LETTER

# Accounting for uncertainty in oil and gas development impacts to wildlife in Alaska

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**Keywords**
Caribou; cumulative effects; development; environmental assessment; environmental impact statement; Monte Carlo Simulation; National Petroleum Reserve-Alaska; passerine.

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**Received**
7 November 2012
**Accepted**
15 February 2013

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**Editor**
Atte Moilanen

doi: 10.1111/conl.12016

## Abstract

Around the world, oil and gas exploration and development are moving into areas previously undisturbed by industrial development. These activities and associated infrastructure can significantly impact wildlife populations and their habitat. Uncertainty in the location of oil and gas accumulations, however, makes it difficult to assess potential impacts to wildlife populations from future development. We present a modeling approach that takes this uncertainty into account by randomly sampling the locations of oil and gas accumulations across the landscape and building out simulated infrastructure. We evaluated four management alternatives outlined for the National Petroleum Reserve-Alaska to demonstrate how this model can quantify the relative impacts to caribou (*Rangifer tarandus*) calving habitat and passerine nest survival. We were able to identify clear differences in impacts for wildlife under the four alternatives and highlighted the range of variability in how development might proceed under each scenario.

## Introduction

Around the world, oil and gas exploration and development are moving into areas previously undisturbed by industrial development. Understanding how wildlife will be impacted by this surge in energy production is likely to be a major challenge for researchers and resource managers in the coming decade (Northrup & Wittemyer 2013). We can expect that wildlife populations will continue to be impacted through the direct conversion of habitat to industrial infrastructure and indirect losses associated with the avoidance of industrialized areas (Cameron *et al.* 2005; Harju *et al.* 2010; Dzialak *et al.* 2011) or abundance of predators (James & Stuart-Smith 2000; Liebezeit *et al.* 2009). It is imperative to evaluate the potential intersection of high value habitat and oil and gas accumulations to achieve an effective balance between conservation and industrial development (Copeland *et al.* 2009).

Assessing the impacts of future oil and gas development can present a greater challenge than other types of uses (e.g., logging) because there is often considerable uncertainty about where oil and gas accumulations occur (e.g., Gautier *et al.* 2009). Even if spatially explicit examples of where development might occur are presented, they might only represent one scenario of how development could proceed. Considering a range of possible scenarios allows for consideration of plausible futures and their uncertainty, and provides the basis for quantifying the potential impact to natural resources.

It is equally important to consider spatial variation in wildlife habitat and wildlife response to disturbance. For example, caribou have shown both greater habitat

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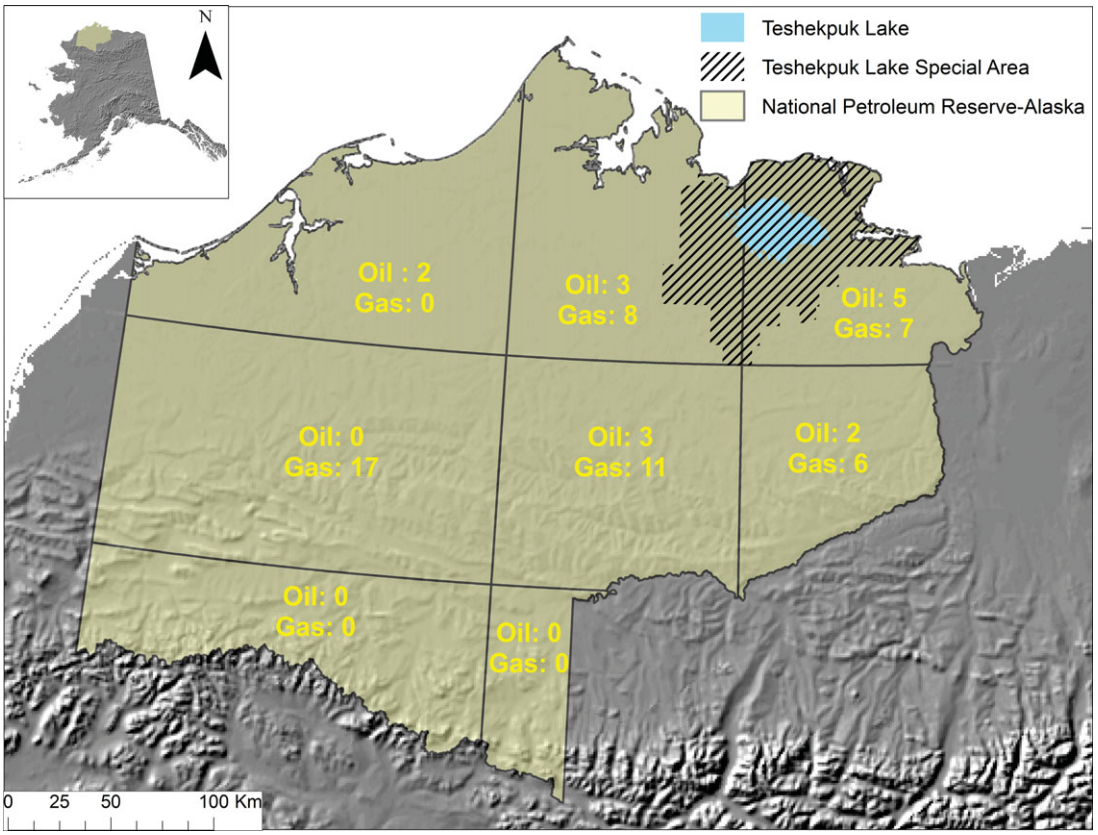


