA have high site fidelity and reducing the habitat quality around a nest could result in hawks being forced to move to a new nest site, decreasing reproductive success of hawks that remain, or reducing the overall probability of the nest being selected by other individuals.

Current guidelines for nest protection (i.e. setback distances) assume that nest reoccupancy is predictable, with a nest either being used continuously or the nest is never used again after not being occupied for two years. This assumption has never been tested for FEHA and the results could be used to improve the effectiveness of setback distances. If hawks consistently fledge young at some nests, then changing the landscape around that nest should be avoided. Conversely, if nests could be predicted to have low probability of nest reoccupancy, then guidelines around those nests could potentially be relaxed.

Our objective in this section was to examine how landcover characteristics, energy sector development, and previous nest occupancy and outcome influence FEHA nest reoccupancy in southern Alberta and Saskatchewan, Canada.

METHODS

Sampling design

We included nests that were previously occupied by a FEHA for at least one year and where the nest fate was known (i.e. whether or not the FEHA using the nest successfully fledged at least one young) for the years occupied by FEHA. If the nest was not occupied by a FEHA after the initial year

of discovery, we tracked whether the nest was empty in the subsequent year or occupied by another species.

To test for landscape effects, we used a stratified random sampling design to select FEHA nests to include in nest reoccupancy surveys. Nests were selected based on 1) previous year nest history (FEHA-successful, FEHA-failed, Empty, or Other Species), 2) proportion of grass surrounding the nest, and 3) density and proximity to specific industry infrastructure.

We further stratified nests across a gradient of landscape composition. Nests were selected in areas with low to high amounts of crop and areas with varying intensities of industrial development, as represented by a gradient of proximity and density of transmission lines, road density, and oil/gas well density. We also monitored and checked reoccupancy at nests across southern Alberta and Saskatchewan to reduce spatial bias. For example, we monitored and checked nests in several different oil fields (e.g. oil fields near Cessford, AB, Tide Lake, AB, Shaunavon, SK, Kindersley, SK, and Estevan, SK) to reduce the likelihood of one or more geographically-dependent factors influencing localized nest reoccupancy.

The stratified design allowed us to evaluate the potential effect of oil and gas development on nests located in areas low to high proportions of grassland, while controlling for the influence of nest fate history.

Survey protocol

Reoccupancy surveys were conducted in early spring when FEHA were nest building and laying. Surveys were generally conducted by vehicle unless a nest was inaccessible by road. In these situations, we approached by foot to a distance where the nest was visible. Observers used spotting scopes and binoculars to evaluate nest occupancy. Nests were considered occupied by FEHA if at least one FEHA was observed with nesting material within 50 metres of the historically occupied nest, if a FEHA was observed within 5 meters of the historically occupied nest, or if a FEHA was observed in the nest. If the nest was occupied by a different species, the species was recorded.

FEHA nests were monitored through the breeding season until completion and nest outcome was determined. Clutch size, number of young hatched and fledged, and sources of mortality were recorded when possible.

Variables to predict nest reoccupancy

We used ArcGIS 10.1 (ESRI 2012) to measure proportion of and proximity to nearest native grass, distance to water, proximity and density of industrial infrastructure by class (i.e. oil wells, gas wells, roads, and transmission lines) within 2.5 km radius of each nest. Land cover spatial data was developed from Agriculture and Agri-Food Canada's Land Cover for Agricultural Regions of Canada, circa 2000. Human infrastructure spatial data was developed from data provided by IHS Energy (version November 2013).

Statistical analyses

Data was analysed using STATA 12.0 (Statacorp 2011). Our response variable was developed by counting the years a FEHA nest was occupied again by FEHA and dividing by the total number of

years the nest was monitored for nest reoccupancy, resulting in a proportion of years reoccupied by FEHA. Data was examined for outliers, collinearity, excess zeros, normality, homogeneity of variances, and model structure (Zuur et al. 2010). All predictor variables were standardized to zero mean and unit variance to allow for direct comparison between variables.

Models were developed in five stages:

- 1) We controlled for spatial trend by creating a trend surface using GIS to explain large-scale spatial patterns in FEHA nest reoccupancy, thereby accounting for unmeasured environmental factors that might influence the spatial distribution of FEHA (i.e. prey abundance, nest site availability, etc.). Non-significant terms were dropped from the spatial model.
- 2) While controlling for spatial trend, we developed a biological null model that controls for intrinsic factors that influence nest reoccupancy. Variables in the null model include previous year occupancy (i.e. FEHA, empty, or other species) and if occupied by a FEHA the previous year, the reproductive outcome. Combined with the spatial model, we evaluated whether including the year the nest was first monitored by REACT (i.e. first known FEHA occupancy) improved the model using Akaike Information Criteria (AIC) values. We also included the number of years monitored in all models to account for potential bias for nests monitored for a longer period of time.
- 3) Next we tested for the influence of landcover and found that proportion of grass within 2.5 km of the nest improved the fit of the null model. We then included proportion of grass in all subsequent models to account for landcover influence, allowing us to detect potential effects of industrial variables independent from landcover. Our null model now controls for space, year effects, and proportion of grass surrounding the nest.
- 4) We then evaluated whether each continuous variable describing industrial impacts was best described as linear, non-linear, or categorized (i.e. low, medium, and high). We grouped these different forms of each variable into variable sets and evaluated fit using AIC. For example, the performance of oil well density, distance to nearest oil well, oil well density transformed into a quadratic form, and oil well density categorized into low, med, high were tested against each other. Distance variables were transformed using a natural log transformation. The form with the best fit (i.e. lowest AIC value) was included in the final model building procedure.
- 5) We individually and in combination added each of the best variables from the variable sets in Step 4 to the null model. Here, we evaluated the potential additive cumulative effects of human disturbance as predictors of FEHA nest reoccupancy.
- 6) Lastly, we evaluated if synergistic cumulative effects improved our predictive model. We created interaction terms between proportion of grass and each human disturbance variable, and all combinations wherein, and tested for improved model fit with each new interaction term.

Our models were created using generalized linear models (GLM) using a binomial error distribution and robust standard errors. We used AIC to compare model fit. We also evaluated the statistical significance of each term and checked how coefficients changed as terms were added or removed from the model.

RESULTS

Between 2011 and 2013, we conducted 1,037 reoccupancy surveys at 600 unique nests (Table 4, Figure 11). We checked nests from one to four years in a row after initial FEHA occupancy, averaging 1.7 checks per nest. Annually, 57% of nests are occupied the next year by FEHA, 29% were empty, and 14% of nests were occupied by other species including Great Horned Owls (*Bubo virginianus*), Canada Geese (*Branta canadensis*), and other *Buteo* species (Table 5). We also found 11% of nests had fallen out of trees and become unusable between years.

Table 4. Summary of number of nests checked for reoccupancy from 2011 to 2013. FEHA nest monitoring began in 2010, therefore allowing reoccupancy surveys to begin in 2011.

Year	Number of reoccupancy surveys
2011	61
2012	255
2013	333
2014	388
Total	1037

Table 5. Species found during reoccupancy surveys in 2011 to 2013.

Occupying Species	Total
FEHA	603
Empty nest	292
Great horned owl	59
Canada goose	35
Swainson's hawk	17
Red-tailed hawk	12
Unknown species	11
Common Raven	8
Total	1037

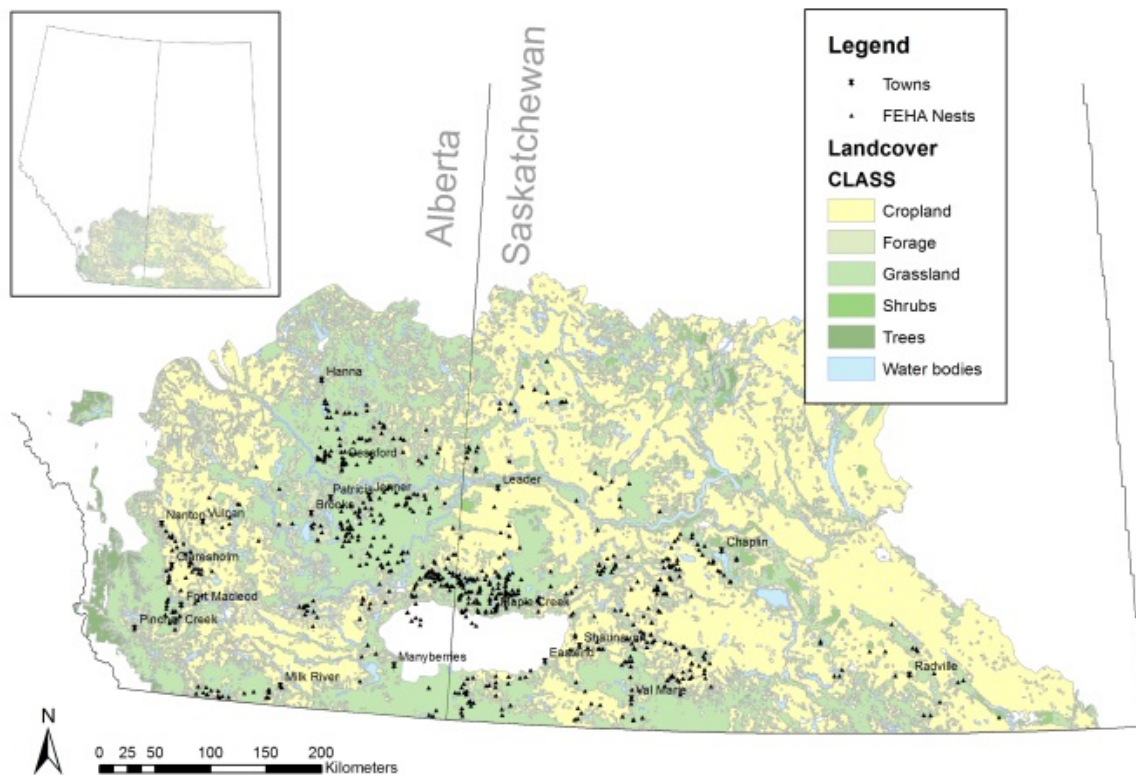


Figure 11. Map of study area located in southern Alberta and Saskatchewan, depicting the spread of nests where reoccupancy surveys were conducted. Nests were selected based on landscape characteristics and geographic spread, where nests were located across a gradient of landcover composition and industrial development intensity.

Previous nest history was a good predictor of nest reoccupancy. Of previously successful FEHA nests, 72% were reoccupied by FEHA the following year. Nests that were empty the year after a FEHA occupied it had a 28% reoccupancy rate in the 3rd year.

Longitude was a good predictor of FEHA nest reoccupancy, where nest reoccupancy by FEHA was more likely with decreasing longitude (reoccupancy rates decreased towards the west in the study area). The more years the nest was checked for reoccupancy, the more likely the nest was used again by a FEHA pair. Controlling for these variables, we found that proportion of grass within 2.5 km was a good predictor of FEHA nest reoccupancy (Figure 12, Table 6). We also found a weak relationship between proportion of years occupied by a FEHA and the density of active oil wells within 2.5 km, where the higher the density of oil wells the lower the rate of FEHA nest reoccupancy (Figure 13).

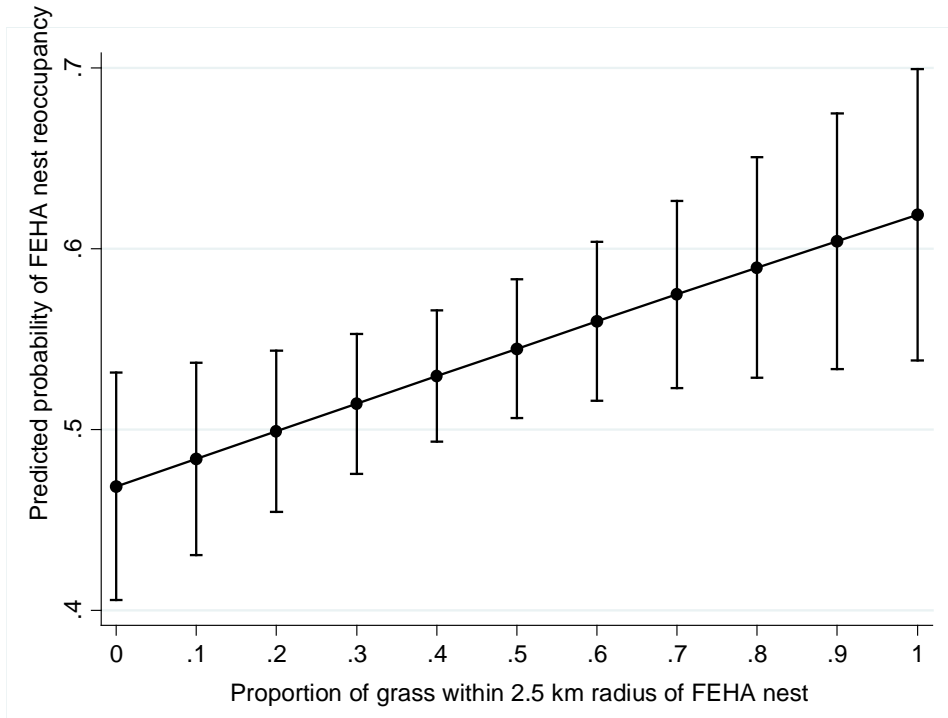


Figure 12. Predicted probability of FEHA nest reoccupancy. Years occupied by FEHA increased with greater amounts of native prairie within 2.5 km of the nest (n=600), shown with 95% confidence intervals.

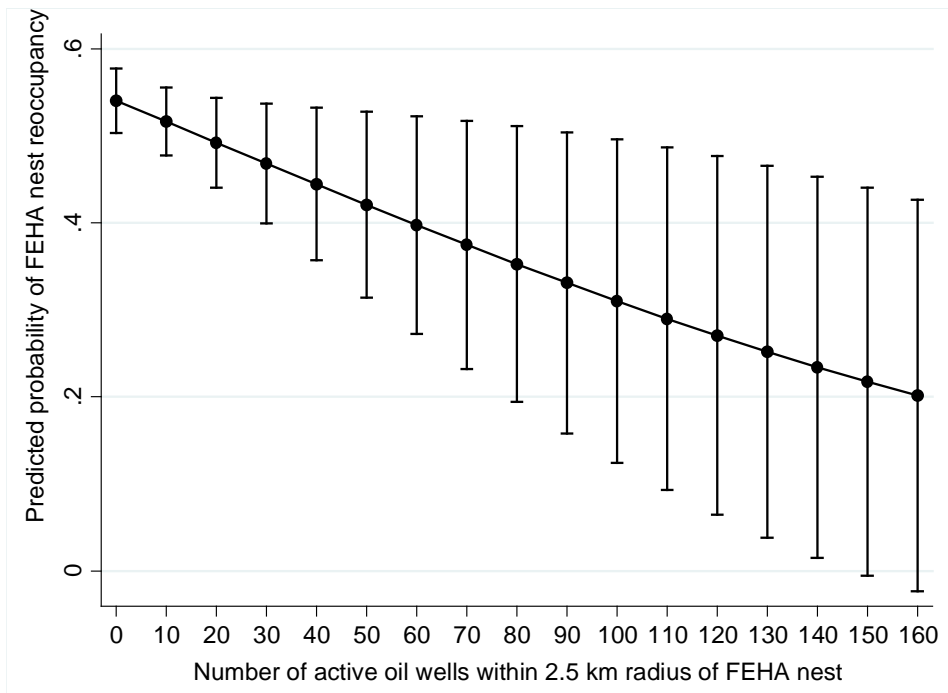


Figure 13. Predicted probability of FEHA nest reoccupancy. Of years occupied by FEHA decreased with fewer active oil wells within 2.5 km of the nest (n=600), shown with 95% confidence intervals.

Table 6. Estimated coefficients (β) and standard errors for the final FEHA nest reoccupancy model for 600 nests in southern Alberta and Saskatchewan from 2011 to 2013.

Variable	Std. β	Std. Err	z	P>z	95% Conf. Interval	
NumberYearsSurveyed	0.58	0.09	6.45	0.00	0.40	0.75
Longitude	-0.20	0.05	-4.33	0.00	-0.29	-0.11
Grass2500	0.67	0.26	2.63	0.01	0.17	1.18
Oil2500	-0.01	0.00	-2.11	0.04	-0.02	0.00
Constant	-23.02	5.06	-4.55	0.00	-32.95	-13.10

DISCUSSION

Nests where FEHA young were successfully fledged the previous year were more likely to be occupied again by FEHA in a subsequent year. Without identifying individuals, it is impossible to differentiate returning individuals that are following a decision rule or bet-hedging strategy based on prior nest history, or different individuals using the same environmental cues to select a nest site. Despite this limitation, this strong pattern suggests that nests are more likely to be reoccupied if the probability of nest success is also high.

Interspecific competition and loss of nest sites, generally where severe weather knocked nests out of trees, rendered 25% of nests unavailable each year, suggesting that nest site availability of FEHA nests should be included in future analyses to better understand potential nest site limitations. Trees planted in the early 1900's, often cottonwoods that are used by nesting FEHA, are dying from senescence which may continue to reduce the number of available nesting structures. In addition, climate change projections predict increased storm frequency and severity, which may result in more blown out nests.

We found a strong positive association between FEHA nest reoccupancy and amount of native grass, but we also found a weak negative association with oil well density. These results suggest setback distances could be adjusted based on known previous nest history and landscape context. Nests with several years' history of FEHA use and high nest success should be protected and environmental planners can expect setback distances around those nests to continue for several years. Conversely, FEHA nests that fail to fledge young or were not occupied the previous year are less likely to have FEHA occupancy in the near future and thus may require less protection.

RECOMMENDATIONS

- Nests that have been used for several years in a row consistently are used by FEHA. Ensuring that such nests are protected will increase reoccupancy.
- While FEHA will nest in agricultural landscapes, these landscapes seem to have lower reoccupancy. Areas where the density of oil wells is high also have lower reoccupancy. The underlying mechanism causing this reduced reoccupancy is not fully understood. In the areas we studied oil extraction much of the oil is moved out by trucks rather than pipelines. The precautionary principle would suggest that activities such as slowing vehicle speeds, reducing the number of trucks hauling oil near FEHA nests, and potentially shutting down pump jacks during the nesting season might mitigate some of these effects. However, it is possible that the overall footprint has altered suitability of these sites for nesting (perhaps through altered

predators or altered food abundance). Any actions taken should be monitored before or after the action to see if they are effective at increasing reoccupancy and recolonization rates of old FEHA nests.

9. NEST BEHAVIOR

OBJECTIVE

Describe timing of nesting activities relative to timing restrictions & setback distances

INTRODUCTION

Setback distances were selected as a management tool for FEHA based on the observation that FEHA are particularly sensitive to human disturbance, especially during the nest selection and incubation phases of the breeding season (Olendorff 1974). Setback distances can be effective tools for wildlife protection if a buffer can effectively minimize negative human impacts to wildlife behaviour and reproduction, and allow human presence outside of the buffer distance with no negative impact for the species. However, if the response by wildlife is not consistent, both through time and across individuals, static setback distances may not be effective. Furthermore, if some negative impacts to wildlife behaviour and fitness occur regardless of exclusion of humans from a buffer distance, additional management strategies should be implemented.

In Alberta and Saskatchewan, the current and most commonly applied tool used to manage industrial impacts on FEHA are setback distances (Environment Canada 2009) and activity specific timing restrictions, such as well site maintenance. Industrial activity is currently restricted around FEHA nests from March 15 to July 15 each year (see Table 7 for details). Here we examine the timing of FEHA nesting events observed during nest monitoring by our project from 2010 through 2014. If the current timing restrictions are effective, our data should suggest that FEHA and their young are able to complete their entire breeding cycle within the boundary of the timing restriction. Additionally if the current setback distances are effective, changes to FEHA behaviour should be prevented when our activities (low disturbance: e.g. surveying and driving by, see Environment Canada 2009) remain outside of the corresponding distance restriction (500 m or 1000 m; Table 7).

Table 7. Provincial setback distances adapted from the Petroleum Industry Activity Guidelines for Wildlife Species at Risk (Environment Canada 2009).

Level of Disturbance	Alberta		Saskatchewan
	Mar. 15 - Jul. 15	Jul 16. - Mar. 14	Mar. 15 - Jul. 15
Low	1000 m	50 m	500 m
Medium	1000 m	50 m	750 m
High	1000 m	1000 m	1000 m

METHODS

We conducted a large scale FEHA nest monitoring program across the Canadian mixed grasslands. We monitored nests during the breeding season (April - August) from 2010 through 2014. Each nest was monitored for at least one full breeding attempt and some were monitored for the entire four year study duration. We observed each nest between two and fifteen times per breeding season (referred to as an approach). The goal of this nest monitoring was to gather reproductive information for as many FEHA nesting pairs as possible. For some nesting attempts we were able to visit the nest site to collect detailed information, such as age and number of young. However access to the nest site sometimes limited us to viewing the nest from a distance and assessing whether it was actively used by a nesting FEHA pair.

During our nest monitoring, we documented whether nests were active (i.e. nesting activity associated with the nest), the number of FEHA adults seen from near the nest, whether a FEHA was on the nest, the number of FEHA adults seen when visiting the nest and, whether any fledglings were visible around the nest. In the early stages of the nesting season, we classified nests as active if adult FEHA adults appeared to have selected a nest (nest building, apparent incubation) for the breeding year. Later in the nesting season we classified a nest as active if eggs or young were detected, or if adult adults or fledgling FEHA were present in the home range and there was no evidence of egg, nestling, fledgling or adult mortality. When FEHA adults were in the nest, we documented if our observations caused the adult to initiate flight from the nest and, starting in 2012, at what distance.

We assume that we detected all adult FEHA present on the nest. However, our detection error is much higher for adults and fledglings perching or flying elsewhere in the home range. Our staff scanned the home range for adults and fledglings soaring or perching on fenceposts, hillsides, and other common perches, before approaching each nest site. We assume that, although error detecting adults and fledglings away from the nest is non-zero, detections correlate with adult and fledgling presence at the nest through the FEHA nesting period.

Statistical Analysis

We used logistic regression to predict the probability of a nest being occupied by FEHA, seeing a FEHA adult, FEHA adult being present on the nest and, whether fledglings were seen by date. We also used logistic regression to predict the probability that a FEHA would initiate flight from the nest by date.

RESULTS

We made a total of 8217 observations of FEHA nests, 6924 of which were deemed active. We documented at least one FEHA adult on the nest in 3695 instances.

We found that FEHA nests tend to be active through to early April followed by a gradual decline in number of active nests ($\beta = -0.044$, $p < 0.001$) and, adults are often present on the nest early in the nesting season though the probability drops off sharply in June ($\beta = -0.064$, $p < 0.001$; Figure 14). When observing from a distance, early in the nesting season we were often able to see at least one FEHA adult in the home range ($\beta = -0.047$, $p < 0.001$), however the probability of detecting an adult FEHA from a distance declined in early June. When observing FEHA nests we began to see FEHA fledglings as early as late June and as late as mid-August ($\beta = 0.094$, $p < 0.001$; Figure 14).

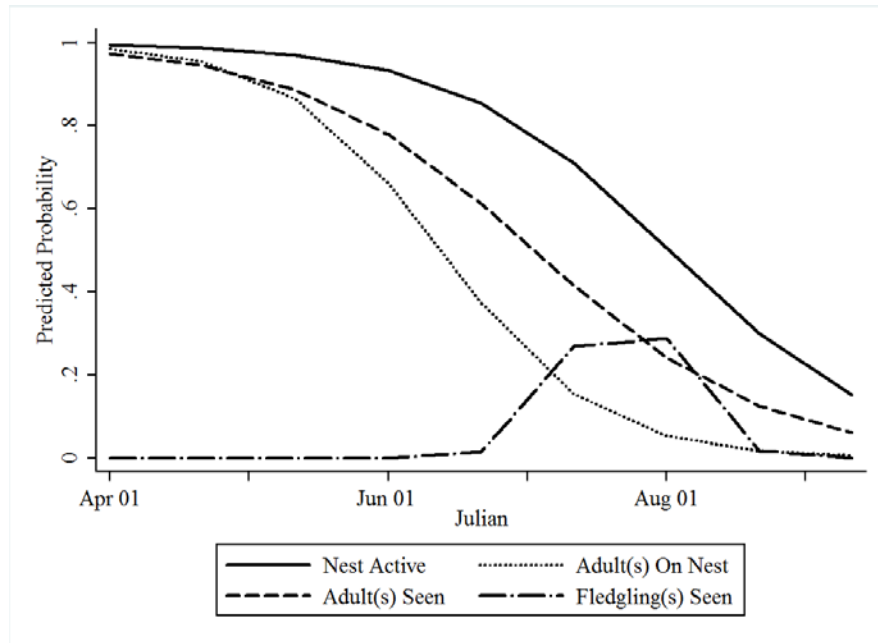


Figure 14. The predicted probability of witnessing FEHA adults and Fledglings at nest sites during nest monitoring from April through August from 2010 through 2014. Predicted probabilities were generated using logistic regression.

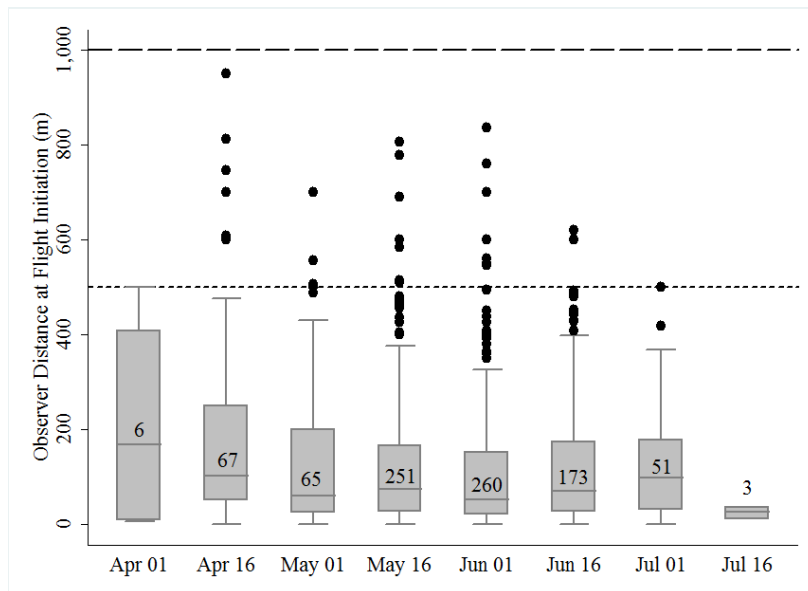


Figure 15. Boxplot showing the flight initiation distances (FID) in meters by FEHA adults when approached by an observer by date. Dates below boxes indicate interval boundaries over which the data is summarized. Box edges indicate the 25th and 75th percentiles, horizontal lines indicate median values and whiskers indicate 5th and 95th percentiles. Black markers indicate values outside the 95th percentile. Numbers within boxes indicate number of documented FIDs. The short-dash and long-dash horizontal lines indicate 500 meter and 1000 m setback distances used for current management of low disturbance events in Saskatchewan and Alberta, respectively.

We recorded a flight initiation from the nest by a FEHA adult April 11th at the earliest and July 23rd at the latest. Throughout the breeding season we witnessed FEHA that did not initiate flight until we reached the nest, and extremely large FIDs occurred throughout the nesting season (Figure 15). The median FID was 72 meters and the mean is 129 meters.

Though the probability of an adult FEHA being present on the nest decreases with date, the probability of initiating flight remains constant over the season. When observers visit a nest with a FEHA adult present they flushed nearly 100 % of the time (Figure 16). However, there was a slight tendency toward remaining on the nest early on the nesting stage ($\beta = -0.012$, $p = 0.007$). If we maintained a buffer of 150 m (~ mean FID; $\beta = -0.19$, $\beta_2 = 0.0007$, $p = 0.015$) or 500 m (low disturbance setback in Saskatchewan; $\beta = -0.26$, $\beta_2 = 0.0008$, $p = 0.34$) the probability that a FEHA adult initiated flight was dramatically lowered throughout the nesting period, with little difference between the two (Figure 16).

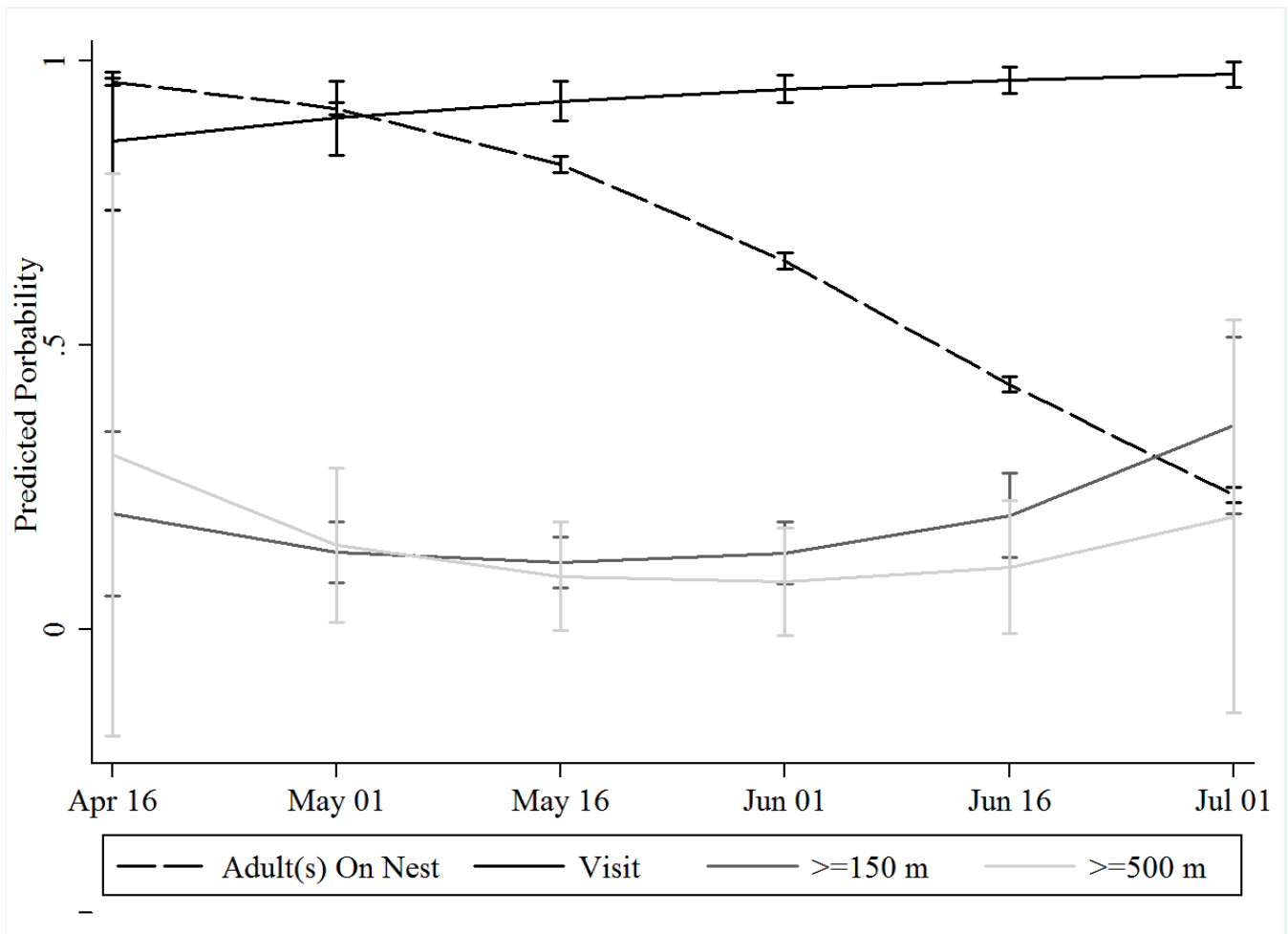


Figure 16. The predicted probability of FEHA adults presence on the nest throughout the nesting season compared to the predicted probability of FEHA adults initiating flight from the nest when Visited, maintaining a 150 m buffer and maintaining at 500 m buffer. Vertical bars are 95 % confidence intervals.