**Figure 1** Location of the National Petroleum Reserve-Alaska (NPRA) within Alaska. Borders of Economic Zones within the NPRA are depicted and labeled with the number of oil and gas accumulations expected to be economically viable to develop if the entire reserve were open to development. The Teshekpuk Lake Special Area depicted with hash marks. Accumulation data are from Attanasi & Freeman (2011).

selectivity (Wilson *et al.* 2012) and greater disturbance response (Cameron *et al.* 2005) during the calving season. Small-scale variation in landscape attributes can also lead to variation in where migratory birds choose to nest (Rodriguez 1994; Liebezeit *et al.* 2011) and nesting near industrial activity can lead to lower nest survival (Liebezeit *et al.* 2009). Modeling the cumulative effects of full-scale development (rather than a piecemeal assessment) on seasonal wildlife habitat is a potentially powerful tool to inform land-use planning and conservation (Johnson *et al.* 2005; Krausman 2011).

Here, we present an approach that obtains a range of oil and gas development scenarios to evaluate impacts on wildlife habitat in a proposed land management plan. As a case study, we used the stipulations and assumptions for oil and gas exploration and development outlined in the National Petroleum Reserve-Alaska (NPRA) draft environmental impacts statement (DEIS, Bureau of Land Management 2012) to develop spatially explicit simulations of development. For each of the scenarios, we quantified the relative impacts to caribou calving habitat and passerine nest survival while accounting for uncertainty in where oil and gas resources may be developed.

## Methods

### National petroleum reserve-Alaska

The NPRA is located in northern Alaska (Figure 1) and is approximately 95,000 km$^2$. While initially established as a strategic oil reserve for the United States Navy in 1923, it is mandated to be managed to protect significant subsistence, recreational, fish and wildlife, and historical or scenic values (Federal Register 1977). The area provides globally important migratory bird habitat (King & Hodges 1979; Earnst *et al.* 2005; Andres *et al.* 2012), is home to two large caribou herds, and provides subsistence hunting opportunities for rural communities.

In 2012, the Bureau of Land Management released a DEIS that outlined four proposed management scenarios to guide where oil and gas exploration and development

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**Table 1** Differences in the level of development, and percent of areas open to development, simulated for each of the four management alternatives for the National Petroleum Reserve–Alaska. Under Alternative A, we assumed that areas with deferred leasing would be made available when the deferrals expired

| | Model Parameters | | |
|---|---|---|---|
| Alternative | No. Oil Accumulations | No. Gas Accumulations | Open to Leasing (%) |
| A | 15 | 32 | 57 |
| B | 8 | 24 | 48 |
| C | 15 | 46 | 76 |
| D | 15 | 49 | 100 |

can occur in the NPRA. In all scenarios, areas within the NPRA were designated with one of three levels of development allowed: (1) Available for leasing, allowing production facilities, roads, and pipelines, (2) Not available for leasing but allowing passage of roads and pipelines to connect production facilities on leased lands, and (3) Not available for leasing and no roads or pipelines allowed. Differences in how much area was designated under each of the three classes and locations of these designations were the primary differences between the four alternatives.

## Development simulation

The NPRA is partitioned into eight economic zones, with different amounts of economically recoverable oil and gas for each (Figure 1; Attanasi & Freeman 2011). Attanasi & Freeman (2011, p. 6) estimated the frequency of various sized accumulations of oil and gas (i.e., areas where oil and gas have pooled) in zones based on geologic data from the NPRA. They then determined what sized accumulations would be economically viable based on the future price of $180 per barrel of oil, and $9.33 per thousand cubic feet of gas (Bureau of Land Management 2012). The number of economically viable oil and gas accumulations estimated by Attanasi & Freeman (2011) represents the total number available to develop in the absence of land-use restrictions. Thus, to determine the number of oil and gas accumulations that could be developed under each proposed scenario, we multiplied the total number of accumulations by the proportion of each economic zone available for leasing under each scenario (Table 1; Bureau of Land Management 2012). We assumed that areas with deferred leasing would be available when deferrals expired. We randomly selected locations of accumulations within economic zones, with the restrictions that they occur in areas allowing leasing, surface-occupancy, and were not in water. Further, we followed assumptions in the plan about how facilities would be developed (e.g., stand-alone, or joint production facilities connected by roads) and derived guidelines for distance between developments based on information in the DEIS (Table 2).