For those FEHA nesting pairs where we recorded at least 5 FIDs in a given year, we found a large amount of variation between nesting pairs in FID (Figure 17). The largest mean FID among 19 nests at which at least 5 FIDs were recorded was 270 meters while the smallest mean FID was 11.8 meters. The largest range of FID values was 489 meters and the smallest was 10 meters.

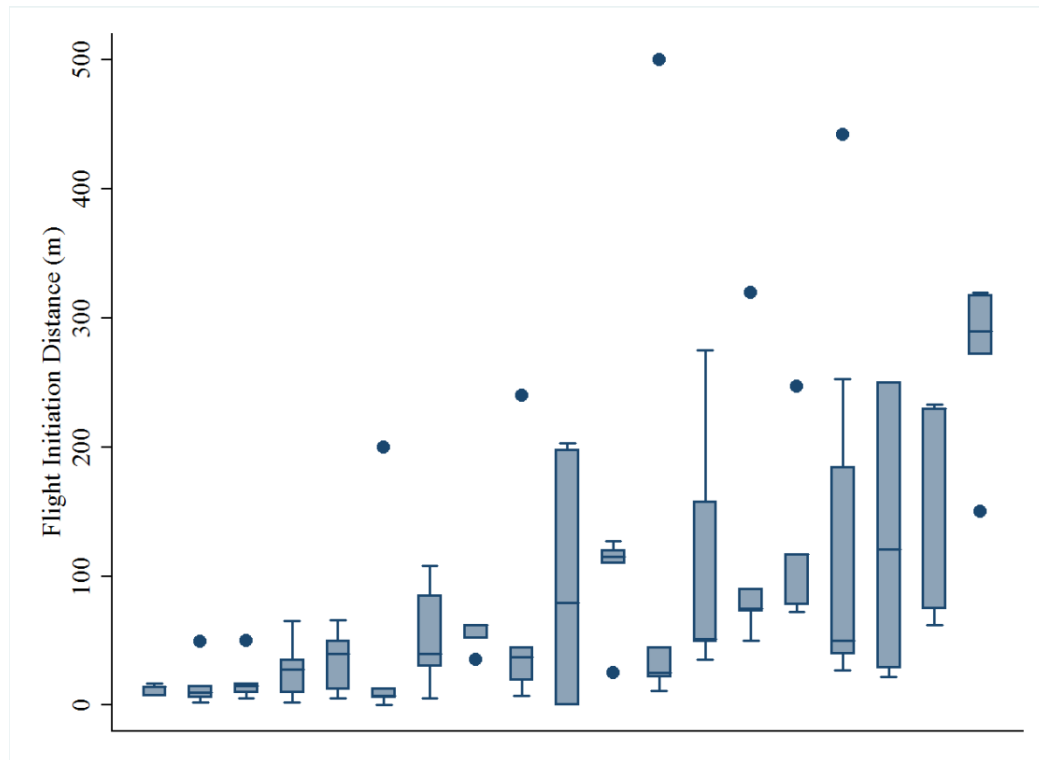


Figure 17. Boxplots demonstrating variation in FID between 19 nesting pairs of FEHA adults that were documented to initiate flight from the nest in response to observers at least 5 times in a nesting season. Box edges indicate the 25th and 75th percentiles, horizontal lines indicate median values and whiskers indicate 5th and 95th percentiles. Black markers indicate outlier values outside the 95th percentile.

DISCUSSION

It is unsurprising that we observed a decline in the number of active nests through the nesting period. We find nearly all of our study nests early in the nesting period, and the number of active nests declines over time as nests fail (e.g. predations, starvations, nest damage) and, eventually, fledge. We also observed that FEHA adults are less likely to be found on the nest as the nesting season progresses. This is likely driven by the needs of the nestlings as adults are able to spend less time feeding and thermoregulating nestlings as the season progresses (Brodin et al. 2003). The probability of observing a FEHA adult before approaching the nest site decreased through the nesting season with a similar curve as observing them on the nest. As the nesting season progresses and nestlings become more independent, the adults spend more time away from the nest.

Fledglings could be observed at the nest site beginning in late June through to mid-August. The fledgling hawks likely reduce the probability of predation by hiding and remaining silent, and this meant

the probability of observing a fledgling was quite low (Sullivan 1989). In section 14, we discuss patterns of FEHA fledglings as they leave the nest.

Disturbing a FEHA adult that is on the nest is assumed to have a greater effect on reproductive success than disturbing an adult elsewhere in the home range. Flushing an adult hawk from the nest may expose the nestlings to adverse temperature conditions or predators, but disturbing a hawk foraging elsewhere in the home range may incur a cost to the adult and/or if it results in a lost foraging opportunity.

The average distance at which FEHA initiated flight in response to observers was approximately the same throughout the nesting season. We observed a smaller number of flight initiation events in the first two weeks of April. This could be caused by FEHA adults being more reluctant to flush from small young and eggs. However, we flushed fewer birds at this time because of access constraints so this result could be spurious. The effect was quite weak regardless.

In the last two weeks of July, we had few flight initiations, likely because few adults spent time on the nest at this time of the year. However, when adults are present the probability that FEHA initiate flight when an observer visited the nest was essentially 100 %, with a few exceptions. However, maintaining some distance (as little as 150 m) decreased the probability of initiating flight dramatically to about 25 %. These probabilities were quite consistent throughout the year. However, it is important to note that maintenance of buffer distances does not reduce the probability of initiating flight to 0 %.

Flight initiation distances in our study area are smaller than those documented by Keeley and Bechard (2011) and Holmes et al. (1993), and more similar to those found by White and Thurow (1985) and Hansen (1994). The shorter FID for FEHA in our study area related to observer presence may be attributed to the high level of human development on the grasslands of Alberta and Saskatchewan (Braun et al. 2002, Samson et al. 2004, Kissinger and Rees 2009). The mean FID of adult FEHA is smaller than the current setback distances imposed on low disturbance human activity, but extreme FIDs, near 1000 meters, were documented.

RECOMMENDATIONS

- We documented FEHA adult and fledgling activity at nests into August, outside the current timing restriction around FEHA nests. Our data suggests that some FEHA adults and fledglings remain around nest sites into mid-August and extending timing restrictions to August 15th will better protect these individuals from human disturbance.
- Our data suggests use of 1000 meter setback distances on low level activity should prevent nearly 100 % of adult FEHA flight initiations and 500 meters should prevent all flight initiations except for a small percentage (>95th percentile). Thus, current setbacks may be overly cautious and low level disturbances may be permitted to within 500 meters of FEHA nests in most instances without changing adult behaviour. However, reports of nest abandonment during early nesting stages (Olendorff 1993) have been reported. Because of this concern, we did not study FEHA behavior during this time period. Thus, if reduced setback distances were applied they should take place no earlier than June 15th, when most nestlings should be at least 10 days old. This would increase protection for the species during early nesting periods when the potential for abandonment is likely higher.

10. NEST ATTENDANCE BEHAVIOUR

OBJECTIVE

Determine the influence of anthropogenic features around FEHA nests on their nesting behaviours.

INTRODUCTION

FEHA, although closely linked to native prairie habitat, are known to nest in landscapes with a gradient of industrial and agricultural development, such as their range in the mixed grasslands of Alberta and Saskatchewan (Braun et al. 2002, Samson et al. 2004). In this section, we aim to understand whether the anthropogenic footprint of the landscape around some FEHA nest sites is associated with different nesting behaviours when compared to individuals nesting in native grassland far away from human infrastructure.

It is important to make the distinction between the "footprint" and the "foot" in anthropogenic landscapes. We define footprint as the static human features present on the landscape, whereas the foot is the human activity associated with these features. These two components of an altered landscape may differentially influence an animal's behaviour. As a hypothetical example, a FEHA may respond to an industrial "footprint" by foraging along oil and gas access roads whereas a FEHA responding to industrial "foot" may decrease nest attendance in favour of defending against humans in their home range. The footprint is often the simpler metric to quantify. In this section, we use metrics of human footprint to examine whether anthropogenically altered landscapes are associated with different adult FEHA nesting behaviours (see Section 12 for analyses of foot features). It is important to note that behaviours which correlate with footprint features may have derived instead, from the associated change in human activity (or foot).

Adult nest attendance is important because nestlings need help with thermoregulation, feeding and protection from potential predators (Brodin et al. 2003). We observed that female FEHA are primarily responsible for these nest attendance behaviours, while the males hunt and defend the territory (Bechard and Schmutz 1995). It is unclear whether FEHA present in highly anthropogenic landscapes adjust their behaviours such that they can tolerate human features around their nest. Keeley and Bechard 2011 demonstrated that (1) FEHA nesting in rural habitats tend to respond more extremely to researcher approaches than those nesting in urban areas, and (2) that FEHA defensive responses decrease with repeated visitation, suggesting potential tolerance of this species to human activity. However, FEHA are considered a sensitive species to human disturbance (White and Thurow 1985) and this species may not tolerate human disturbance, such that those nesting in anthropogenically altered areas could demonstrate significantly different behaviour patterns compared to those in less human-impacted landscapes. Other raptors, for example, have been shown to change their space use as a result of increasing weekend road traffic (Bautista et al. 2004). Individuals that frequently engage in energetically costly/wasteful behaviours in response to human disturbance are at risk of reducing their own survival and that of their young (Houston et al. 2012).

We hypothesize that, if FEHA are effected by either human footprint features or the associated foot, we will see significant differences in magnitude and timing of adult nest attendance behaviours between high and low disturbance landscapes. Alternatively, if we find no relationship with nest

attendance and human footprint features we suggest that either (1) FEHA nest attendance is unaffected by anthropogenic features or (2) FEHA can adjust their behaviour to tolerate features that might cause negative behavioural responses if the behaviours were less plastic.

METHODS

We filmed 90 FEHA nests in the months of June and July of 2011, 2012 and 2013. Over 6000 hours of footage from 75 nests with nestlings aged from 5-45 days old has been viewed and translated into FEHA behaviour and used in this analysis. Behaviours quantified included time spent on the nest and number of departures from the nest. We summarized this data at both the daily and hourly timescale (Table 8).

Using ArcGIS 10.2 we quantified the human footprint surrounding filmed nests (Table 9). We quantified the number of active oil wells, active gas wells and active facilities from IHS (version November 2013), the amount of agricultural land and the number and type of roads around nests based on a 400 meter buffer. We used this buffer because we found that 95 % of flights from the nest were initiated when our research staff was 400 meters from the nest or closer (See Section 12) and we imagine industrially drivers of changes in nest attendance would likely also occur at this scale.

Table 8. Adult FEHA behaviours modeled during this analysis.

Behaviour	Data Type	Time Frame	Sex
Time On Nest	Proportion	Daily, Hourly	F
Number of Departures	Count	Daily	F

Table 9. Variables used in quantification of anthropogenic footprint around video recorded FEHA nests.

Landscape Feature	Buffer (km)	Data Type	Units
All Roads	0.4	Continuous, total length	Kilometers
Oil and Gas Roads	0.4	Continuous, total length	Kilometers
Highways, Arterials and Collectors	0.4	Continuous, total length	Kilometers
Active Oil Wells	0.4	Count	NA
Active Gas Wells	0.4	Count	NA
Active Facilities	0.4	Count	NA
Area of Agriculture	0.4	Proportion	NA
Distance to Oil Well, Gas Well and Facilities	NA	Continuous	Meters
Distance to Agriculture	NA	Continuous	Meters
Distance to Roads	NA	Continuous	Meters
Nearest Road Type	NA	Category	1 - Oil & Gas, Truck Tracks 2 - Range Roads,

Statistical Analysis

We used a mixed effects generalized linear model to examine the effect of anthropogenic features on FEHA nesting behaviour. Nest Departure counts were modelled using the Poisson error family and the amount of time spent on the nest by the female was converted to a proportion and modelled using a binary family and logit link function. A random effect for nest was included to control for non-independence of multiple time samples at a given nest.

We used a three step analytical process to evaluate the influence of anthropogenic features on nest attendance. All analyses were done in Stata 13 (StataCorp 2013).

- (1) First, we built a base model which included intrinsic factors that were important for adult nest attendance such as nestling age and brood size.
- (2) We then compared this base model to models including linear terms to describe anthropogenic landscape variables using Akaike's Information Criterion (AIC) to assess parsimony.
- (3) After identifying potentially important factors using AIC, we explored additive cumulative effects models by adding additional variables to the best fitting model from step 2 until model fit no longer improved.

RESULTS

Daily Nest Attendance

Latent differences between nesting pairs were important in explaining female nest attendance and were controlled for using a random effect. Daily nest attendance was variable through time. The proportion of time spent by the female on nest dropped dramatically after the age of 30 days (Figure 18). Though Julian date also influenced female nest attendance, age of young was a more parsimonious predictor ($\Delta\text{AIC} = 10.15$). The number of departures by female FEHA for each hour spent on the nest increased as nestling age increased (Figure 18) and nestling age was a better predictor than Julian date ($\Delta\text{AIC} = 8.40$).

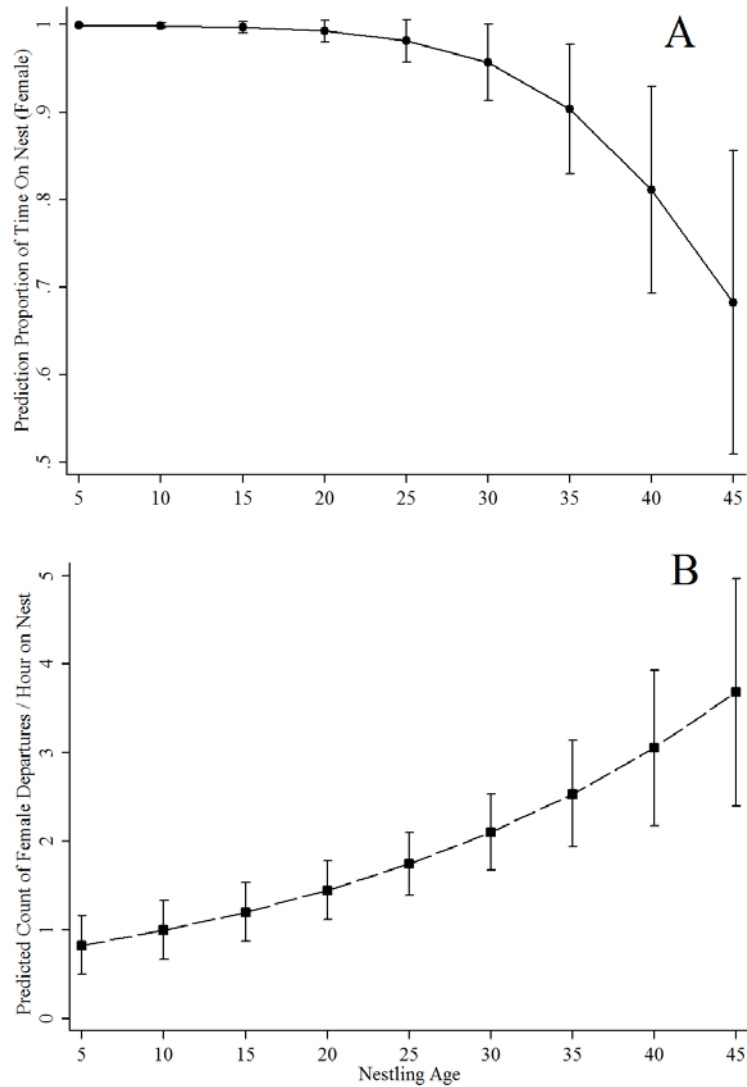


Figure 18. Marginal effects plot showing (A) change in predicted proportion of day spent on the nest by the female FEHA with 95 % confidence intervals with an increase in nestling age and (B) change in predicted count of FEHA female departures from the nest per hour present with 95 % confidence intervals with an increase nestling age while all other model parameters are held constant at their means.

This produced our base model for testing for anthropogenic effects.

$$A = b + y + \text{random}(n) + L$$

Where 'A' is daily female nest attendance, 'b' is the brood size, 'y' is the age of the nestlings and 'n' is a unique nesting attempt. *L* represents quantities for anthropogenic landscape features.

The addition of variables that described distance of the nest to a road improved the Daily Time On Nest model (Table 10), as the top model had a ΔAIC of 8.3 units over the base model and received 74% model weight. Adding additional human impact variables to distance from road did not improve model fit. Figure 19 shows the relationship between the daily female nest attendance relative to distance to road. Females closer to roads or in areas with more roads were more likely to a greater proportion of

time on their nest than birds further away or in areas with lower road density. A similar pattern was found using Number of Departures where Distance to Road had a ΔAIC of 6.5 units over the base model and received 55% model weight. Adding any additional human impact variables after accounting for the road variables did not improve model fit (Table 11).

Table 10. The top candidate models for individual human disturbances and their effect on Daily Time On Nest model by the adult female FEHA compared to the base model. Additive cumulative effects models created by adding a single variable at a time to the Base + DistRoad model are also shown.

Model	df	AIC	ΔAIC	Weight
Single effect models				
DistRoad	5	163.2	0	0.74
RdsAll400	5	167.3	4.1	0.10
Crop400	5	168.2	4.9	0.06
RdsHAC400	5	170.3	7.1	0.02
DistOil	5	170.5	7.3	0.02
BaseModel	4	171.5	8.3	0.02
Additive cumulative effect models				
Base + DistRoad + Crop400	6	161.9	0	0.20
Base + DistRoad + DistCrop	6	162.6	0.7	0.14
Base + DistRoad	5	163.2	1.3	0.11

Table 11. The top candidate models for individual human disturbances and their effect on Daily Number of Departures model by the adult female FEHA compared to the base model. Additive cumulative effects models created by adding a single variable at a time to the Base + DistRoad model are also shown.

Model	df	AIC	Δ AIC	Weight
Single effect models				
DistRoad	6	1766.4	0	0.55
Crop400	6	1769.3	2.9	0.13
RdsOG400	6	1769.7	3.3	0.10
DistOil	6	1771.4	5.0	0.04
RdsAll400	6	1771.5	5.1	0.04
DistFac	6	1772.1	5.7	0.03
BaseModel	5	1772.9	6.5	0.02
Additive cumulative effect models				
Base + DistRoad + Crop400	7	1764.6	0	0.18
Base + DistRoad + RdsOG400	7	1765.3	0.6	0.13
Base + DistRoad + DistOil	7	1765.9	1.3	0.09
Base + DistRoad + RdsHAC400	7	1766.0	1.3	0.09
Base + DistRoad + DistFac	7	1766.3	1.7	0.08
Base + DistRoad	6	1766.4	1.8	0.07

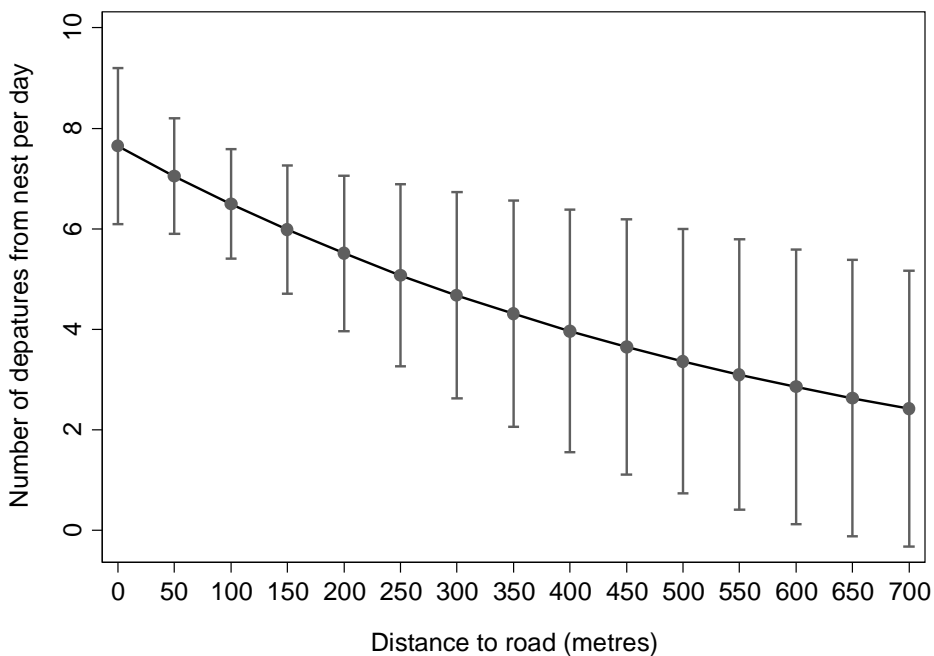
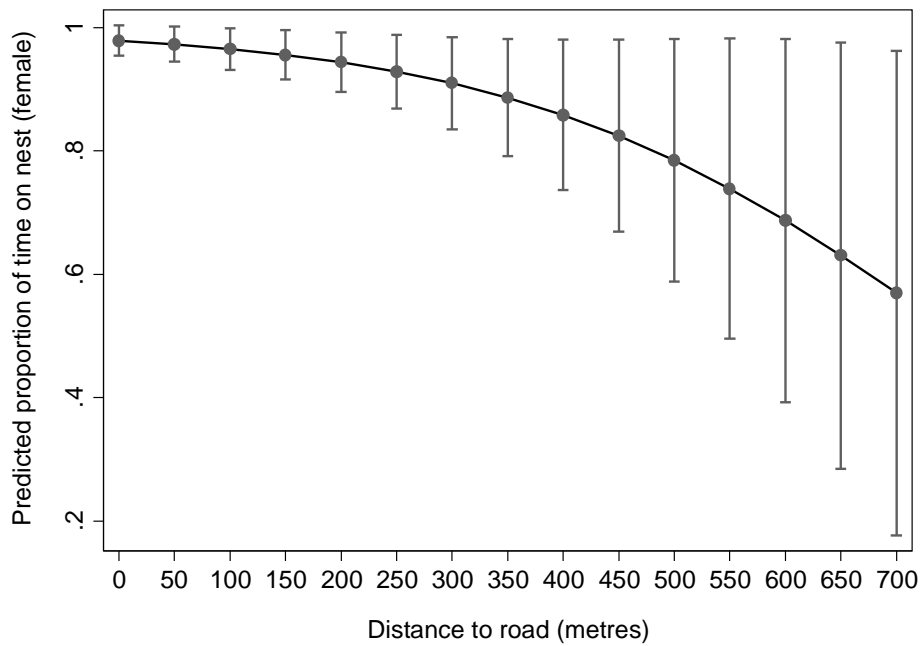


Figure 19. The addition of distance to road improved the model that predicted the proportion of time the female spent on the nest (Table 10). Distance to road also influenced how often females left the nest (Table 11). Results shown for average number of young and average age of chicks at time of observation.

Hourly Nest Attendance

Hourly nest attendance by female FEHA was largely dependent on the time of day, with a higher probability of spending time on the nest through the night. We modelled this using a second degree polynomial term ($\beta = -0.088$, $\beta_2 = 0.0043$; Figure 20) and found this time of day relationship interacts with nestling age ($\beta_{hr} = -0.36$, $\beta_{hr^2} = 0.015$, $\beta_{age} = -1.5$, $\beta_{agexhr} = -0.0092$, $\beta_{agexhr^2} = -0.00036$; Figure 20).

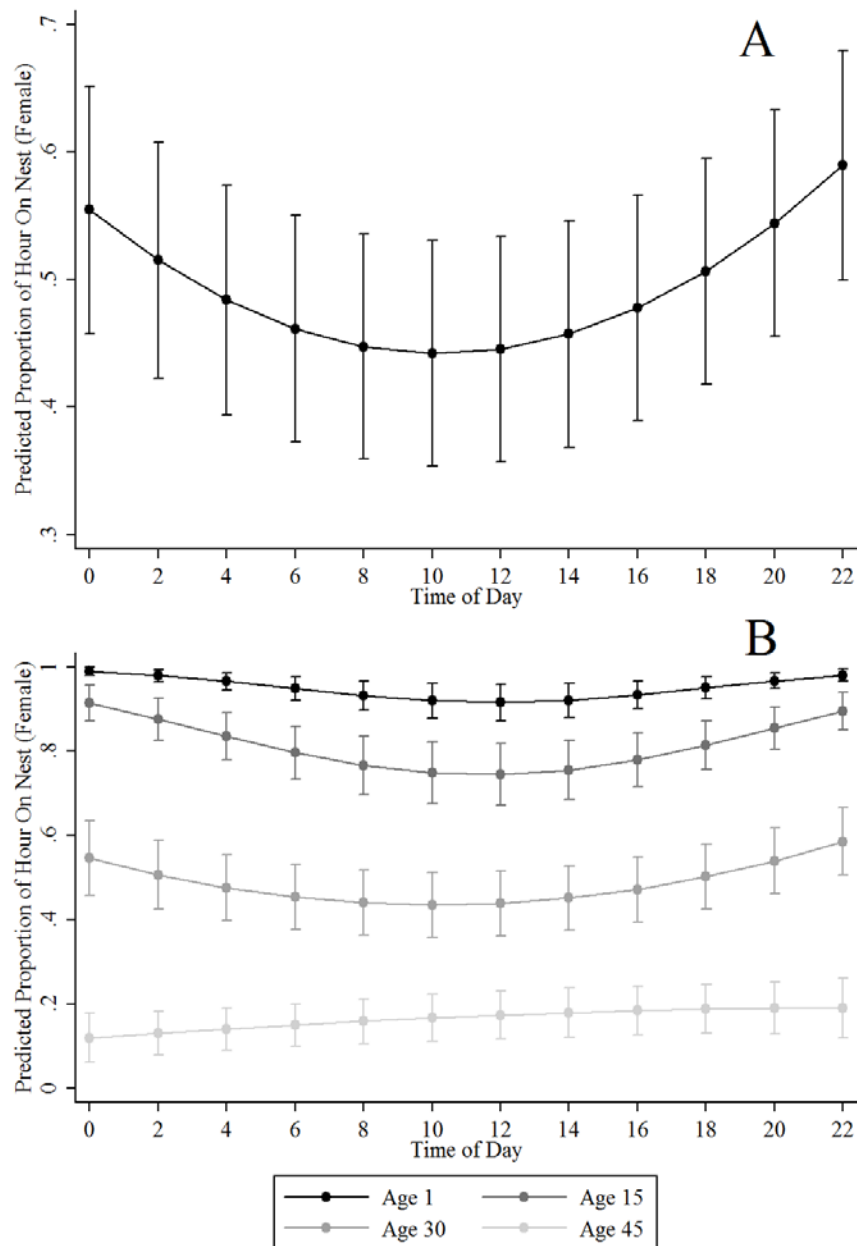


Figure 20. Marginal effects plot showing (A) change in predicted proportion of the hour spent on the nest by the female FEHA at different times of day and (B) change in predicted proportion of the hour spent on the nest by the female FEHA at different times of the day when nestlings are various ages (in days) with 95 % confidence intervals. All other model parameters are held constant at their means.

Based on this we used the base model for testing for anthropogenic effects.

$$a = h^2 + b + y(<31) + \text{random}(n) + L$$

Where ‘a’ is hourly female nest attendance, ‘h’ is the time of day, ‘b’ is the brood size, ‘y’ is the age of the nestlings and ‘n’ is a unique nesting attempt. ‘L’ represents quantities for anthropogenic landscape features. The addition of anthropogenic features did not parsimoniously improve the Hourly Time On Nest model (Table 12), as the top model was only a very small improvement over the base model, with an AIC score improvement of 2.6 and 30% of the total model weight.

Table 12. The top candidate models for the Hourly Nest Attendance model by the adult female FEHA, compared to the base model.

Model	df	AIC	Δ AIC	Weight
DistRdsOG	7	3529.4	0	0.30
DistRdsHAC	7	3531.4	2.1	0.10
DistRoad	7	3531.8	2.5	0.09
BaseModel	6	3531.9	2.6	0.06

DISCUSSION

The observed decline in daily female nest attendance with age is common in altricial bird species. The nestlings can thermoregulate more efficiently with age and also develop the musculature to rip prey and feed themselves (Powers 1981, Brodin et al. 2003). The increase in departure rate per hour spent on the nest is likely a result of the female spending fewer prolonged periods with the nestlings over time, instead coming and going as they engage in a greater number of behaviours away from the nest (i.e. hunting). Our data suggests that FEHA spend the largest proportion of their time engaging in nest attendance in the evening and early morning, likely when nestling temperature regulation becomes important and the probability of prey capture is low. However, age of nestlings has a much greater effect on the proportion of time spent on the nest by a FEHA female than time of day.

We found some evidence that female FEHA nesting near roads had different nesting behaviours than those nesting further from roads. Female FEHA near roads tended to spend more time on the nest but seemed to be more likely to leave and return to the nest than those further from the nest. This could reflect disturbance from traffic, resulting in the birds leaving the nest but returning very quickly and then spending an extended period of time at the nest after the vehicle had passed. Importantly, when we excluded nests past 500 metres (4 nests) these patterns became much weaker. This suggests that a relatively small number of females were driving these patterns, which calls into question the generality of the result. Relatively few FEHA exist in prairie Canada that can be much greater than this distance from roads due to the ubiquity of roads in this landscape. However, these patterns are suggestive that FEHA females farther from roads may be more willing to leave the nest for extended periods of time, potentially to find prey. In section 10 we found some very little evidence of prey delivery differing as a function of distance to roads, especially when the bird furthest from roads was removed from analysis.

It is important to consider that, although FEHA nest attendance may not vary between undisturbed and anthropogenic dominated landscapes, it is important to note that these anthropogenic features may have other effects, such as increased agitation (Steidl and Anthony 2000) or stress levels (Bortolotti et al. 2008) that we did not measure directly.

RECOMMENDATIONS

- Being near a road has a potential influence on nest attendance behaviours on a daily basis but this pattern is driven by a few birds. There is no strong support for any additional effects of wells or other energy sector disturbances once roads are controlled for.
- FEHA females spend a larger proportion of their time on the nest in the early nesting season and during the morning and evening. If an approved activity (i.e. well check) is required visiting mid-day would reduce the risk of causing the female to leave the nest

11. PREY DELIVERY RATES

OBJECTIVE

Determine the influence of anthropogenic features around FEHA nests on prey delivery rates to the nest

INTRODUCTION

FEHA are closely linked to their primary prey species (Bak et al. 2001), which largely consists of Richardson's Ground Squirrel (*Urocitellus Richardsonii*; henceforth, RGS) in the mixed grasslands of southern Alberta and Saskatchewan (Bechard and Schmutz 1995). Woffinden and Murphy (1989) suggest that prey availability may drive population trends of this species. Giovanni et al. (2007) suggest that FEHA deliver 4.6 prey items to the nest per day on average, though this depends on the number of young. It is unknown if anthropogenic features around FEHA nests might influence their ability to capture prey and deliver them to the nest. Fortney (2013) found no relationship with RGS abundance and human structures. It is unclear whether RGS will use human features such as roads and whether these areas are good foraging locations for FEHA. Fortney (2013) also suggests that land use is important for RGS abundance, with the largest mean number of RGS found in tilled cropland, and less than half that found in native grass. Though RGS occur in high abundance in some types of cropland, it is unclear whether these individuals are available prey items for FEHA. For example, the tall dense character of some cropland may prevent FEHA from foraging effectively (Bechard 1982).

If anthropogenic features around the nest site affect the ability of FEHA to forage we predict that presence or density of certain features, such as roads or industrial infrastructure, will affect the rate at which adult FEHA deliver prey to the nest. If the presence of cropland changes the availability of RGS as prey for FEHA we predict that there will be a decrease in number of prey deliveries to the nest as the amount of cropland in the home range increases.

METHODS

We filmed 90 FEHA nests in the months of June and July of 2011, 2012 and 2013. Over 6000 hours of footage from 75 nests with nestlings aged from 5-45 days old has been viewed and translated into FEHA behaviour and used in this analysis. Here, we specifically quantified the timing of prey deliveries to the nest by both the male and female adults, as well as the species (whenever possible) of the prey item. We summarized this prey delivery data as a count of prey delivered daily.

Using ArcGIS 10.2 we quantified the human footprint surrounding filmed nests (Table 13). We quantified the number of active oil wells, active gas wells and active facilities from IHS (March 2012), the amount of annual cropland and perennial crop / rangeland, and the number and type of roads around nests at a 2500 meter buffer. This is the approximate mean FEHA home range in our study area (See Section 13).

Table 13. Variables used in quantification of anthropogenic footprint around video recorded FEHA nests.

Landscape Feature	Buffer (km)	Data Type	Units
All Roads	2.5	Continuous, total length	Kilometers
Oil and Gas Roads	2.5	Continuous, total length	Kilometers
Highways, Arterials and Collectors	2.5	Continuous, total length	Kilometers
Active Oil Wells	2.5	Count	NA
Active Gas Wells	2.5	Count	NA
Active Facilities	2.5	Count	NA
Area of Agriculture	2.5	Proportion	NA
Area of Annual Cropland	2.5	Proportion	NA
Area of Perennial Crop and Rangeland	2.5	Proportion	NA
Distance to Oil Well, Gas Well and Facilities	NA	Continuous	Meters
Distance to Agriculture	NA	Continuous	Meters
Distance to Roads	NA	Continuous	Meters
Nearest Road Type	NA	Category	1 - Oil & Gas, Truck Tracks 2 - Range Roads, Highways

Statistical Analysis

We used a mixed effects generalized linear model to examine the effect of anthropogenic features on FEHA prey delivery counts. Prey counts were modelled using the Poisson error family. Random effects for year and nest were included to control for confounding differences between years and non-independence of repeated sampling at individual nests.

We used a three step analytical process to evaluate the influence of anthropogenic features on nest attendance. All analyses were done in Stata 13 (StataCorp 2013).

- (1) First, we built a base model which included intrinsic factors that were important for prey deliveries such as nestling age and brood size.
- (2) We explored the effect of landcover, including area of annual and perennial cropland, on FEHA prey deliveries.
- (3) We then used the base model constructed in steps 1 and 2 and compared anthropogenic landscape variables using Akaike's Information Criterion (AIC) to assess parsimony.

RESULTS

Daily Prey Deliveries

A significant source of variation in prey delivery rates was found between years (Figure 21) and between nesting pairs, which were controlled for using a random effect. Nests with more chicks had more prey deliveries.

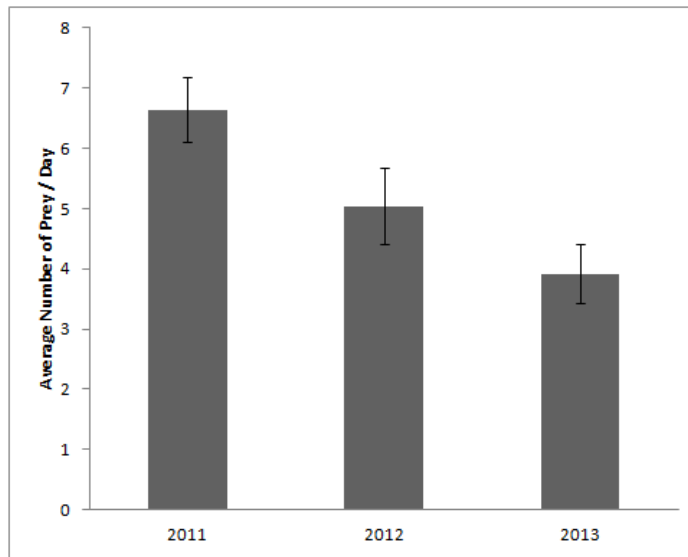


Figure 21. Mean number of prey delivered to the nest per day from 2011 to 2013 FEHA prey deliveries with 95 % confidence intervals

The probability of delivering prey decreased with Julian date (Figure 22). The number of prey delivered to the nest also decreased with age but Julian date was a more parsimonious predictor ($\Delta AIC > 10$).

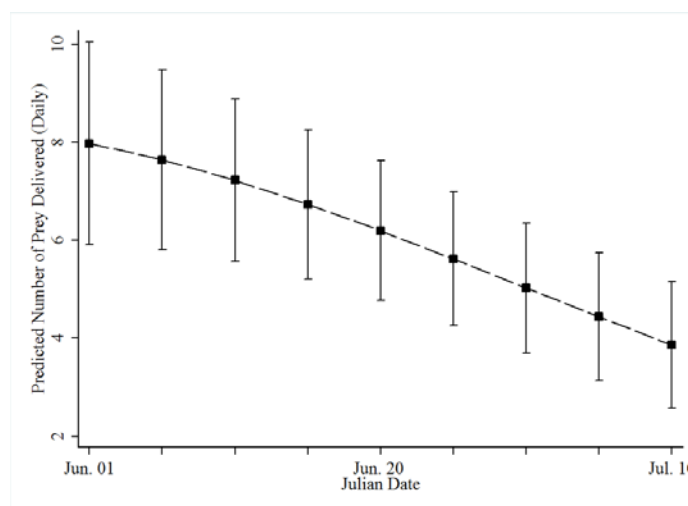


Figure 22. Marginal effects plot showing the change in predicted count of prey delivered to the nest per day with an increase Julian date with 95 % confidence intervals while all other model parameters are held constant at their means.

Controlling for Julian date (or age of chicks), number of young, and year we found very little evidence of a difference in prey return rate as a function of land cover (Figure 23).

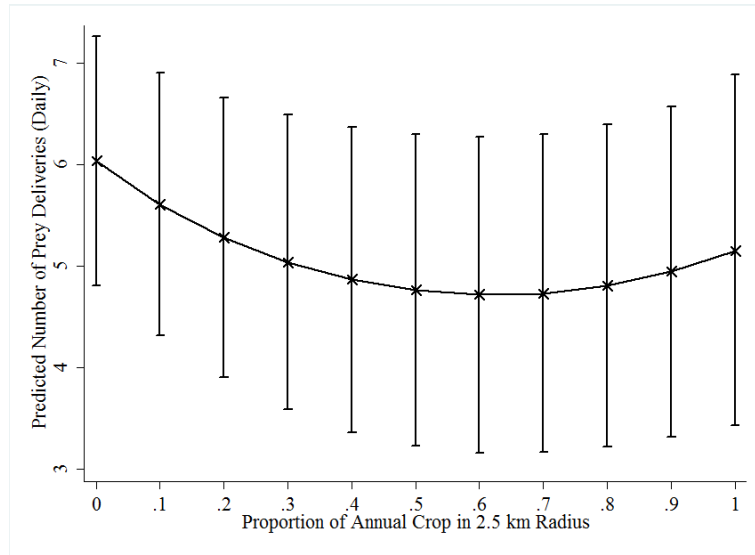


Figure 23. Marginal effects plot showing change in predicted count of FEHA prey deliveries with 95 % confidence intervals when an increase in proportion of annual cropland in a 2.5 km buffer around the nest while all other model parameters are held constant at their means. The overlap of confidence intervals indicates no strong effect of landcover type.

Based on this we used the base model for testing for anthropogenic effects.

$$P = b + d + yr + \text{random}(n) + L$$

Where P is daily count of prey delivered, b is the brood size, d is the date, ac is the proportion of annual cropland around the nest, n is a unique nesting attempt and yr is the year. L represents quantities of anthropogenic landscape features.

One landscape feature, distance to roads, received 35 % of model weight, had an AIC score improvement of 3.1 and was identified as a weak improvement over our base model (Table 14). Dropping the furthest nest removed this effect, suggesting that prey delivery rates were similar between nests close to versus far from nests.

Table 14. The top candidate anthropogenic model explaining Daily Prey Deliveries by the adult FEHA, compared to the basemodel

Model	df	AIC	ΔAIC	Weight
Distroad	7	1637.7	0	0.34
Distoil	7	1640.1	2.3	0.11
Distgas	7	1640.8	3.0	0.08
RdsHAC2500	7	1640.8	3.1	0.07
BaseModel	6	1640.8	3.1	0.07

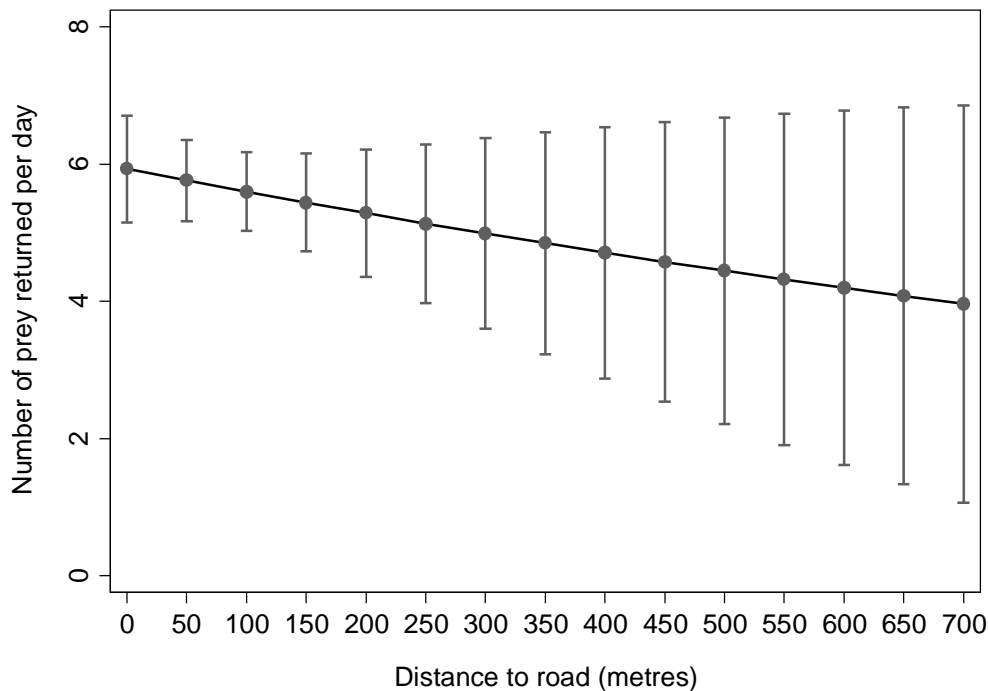


Figure 24. Marginal effects plot showing change in predicted count of FEHA prey deliveries with 95 % confidence intervals with an increasing distance from the nest to the nearest road while all other model parameters are held constant at their means. This figure removes the most distant nest which had the lowest feeding rate.

DISCUSSION

Inter-annual differences in the mean number of prey delivered to the nest likely reflect changes in prey (specifically RGS) abundance or availability between years. RGS densities have been associated with inter-annual changes in precipitation, such that RGS densities tend to be lower in wet years (Proulx 2010). Additionally, extreme spring precipitation was associated with dramatically decreased RGS populations (by 30%) in Saskatchewan in 2010 (Proulx 2012). In our study, further analyses to evaluate the influence of annual weather patterns on RGS abundance and FEHA prey delivery are needed.

The decrease in prey delivered to the nest with Julian date may be counterintuitive. We hypothesize that this pattern arises from 3 phenomena. (1) Nestling energy requirements are highest in the early nesting period (Brodin et al. 2003), (2) fewer prey items are delivered to the nest when female nest attendance decreases and she is able to feed herself away from the nest and (3) a shift to larger prey items may occur later in the season, maintaining total energy intake by nestlings throughout the nesting period.

RECOMMENDATIONS

- We found little evidence to suggest that industrial features, such as oil and gas wells, change the rate at which FEHA deliver food to their nest.

12. COMPARISON OF TREE VS PLATFORM NEST SUCCESS

OBJECTIVE

Determine if nests on artificial nest platforms have comparable nest success to tree nests.

INTRODUCTION

Artificial nest platforms (hereafter, ANP's) are a widely used mitigation and management strategy for FEHA across North America. The energy sector, transmission line companies, and regulators are increasingly using this strategy as a 'go to' tool to replace FEHA nests displaced from human structures, or to replace damaged natural nest structures (e.g., trees). In extreme cases, ANPs are used to offset nest disturbance by moving FEHA nests away from potential sources of disturbance or away from areas where known habitat is expected to be degraded or lost. Despite widespread adoption of this mitigation technique, most information regarding nest success has been anecdotal or limited to small sample sizes. Our main objective here was to evaluate whether nests on ANP have comparable nest success to tree nests.

During our nest monitoring study, we observed a high number of nest failures resulting from weather-related damage. In heavy rain and/or wind storms, nests can be blown out or may fall out due to the weight of water-soaked nesting material. We have observed 20% of nest failures attributed to weather-related nest damage. However, we have observed nest blowouts for nests in both trees and ANP. Our second objective was to evaluate whether nests in trees are more likely to become damaged or blown out than nests on ANP.

METHODS

Sampling design

We surveyed and monitored FEHA nests in southern Alberta and Saskatchewan from 2010 through 2013. Nest monitoring was restricted to nests found in the fescue, moist-mixed, and mixed grassland ecoregions. We monitored nests across a gradient of land use types and industrial intensities, allowing for us to control for variation explained by landscape characteristics.

Nest monitoring protocol

We recorded nest location and nest structure type (i.e., tree, artificial nest platform, transmission tower, cliff, ground, and etc.) (Figure 25). We monitored nests until completion and recorded the outcome (successful (i.e., naturally fledged at least one young) or failed (i.e., fledged no young)), sources of nest mortality, and other reproduction parameters. Hatch dates were estimated from nestling age.



Figure 25. Left: Photo by Ashley Burkatsky. Trees are natural nest substrate found in southern Alberta and Saskatchewan. Right: An ANP with > 40 day old nestlings.

Statistical analyses

STATA 12.0 (Statacorp 2011) was used for statistical analyses. Data was explored for outliers, homogeneity of variances, normality, excess zeroes, collinearity, model structure, and overdispersion (Zuur et al. 2010).

These analyses differ from our previous section where we used nest structure type to control for intrinsic factors that influence nest success. Here, we are specifically interested in how nest structure type influences nest success. We included all nesting attempts with known nest outcome and did not exclude nests that were blown out by wind or rain because this variation is important to understanding how structures potentially influence nest failure. We grouped any nest that was supported by a flat, man-made surface, similar to an ANP. For example, we grouped nests located on injection shacks, broken flat-topped windmills, and platforms installed on transmission towers as ANP. We excluded cliff nests and ground nests due to low sample sizes.

In a previous section, we evaluated the influence of land use and industrial infrastructure within home ranges on nest success. We did not find strong effects and therefore did not include them to control for landscape variation.

We evaluated the influence of nest structure type (NESTTYPE) relative to intrinsic nest factors: year (YEAR) of nesting attempt, date of monitoring start (FIRSTVISIT), and estimated hatch date (HATCHDATE). We used a mixed effects logistic regression with individual nest (NESTID) as our random effects variable. By grouping multiple nesting attempts by individual nests, we control for variation within individual nests.

In our first analyses, we evaluated the influence of these nest factors on nest success. Using a forward stepwise approach, we added each nest variable to the model and compared how the model performed using AIC values. The variable that resulted in the model with the lowest AIC value, if better than the null model, was included in the next set of models. Our top model was the model with the lowest AIC, where the fewest parameters explained the most variation in nest success.

Our second analyses examined how nest structure type influenced the probability of a nest blowing or falling from its supporting structure. Our response variable was categorized as either fallen/blown out (1) or not (0) and we used the same nest structure categories as previous analyses.

Similarly to our previous analyses, we used mixed effects logistic regression with individual nests grouped as random effect.

Lastly, we assessed whether a fallen or blown out nest always resulted in a failed nest (i.e., no young fledged). Using logistic regression, we developed a probability for failure resulting from a damaged or destroyed nest.

RESULTS

We monitored 1,017 FEHA nesting attempts at 687 individual nests from 2010 to 2013. Of these nests, 804 nests attempts (79%; 579 unique nests) were found on trees and 213 nests (21%, 108 unique nests) were on ANPs. Out of all 1,017 nesting attempts, 64% successfully fledged at least one young, and 48% of the successful nests were located in trees (Table 15). Of 1,017 nesting attempts, 81 nests (8% of nesting attempts) were found damaged or destroyed during the breeding season.

Hatch date was the single best predictor of nest outcome, closely followed by the nest structure type and date of first visit. Nests with relatively earlier hatch dates, located on platform structures (Figure 26), and found later by observers in the season were more likely to be successful (Table 16, 17).

Nests were also more likely to become damaged or destroyed when located in trees (Figure 27). The majority of nests that were damaged did not fledge young after a blowout. However, ~15% of FEHA pairs fledged at least one young after their nests were damaged or destroyed.

Table 15. Nest success is higher for ANP nests compared to tree nests.

	Nest Structure Type				Total
	Tree		Platform		
	n	%	n	%	
Successful	488	61	169	79	657
Fail	316	39	44	21	360
Total	804	100	213	100	1017

Table 16. Top and competing models that predict FEHA abundance. Models within 2 delta Akaike information criterion (Δ AIC) units from the top model, plus null model. (YEAR = year, FIRSTVISIT = date of first monitoring, HATCHDATE = estimated hatch date based, NESTTYPE = nest structure type (1 = tree, 2= platform)).

Model	K	Log-lik	AIC	ΔAIC	AIC Weight
CONSTANT	1	-651.18	1306.35	612.59	0.00
+ YEAR	6	-641.82	1293.64	599.87	0.00
+ FIRSTVISIT	4	-627.76	1261.52	567.75	0.00
+ HATCHDATE	5	-353.59	715.18	21.41	0.00
+ NESTTYPE	4	-640.42	1286.83	593.07	0.00
+ HATCHDATE + YEAR	8	-351.29	716.58	22.81	0.00
+ HATCHDATE + FIRSTVISIT	6	-347.68	705.37	11.60	0.00
+ HATCHDATE + NESTTYPE	6	-346.74	703.48	9.72	0.01

+ HATCHDATE + NESTTYPE + YEAR	9	-344.40	704.81	11.04	0.00
+ HATCHDATE + NESTTYPE + FIRSTVISIT	7	-340.88	693.76	0.00	0.67
+ HATCHDATE + NESTTYPE + FIRSTVISIT + YEAR	10	-338.61	695.21	1.45	0.32

Table 17. Top model predictors and standardized coefficients.

SuccFail	Coef.	Std. Err.	z	P>z	95% Conf. Interval	
HATCHDATE	-0.05617	0.020324	-2.76	0.006	-0.096	-0.01633
2.NESTTYPE	1.226365	0.366022	3.35	0.001	0.508976	1.943754
FIRSTVISIT	0.413211	0.13274	3.11	0.002	0.153046	0.673376
CONSTANT	-3.28125	0.501154	-6.55	0	-4.26349	-2.299

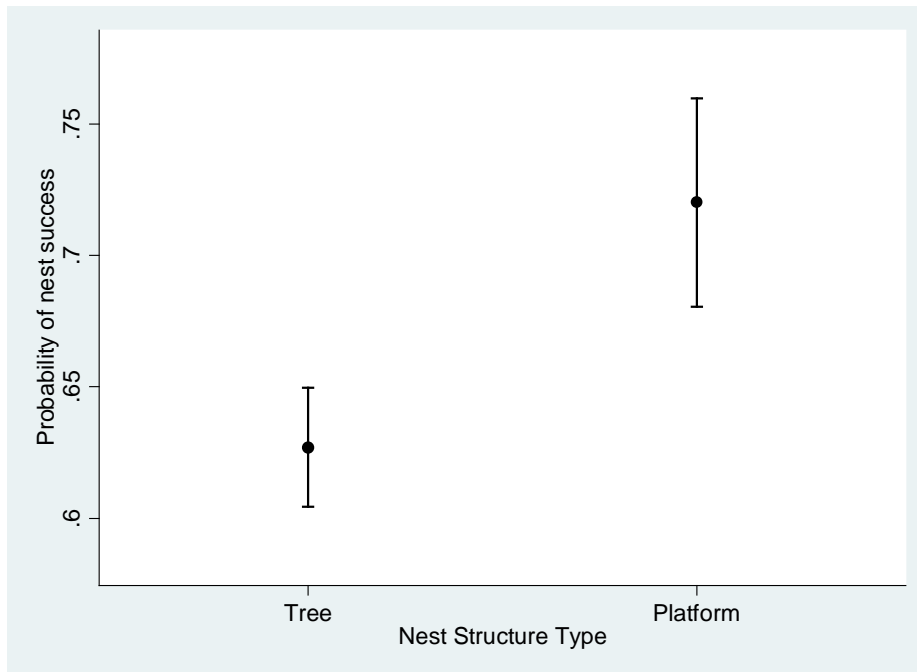


Figure 26. Nests on ANPs were three times more likely to be successful compared to nests supported by trees.

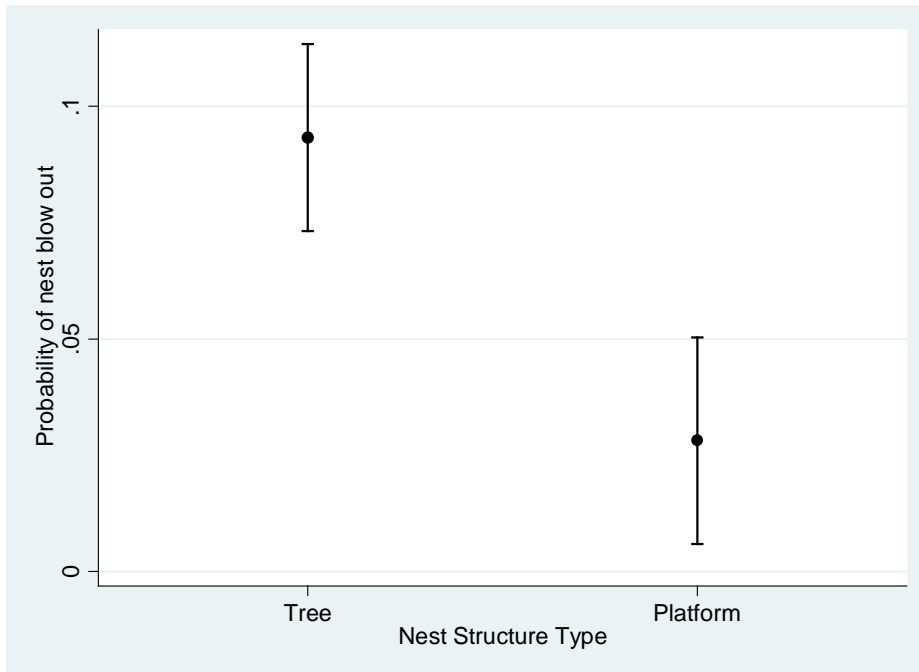


Figure 27. Nests in trees are more likely to blow out than nests located on ANP.

DISCUSSION

ANP nests monitored during our study were three times more likely to be successful relative to tree nests, suggesting that ANPs can potentially be an important mitigation tool if a natural nest needs replacement.

Damaged or destroyed nests are not limited to nests in trees. Our group has documented several blown out nests that were located on ANPs. However, our results demonstrate that tree nests are more likely to fall out or be blown out compared to nests on ANPs. We observed that a damaged or destroyed nest almost always results in a failed nest. However, we found that nests that were damaged late in the nesting season when nestlings were close to fledging could be successful. This suggests that timing of damage could influence nest success.

These analyses represent the largest ANP and reproductive outcome study ever completed. The strong effect sizes, large sample size, multiple years of data, and wide geographic spread ensure that the findings are robust. However, installing an ANP does not guarantee nest success, and important factors should be considered to improve the probability of nest success. Placement of an ANP should consider the surrounding landscape and potential sources of disturbance or mortality. Our following section will briefly describe some design advantages observed by our group. Other considerations should include distance to nearest potential competitor, such as other raptor species or other FEHA, prey availability through time, and climate. The success of an ANP still requires careful planning before being implemented as a mitigation or management strategy.

RECOMENDATIONS

- FEHA nests on ANPs in our study were more successful than nests in trees. Therefore, ANPs can be at least equally effective when used to replace a damaged or fallen natural nest.

- In REACT's opinion, ANP should be placed in suitable habitat with a known prey base (Migaj et al. 2011), away from potential sources of disturbance of mortality, away from other raptor nests and abandoned buildings where great horned owl may roost, and when replacing a nest, as near as the original nest as possible (see Bayne et al. 2013).
- Placement of ANP also needs to consider risks to all FEHA life stages. As discussed in section 14, juvenile FEHA collide with transmission lines and are hit by vehicles.

13. NEST PLATFORM DESIGN

OBJECTIVE

Determine whether different aspects of structural design of existing ANPs on the landscape influence FEHA nesting success.

INTRODUCTION

During the late 1970s and early 1980s, the first ANPs in Alberta were erected as part of a study to help increase the number of breeding pairs in the Hanna area (Schmutz et al. 1984). Since then, government agencies, non-profit organizations, industrial companies, and landowners have installed ANPs to provide suitable nesting sites for breeding FEHA across the province.

METHODS

Sampling Design

We completed detailed nest descriptions for a subsample of FEHA nests found on ANPs, trees, and industrial infrastructure across our study area. A subsample of described nests included nests where video monitoring and trapping occurred, and for any failed nests.

We recorded nest dimensions (i.e. height and width), and relative nest position in the nesting structure; and dominant landcover type within a 100 m radius of the nest. For ANP nests, we also documented the presence of perches or crossbars and windbreaks, platform material, the number of supporting braces, and the lean angle of the ANP.

Statistical Analyses

STATA 11.0 (Statacorp 2011) was used for statistical analyses. Nest structure types were categorized into ANP and tree nests; where ANP nests included those nests found on freestanding platforms, transmission tower platforms, and on oil and gas shacks. Tree nests included those nests found in living and dead trees. We used univariate tests to determine if structural features of an ANP significantly influenced nest outcome.

RESULTS

We completed nest descriptions for 222 FEHA nests during 2012 and 2013. Over the two years, 45 platform nests, 176 tree nests, and 1 transmission tower nest were described.

Our analyses found that when comparing different types of ANP nests that most ANP structural features (i.e. design characteristics) appear to have no significant influence on the nesting outcome of a given breeding pair (Table 18). Although not significant, a higher proportion of successful ANP nests had a raised edge on the flat platform (i.e., 2 X 4 wood blocks) (Figure 28).

Table 18. The detected level of significance between the two categories of various structural features when using a t-test.

Structural Feature	Feature Categories	df*	t-value	p-value
ANP Material	Wood or Metal	30	0.1648	0.8702
ANP	Present or Absent	36	-1.5188	0.1376
Perch/Cross	Flat with edges** or no edges	21	1.0262	0.3165

* where df refers to degrees of freedom

** where “edge” refers to the raised edge on platform perimeter

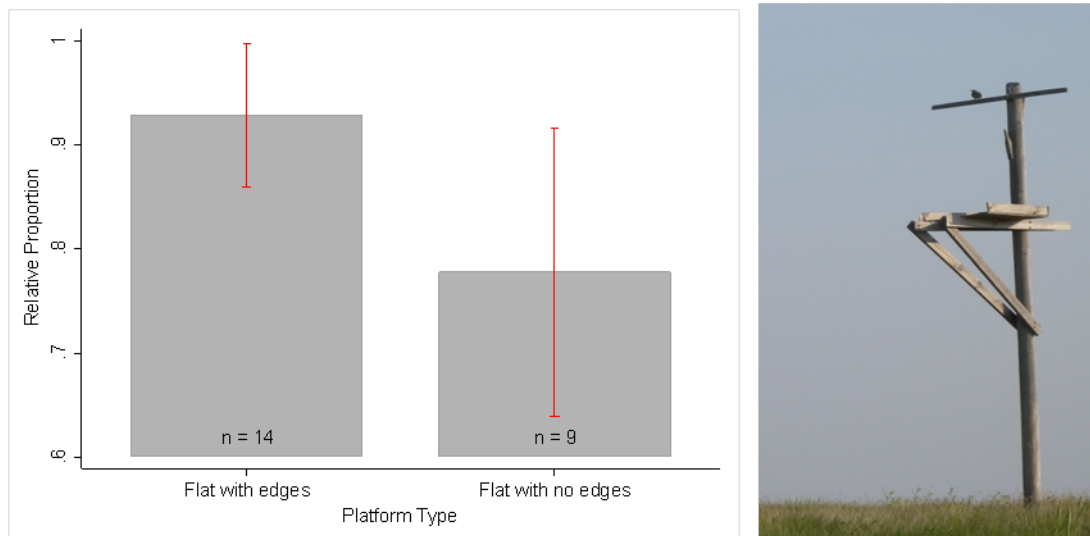


Figure 28. The proportion of successful nests found on each platform type with standard error bars (left). N is the number of nests used to derive the estimate. An ANP with a platform “edge” (right).

There were 39 nests found on ANPs and 161 nests found in trees where precise nest dimensions were taken (Table 19). On average, there was no significant difference in nest volume between platform and tree nests ($t = -1.1063$, $df = 198$, $P = 0.27$). However, platform nests had significantly greater widths ($t = 3.5385$, $df = 198$, $P = 0.0005$) and lengths ($t = 2.6733$, $df = 198$, $P = 0.0081$) than tree nests. When all nest structure types (i.e., trees and ANPs) were considered, nest success was not significantly influenced by nest volume ($z = -0.44$, $n = 184$, $P = 0.659$) nor by nest area (i.e., width by length) ($z = -0.37$, $n = 184$, $P = 0.710$).

Minimum nest heights of ANPs and trees are quite similar; however, nests in trees can be built higher above the ground than ANPs (Table 20). Using a one-way ANOVA, a significant difference was detected in the average nests heights between ANPs and trees ($F_{1,201} = 30.31$, $p > 0.01$). When excluding other variables, such as landscape composition, proximity to industrial infrastructure, etc.,

from this logistic regression analysis, nest success was not significantly influenced by nest height ($z = 1.33$, $n = 186$, $P = 0.183$) regardless of nest structure type (i.e., trees and ANPs).

Table 19. The minimum, maximum, and average nest dimensions of 39 platform nests and 161 tree nests quantified during 2012 and 2013.

Nest Dimensions	ANP Nests			Tree Nests		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Depth (cm)	5.0	60.0	29.4	10.0	180.0	44.9
Width (cm)	40.0	150.0	88.6	6.5	190.0	69.6
Length (cm)	45.0	150.0	90.7	20.0	200.0	76.1
Nest Volume (m ³)	0.018	0.792	0.261	0.008	3.856	0.352

Table 20. The minimum, maximum, and average nest heights of 41 platform nests and 162 tree nests quantified during 2012 and 2013.

Nest Structure Type	Nest Height (m)		
	Minimum	Maximum	Average
ANP	2.15	6.59	3.69
Tree	2.16	13.39	5.69

DISCUSSION

Our results indicate that ANPs are suitable nesting structures for FEHA to build nests on and raise their young. Overall, the structural design of ANPs may explain why a higher proportion of successful nests are found on these structures in comparison to trees; however, there may be other landscape variables which explain this phenomenon, but were not considered in this analysis.

On average, platform nests had a significantly larger surface area (i.e., length x width) than those nests found in trees. This was most likely a result of platform dimensions. By having a larger, secured surface (i.e., wooden platform) available for FEHA, these birds are more likely to build larger nests on ANPs than in trees. In terms of nesting success, platforms may provide more space for young to move, minimizing the risk of accidental falls from the ANP and potential mortality. Additionally, platforms may be able to support the combined weight of larger broods in comparison to trees. We have observed small tree nests collapse under the combined weight of the young. This occurs rarely and it is worth nothing that some trees in our study area are capable of supporting larger nests than ANPs.

ANPs with a platform “edge” had a higher proportion of successful nests than ANPs lacking an “edge”. Although this trend was not significant, it is possible that having a platform “edge” is beneficial

to a FEHA pair and may ensure a higher rate of nest success. In our study area, we observed platforms with 2 X 4 wood blocks nailed on the perimeter of the platform. Erickson et al. (2008) used wooden dowels marked around the edge of the platform. Building a raised “edge” on the platform may prevent nest blowouts due to inclement weather (Erickson et al. 2008). Furthermore, edges may facilitate securing nesting material.

On average, ANP nests are significantly closer to the ground in comparison to tree nests. This was most likely a reflection of where the platform (i.e., the only available nesting structure) is attached to the ANP. In comparison, trees provide numerous locations, such as on an extended branch, along the main trunk, or at the apex of the tree itself, for nest placements, resulting in more variation in nest heights.

In terms of nesting success, there appears to be no significant difference between wood and metal ANPs. Regardless, if wood, metal, or a combination of both, are used, these building materials should be weather-treated, and constructed in such a way to support the weight of a large FEHA nest. Some ANPs in our study area have collapsed due to the weight of the nest (Migaj et al. 2011).

RECOMENDATIONS

- Based on our video monitoring and field observations; perches, crossbars, and windbreaks on ANPs may be beneficial to FEHA. When a perching site (i.e., perch or crossbar) is in close proximity to the nest, adults may respond more quickly or display increased vigilance if approached by humans or predators. Furthermore, windbreaks may prevent young from being blown off the nest during extreme winds.
- Nest platforms might be more effective if they were modified to accommodate larger nests. Based on the maximum nest dimensions recorded for ANP nests, there is the potential that a FEHA pair could be build a nests as large as 1.5 m by 1.5 m (i.e., 4.9 ft X 4.9 ft) nest on a platform. To accommodate larger nests which may be less prone to blowout, industry should consider increasing minimum platform dimensions to a minimum of the average length and width of natural nests, ranging from 70 cm X 70 cm to greater length and width.

14. JUVENILE SURVIVAL & MOVEMENT

OBJECTIVE

Determine if industrial footprint is correlated with post-fledging survival

INTRODUCTION

The post-fledging (PF) period (i.e., the period from fledging to dispersal) represents a critical life-history stage in birds (Weathers and Sullivan 1989) because of the high mortality rates that occur in this period (Henny 1972). Limited information exists on FEHA mortality during the PF period and studies that do exist are mainly based on band recoveries (e.g., Schmutz and Fyfe 1987, Harmata et al. 2001, Schmutz et al. 2008). Band recovery studies provide limited information on causes of mortality and are biased estimates of survival rates because not all dead birds are found. Radio telemetry studies provide substantially more information as it is much easier to both document a mortality event, and habitat use prior to the mortality can be assessed. Only a handful of studies have done telemetry on PF FEHA, and these studies were limited by small sample sizes (Blair and Schitoskey 1982 (n=6), Woffinden and Murphy 1983 (n=2), Zelanak et al. 1997 (n=27), Watson 2003 (n=15), Ward and Conover 2013 (n=46)). Nothing has been documented regarding interactions of PF FEHA with energy sector footprint.

METHODS

To determine how industrial features influenced the survival of juvenile FEHA, we tracked hawks via very-high frequency (VHF) radio telemetry from their time of fledging in June/July until the hawks died or left the study area. Hawks were selected for inclusion in the study by targeting chicks with variable landscape conditions around their nests. When chicks were approximately 40-50 days of age and still within the nest, nestlings were randomly selected to be fitted with either a backpack or tarsal radio-transmitter. Back-pack transmitters were attached with Teflon[®] ribbon, and secured with cotton thread at the breast cross piece so as to be releasable (i.e., the cotton thread was meant to rot over time or break with sufficient pressure). Tarsal mounts were attached to a leather bewit and also were attached using cotton thread. Tagged birds were returned to nests after processing.

Juveniles were tracked approximately every 3 days using ground searches (telemetry signals detected using truck-mounted omni-directional and hand-held yagi antennas) and aerial searches (via a fixed wing aircraft) if hawks could no longer be located during ground surveys. Tracking of the hawks persisted until they were no longer detectable and were assumed to have left the study area to begin their fall migration.

When a dead bird was located, a GPS location was taken, and cause of death was ascertained where possible and classified as: (1) owl predation when feathers were plucked, carcasses were decapitated, and/or triangular puncture marks were present on the body; (2) coyote predation/scavenging when carcasses were buried, transmitters showed evidence of chewing, and/or bones were crushed and broken; and (3) collision with structures (i.e., vehicular, power lines) by association of the carcass with the aforementioned features and evidence of blunt force trauma. If transmitters were located without a carcass, mortality and subsequent scavenging was assumed when feather piles were present or the transmitter or harness was chewed or sheared. When transmitters were

located without a carcass and the backpack harness was frayed at the center cross-piece with no evidence of trauma, we concluded the cotton-thread released and the hawk was alive.

Statistical analysis

We evaluated whether conditions near the nest influenced survival as this is where most of the mortalities occurred. Analysis units of 1000 m (setback distance for industry as recommended by AESRD) and 2500 m (core adult home range) were compared, and the unit that exhibited the most explanatory power was selected as a buffer for each nest. Landscape features, as determined in ArcGIS 10.1 (ESRI 2012), were classified according to vegetation land cover, distance to industrial development features and a density attribute (e.g., counts of wells or Euclidean distance of roads and transmission lines within the buffer). Survival of PF FEHA at the nest level was analyzed using logistic regression (0 – lived, 1 – died). We evaluated whether PF FEHA hatched from different nest structures (tree, transmission line platform and free-standing platform pole) had differential survival. Landscape features were also evaluated in the same model. All analyses were completed using logistic regression in STATA 11.0 (STATA 2011).

RESULTS

In total, 103 PF FEHA from 84 nests were tagged in 2011 and 2012 (Table 12) with 732 individual tracking events (mean = 5.5 tracking events per bird, SD = 9.6). On average, juvenile FEHA stayed within 1 km of the nest 15 days after fledging (i.e., July 31) (Table 12). Year effects were noted, as birds remained within 1 km of the nest longer in 2011 than in 2012 (August 8, 2011 and July 26, 2012, respectively) (Table 12, Figure 29). Juvenile FEHA did not disperse uniformly from nests, often returning to the nest within the first one- to two- weeks post-fledge. In addition, adults were observed to remain in attendance (defending and feeding PF) until dispersal, indicating that independence is not achieved until dispersal.

Overall mortality rate was 39% with most mortalities occurring within the first two weeks of fledging (Figure 29). Main causes of mortality were avian predation (25%) and vehicle strikes (8%). Scavenged carcasses (33%) may have been the result of mammalian predation or dead birds were eaten opportunistically. Unknown causes accounted for 35% of mortalities; however, due to condition and location of the carcasses, 13% of these were assumed to be starvation events (sharp keel and atrophied breast muscles) and 8% caused by probable transmission line collisions. Mortalities were assumed to be related to the transmission lines as carcass remnants were located directly below, or within 50m of, transmission lines (carcass proximity, including scavenged remains, to power lines is an established method for identifying avian collisions (APLIC, 2006)). One carcass was located 10m from a distribution line corner structure and may have been an electrocution; however, the carcass was scavenged making it impossible to be certain.

Tree nests were the dominant nest type. Overall, 41% of PF FEHA hatched from tree nests died. In contrast, 67% of hawks fledging from transmission line platforms died, representing the highest mortality rate for an individual nest type (Table 13). However, despite this difference in PF FEHA survival there was not a statistically significant difference between trees, transmission towers, and platform/oil and gas sheds ($\chi^2 = 3.7$, $df = 3$, $P = 0.16$) (Table 13 & Table 14).

Table 21. Timing of post-fledging movement from nests in 2011 and 2012. Timing of events varied according to year, with activities occurring approximately two weeks later in 2012 as opposed to 2011. Locations where birds were further from the nest than expected (e.g., carried greater than 2 km from the nest by wind gusts) were excluded from date calculations if they returned to the nest (n=4).

Year	Event	Average	Std. Dev. (days)	Earliest	Latest	N
2011	Fledge	July 22	7.2	July 13	August 7	33
	>1km from nest	August 8	11.2	July 24	August 21	
	Last Detection	August 9	19.3	July 14	September 23	
2012	Fledge	Jul 11	6.8	June 30	July 22	70
	>1km from nest	July 26	7.7	July 11	August 15	
	Last Detection	July 28	12.1	July 5	August 22	
Combined (2011 & 2012)	Fledge	July 16	8.8	-	-	103
	>1km from nest	July 31	11.1	-	-	
	Last Detection	August 1	15.7	-	-	

Table 22. Summary of nest types and mortality of post fledging FEHA. Transmission Platform nests were attached to 240kV steel lattice structures and located approximately 4 m from the ground. Nest poles were free standing platform nest poles, and Oil and Gas Sheds comprise nests built on oil and gas shacks. Numbers in parentheses indicate mortality rate per nest type.

Fate	Tree	Transmission Platform	Nest Pole	Oil and Gas Shed	TOTAL
Alive	44	2	14	3	63 (61%)
Mortality	30 (41%)	4 (67%)	5 (26%)	1 (25%)	40 (39%)
TOTAL	74	6	19	4	103

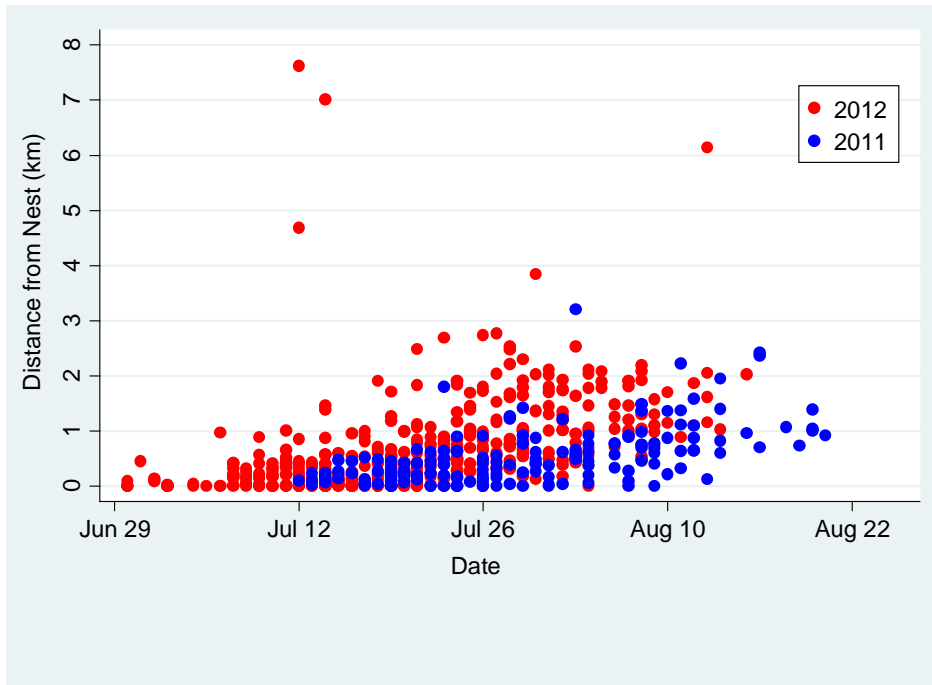


Figure 29. Post-fledging FEHA movement from nests. Distances greater than 20 km from the nest were excluded.

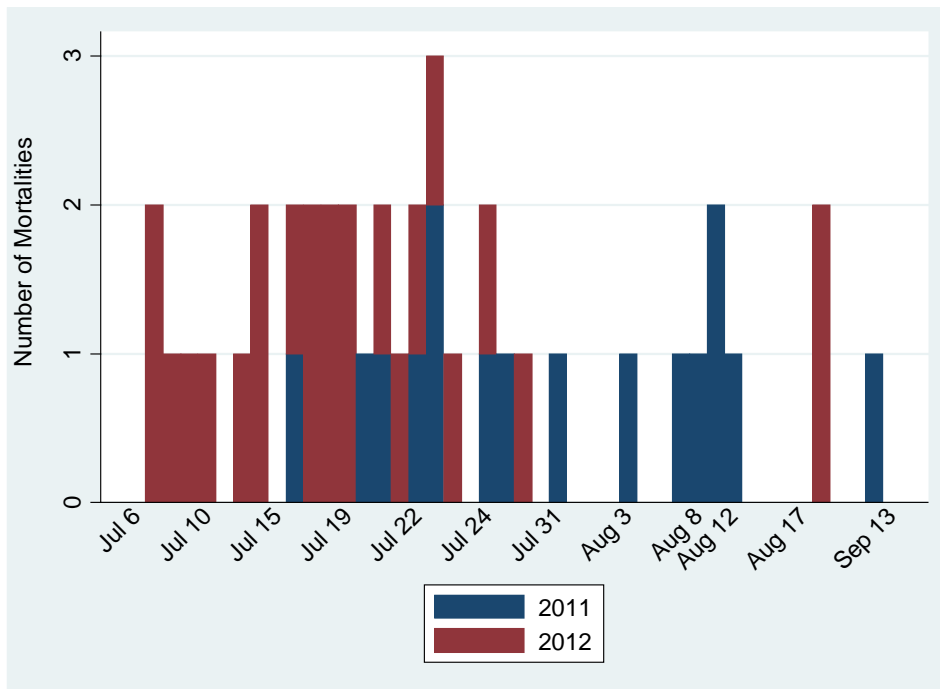


Figure 30. Timing of mortalities of post-fledging FEHA in southern Alberta and Saskatchewan. Most mortalities occurred within two weeks of fledging (2011 mean: August 1, 2012 mean: July 20).

Table 23. Logistic regression coefficient models predicting survival as a function of features measured at nests. None of models were statistically significant predictors of mortality at the nest scale.

Variable	Std β	Std. Err	Z	P>z
TXline1km	0.90	-0.62	1.44	0.150
Distance to Road	0.17	0.20	0.84	0.40
Road Density	-0.34	0.22	-1.58	0.12
Distance to Gas Well	0.09	0.20	0.45	0.66
Gas Well Density	-0.10	0.21	-0.47	0.64
Grassland Area	0.25	0.20	1.21	0.23
Grassland Area + Road Density	0.36 -0.44	0.22 0.23	1.63 -1.89	0.10 0.06
Grassland Area + TXLine1km	0.20 0.78	0.21 0.64	0.95 1.23	0.34 0.22
Road Density + TXLine1km	-0.32 0.84	0.22 0.62	-1.48 1.83	0.14 0.18
Grassland Area + Gas Well Density	0.35 -0.25	0.23 -0.24	1.52 -1.03	0.13 0.30
Grassland Area + Road Density + Transmission Line Density	0.31 -0.41 0.64	0.23 0.23 0.65	1.38 -1.76 1.00	0.17 0.08 0.32

DISCUSSION

This study represents the largest effort to accurately measure PF FEHA survival ever completed. However, even with sample sizes over 100, our ability to test some effects has low statistical power. Post-hoc statistical power testing indicated we would have had to monitor 18 juvenile hawks from transmission tower nests to statistically demonstrate the difference we observed would be significantly different from what was observed at tree nests. Juvenile FEHA appear to have an increased risk of mortality when in association with transmission lines. However, these results should be interpreted with caution as they may also describe patterns that are limited to localized geographical locations. Most of the juvenile FEHA that died in association with transmission lines were localized: transmission line platforms we studied were located on the steel lattice structures of a double circuit 240kV transmission line that is paralleled by an adjacent 240kV wood H-frame single circuit transmission line (over a distance of approximately 30 km). Therefore, the increased risk of mortality may be a local phenomenon rather than a population-wide trend.

Fledglings were often detected within 1 km of the nest after the current timing restrictions were lifted, which is July 15th. REACT also documented fledglings near the nest as late as mid to late August, suggested that traffic or speed restrictions into August would reduce mortality risk to post-fledglings.

RECOMENDATIONS

- PF FEHA spend at least two weeks within 1 km of their nests after fledging. REACT's results suggest that, in areas where nests are near roads, there is an increased risk of hitting a juvenile FEHA with a vehicle. Reducing speeds to less than 50 km per hour and/or the amount of travel occurring in areas less than 1km from the nest until at least July 31, should be considered to reduce the risk of accidental mortality caused by vehicle collisions.
- General industrial activity within 1000 m of the nest also should be avoided until PF have gained independence to avoid increased mortality risk (i.e., after July 31). This recommendation also supports our recommendation in Section 8 where restricting activity to low levels within 1000 m of a nest will prevent nearly 100% of adult FEHA flight initiations.

15. ADULT PERCH USE

OBJECTIVE

Determine if oil and gas infrastructure are priority perches for FEHA relative to other available perch types and evaluate how their use is influenced by other human impacts

INTRODUCTION

Past research has concluded that FEHA spend a large proportion of their daily time budget perching. Wakeley (1978) monitored breeding FEHA and concluded that although they spent a high proportion of their time perching, they were also actively foraging at this time. This distinction is important because it emphasizes the importance of perch selection and suggests it may influence foraging success. Plumpton and Andersen (1997) discussed the importance of utility poles as perches and concluded that wintering FEHA spent 33 % of their time perching on them. Similarly, previous research conducted by our research group indicates hawks may spend up to 50% of their time perching on electrical infrastructure (distribution poles and transmission structures) (Bayne unpublished). However, no research has discussed FEHA use of petroleum infrastructure (e.g., oil and gas well heads and tanks) as perches or how their presence may influence perching behaviour.

METHODS

Hawk Capture and Telemetry

Adult male FEHA were monitored throughout the moist-mixed and mixed grasslands of Alberta and Saskatchewan during the 2012-2014 breeding seasons. Nest sites were located in late April and early May in the early stages of nesting. Adult male hawks were captured in late May through June when chicks ranged from 10 to 25 days old. Highly accurate (± 22 m), 30 g, solar GSM/GPS satellite transmitters (Microwave Telemetry Inc., Columbia Maryland, USA) were attached to adult male hawks using the X-attachment method and Teflon ribbon. Solar GSM/GPS units were deployed in 2013 and 2014 and acquired between 1 to 55 locations/hour. Transmitters recorded 3-dimensional space use (latitude, longitude, and altitude), speed, and direction of travel.

Sampling Design

Transmitters were attached to 36 adult male FEHAs throughout the study area. Males were selected for transmitter attachment based on the combination of habitat composition and industrial features within their home ranges (5 km buffer from the nest). Throughout the FEHA nest sites, we sampled all combinations of habitat composition (e.g., high – low amount of native grassland vs. agricultural land) and industrial features (e.g., high and low oil and gas).

Home Range and Perch Characterization

Minimum convex polygons (hereinafter: “MCPs”) were created using ArcGIS 10.2 (ESRI 2012) to delineate home ranges for individual breeding hawks. Locations collected between the time of transmitter attachment and when the hawk appeared to no longer be tending to the nest (i.e., fall migration) were used to create 95 % MCPs. Elevated perches including transmission towers, distribution poles, oil, and gas wells within 95 % MCPs were included in this analysis.

However, for nest sites in Saskatchewan, we lacked transmission tower and distribution pole data. Thus, this analysis focused on 14 nests located in Alberta.

When telemetry locations were between 0 and 50 m from an elevated perch we assumed the hawk was perching on that feature. Fifty metres was chosen as a cutoff because it accounted for both error in the GPS satellite transmitter locations and error in our point GIS layers for elevated perches. We counted the number of times a hawk was located within 50 metres of a given perch within his home range. We controlled for the number of points acquired across the hawk's entire home range data set to deal with unequal numbers of detections for each bird. We also accounted for individual bird identity as a random effect.

Statistical Analysis

We used STATA 13.1 (StataCorp 2011) for all statistical analyses. Ordinary least squares regression was used to compare the intensity of use among the four perch types. Perch use was natural log transformed prior to analysis. We tested the fit of both linear and quadratic models.

RESULTS

We collected an average of 7,907 locations per bird which were used to model 95 % MCPs. The average number of gas and oil wells within a range was 40 and 27 respectively. The maximum number of gas and oil wells within a home range was 380 and 477 respectively. Home ranges contained an average of 8 transmission towers and 132 distribution poles. The maximum number of transmission towers in a home range was 30 while the maximum number of distribution poles was 673. A total of 3,058 elevated perches were analyzed. We observed variable amounts of use among the different types of elevated perches. The maximum percentage of use on a single gas and oil well was 12 % and < 1 % respectively. The maximum percentage of use on a single transmission tower by a given hawk was 19 % while it was 6 % on a single distribution pole. Hawks were more likely to use transmission towers in comparison to the three other perch types.

The magnitude of predicted use of transmission towers was considerably greater than that of distribution poles, gas wells, and oil wells (Figure 31 and Figure 32). FEHA predicted use of distribution poles, gas wells, and oil wells did not differ greatly. Distribution poles had the highest predicted use followed by gas wells and then oil wells. Predicted use of these perches was most consistent less than 2.5 km from the nest site. In comparison, predicted use of transmission towers was nearly 5 times as high at the same distances from the nest. Similarly, predicted use dropped off near 2.5 km from the nest. Over 2.5 km from the nest, the predicted use of transmission towers increased greatly.

Our analysis of FEHA perching behaviour indicated they were more likely to select perches that were closer to native grass. To emphasize the importance of native grass on FEHA perching preference, native grass composed an average of 42 % of the 14 home ranges included in this analysis suggesting hawks did have a choice to select perches in non-native grass. Additionally, only 32 % of the 3058 perches were available to be used were located in native grass.

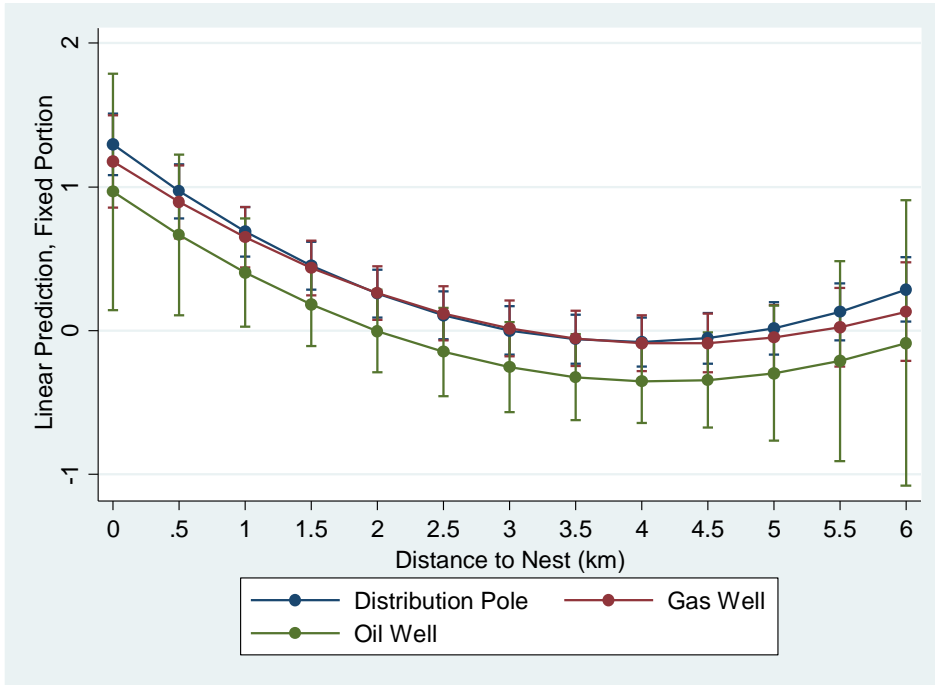


Figure 31. Predicted use of distribution poles, gas wells, and oil wells at varying distances from the nest with 95 % confidence intervals.

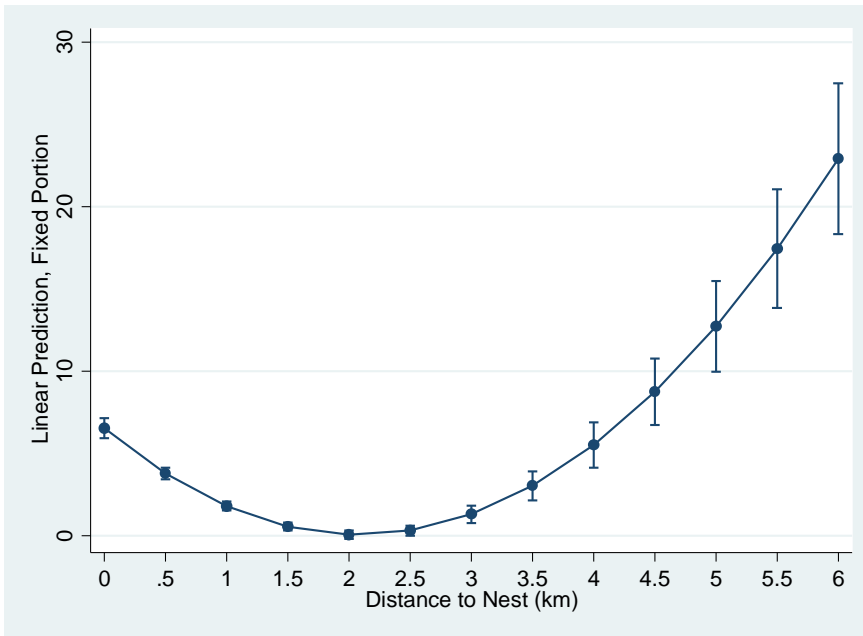


Figure 32. Predicted use of transmission towers at varying distances from the nest with 95% confidence intervals.

DISCUSSION

Of the four perch types used in this analysis, transmission towers were clearly the most heavily used. Relative to the other three perch types it is apparent that FEHA will choose to perch on the tallest perches available. We suspect the height of transmission towers is their most attractive feature which may explain why they are used considerably more in comparison to more abundant distribution poles. To further support the idea that FEHA prefer taller perches, our data indicates a drop off in the amount of use of perch types that incrementally decrease in height. Transmission towers were most heavily used, followed by distribution poles, then oil and gas wells. Fence posts are another type of perch that FEHA use consistently but unfortunately we were unable to include them in this analysis because we were still compiling the data layers required. With our results in mind, and given fence post abundance, we would expect a FEHA in a landscape with all aforementioned perch types to use fence posts slightly less than distribution poles, but more than oil and gas wells.

All individuals displayed variable use patterns across the different perch type categories but a clear trend demonstrates where perches within 2.5 km from the nest were used more heavily. This relationship is somewhat expected as central-place foraging animals (any animal required to return to a nest or den to care for young) tend to display high usage patterns close to the nest.

There are several caveats that must be considered when reviewing the results. The GSM/GPS transmitters collected locations dynamically if the unit was fully charged at a rate of up to 60 locations per hour. Thus, there may be elevated perches with inflated use from instances where a hawk perched on a single perch only once throughout the season but for a long duration. Additionally, the amount of use at a given elevated perch may have been inflated in instances where something other than the perch we analyzed was being used by the hawk (i.e., the bird was actually spending time at an undocumented perch such as a fence post). These issues are partially accounted for by including a random effect for individual birds which helped control for variation in sample size.

RECOMMENDATIONS

- There is no strong evidence that gas wells are used any less frequently as perches than power poles. There is slightly less use of oil wells but this result is not statistically significant.
- Transmission towers are very well used perches and indicate that FEHA prefer to perch on the tallest structures available.
- Overall, there is little evidence that use of energy infrastructure by FEHA differs relative to electrical infrastructure. In general, tall structures are used for perching and we could find no evidence that at very high levels of structures that FEHA begin to avoid an area. Further work is needed to assess the importance of fence posts and natural features. This is being done currently through detailed digitizing and image processing.
- From the perspective of adult perching, there are no strong recommendations about what should be done other than to ensure that the infrastructure does not pose a risk to adult survival (i.e. electrocution)

16. CONCLUSIONS

Throughout this report, we provide a series of recommendations for each life-history stage and behavioral process we studied. At no stage did we find evidence of what we would deem a large impact of oil and gas development on FEHA. This is not to say that energy sector activities do not influence hawk ecology, they do. All human activities influence wildlife in some way just as other predators and competitors do. Humans are a fundamental part of the landscape in which FEHA live. The question is to what degree and is the overall effect positive or negative. Statistically speaking it is very difficult to prove there is no impact of energy development, but our large sample size for most life stages means we can demonstrate there is not large effect sizes (i.e. >25% effect). We can't however rule out the possibility that small changes in some demographic and behavioural parameters have been altered by energy sector activities (i.e. 1-2%).

That large effects were not observed could be for two reasons: 1) FEHA are more tolerant of energy sector disturbance than previously thought; 2) setback distances and other regulatory restrictions have been effective at mitigating risk to FEHA and we simply monitored the success of that strategy. The fundamental challenge for us in conducting this research was to provide concrete recommendations on whether setback distances are appropriate and if they have been effective at mitigating impacts. We do not know what the effect sizes we would have observed if policy had allowed more intense energy development to occur near FEHA nests.

The precautionary principle has been used as the rationale for the setback distances currently used by the governments of Alberta, Saskatchewan, and Canada. Our lack of strong impacts from energy sector activities suggest these likely have been effective. However, whether they could be reduced without impacting FEHA is difficult to know without further work. Our behavioral data on flushing distance indicate that 1 km is more than enough to prevent FEHA from flushing caused by human's walking near the nest. Whether this would be the case when drilling a well with heavy equipment can not be determined with current.

The valid concerns of current policy about causing harm to species at risk is a common conundrum in endangered species research. We see three solutions to help improve our understanding of current setback distances on FEHA biology: 1) we are aware of some exceptions being made in terms of setback distances for FEHA during the breeding season for various industrial activities. To draw more robust conclusions about the effects of these activities on FEHA, careful monitoring, standardized data collection, and a common reporting framework are needed to make effective use of such data; 2) data from other jurisdictions with different setback distances and/or much higher oil & gas densities could be combined into a larger database to increase the range of human disturbance that could be evaluated; 3) after careful evaluation of innate differences between species, using a surrogate species of lesser concern (i.e. Swainson's hawk) might be suitable for conducting manipulative experiments that expose individual birds to different extremes of disturbance.

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