**Table 2** Minimum and maximum distances (km) used to simulate the location of oil and gas accumulations and production facilities within the Nation Petroleum Reserve-Alaska

| | Oil | | Gas | |
|---|---|---|---|---|
| Parameter | Min | Max | Min | Max |
| Distance between accumulations | 32.2 | NA | 16.1 | NA |
| Distance between pads in joint production facilities | 14.5 | 22.5 | 1.6 | 6.4 |

Locations of roads connecting pads within a simulated development were determined by least cost paths between pads using the "gdistance" package for R (van Etten 2011) and by developing a "cost map" based on the stipulations for facility design and construction and land use restrictions (Bureau of Land Management 2012). Where there were no land use restrictions, a cost map pixel was given a value of 1. Where roads were not allowed, pixels were given a value of 0. Because of the high cost of building roads across water, but the need to sometimes build bridges, we assigned water bodies a value of 0.05. Where a stipulation could be relaxed (e.g., Bureau of Land Management [2012, p. 59]), we classified the pixel as 0.10.

We built a development simulation model in R (R Development Core Team 2012) to randomly place accumulations across the landscape and build out industrial footprints. For each alternative we ran 100 iterations of the model to account for the uncertainty in where oil and gas accumulations might be discovered. The only components that remained constant between simulations were the underlying stipulations of where development could occur and the potential roads connecting already discovered oil and gas accumulations in northeastern NPRA (Bureau of Land Management 2012). We ensured that 100 iterations were sufficient to capture variability for each alternative by ensuring that the coefficient of variation reached an asymptote.

## Caribou disturbance

We integrated a map of caribou calving habitat values (Figure 2A; Wilson *et al.* 2012) and a disturbance function into the development model to estimate the potential loss of habitat from development under each development alternative. Previous research in northern Alaska has documented a displacement of female caribou with calves $\leq$4 km from oil development during the calving season (Cameron *et al.* 2005). Cameron *et al.* (2005) measured

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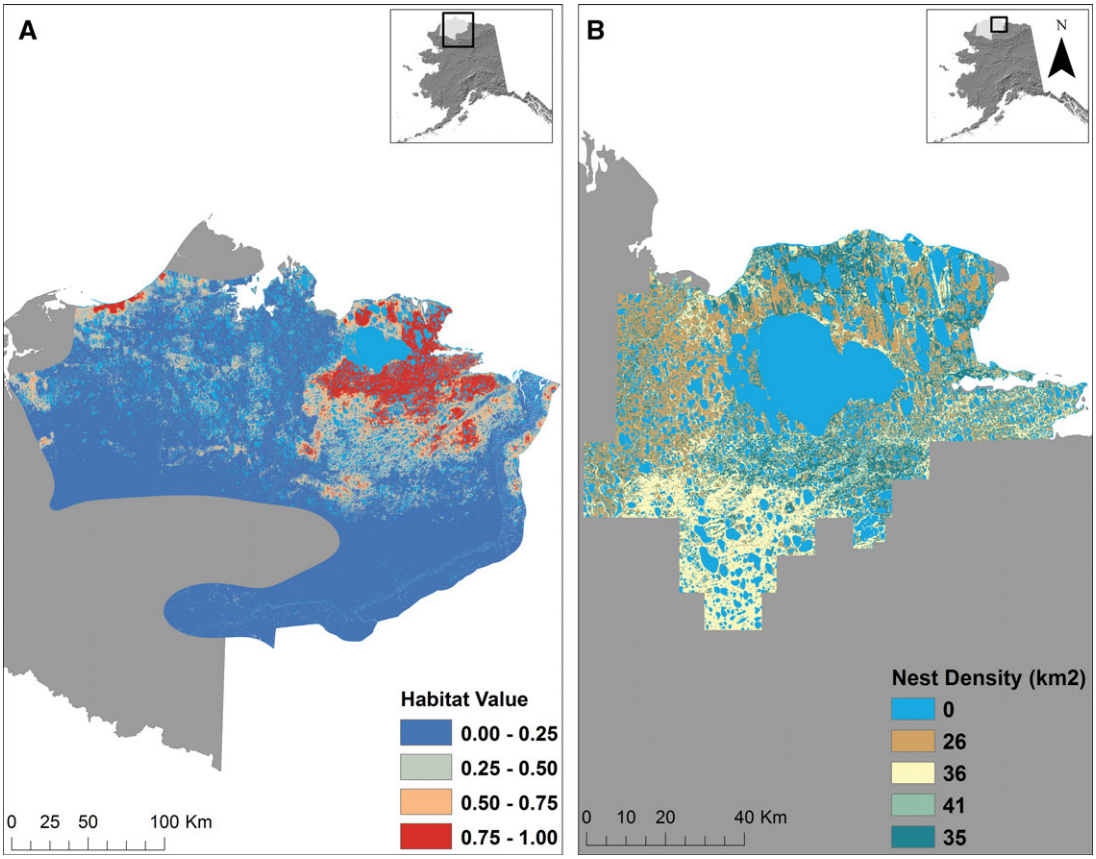


**Figure 2** Habitat maps used for discounting (A) caribou calving habitat and (B) average passerine nest density (nests km$^{-2}$) for four vegetation classes (flooded tundra: 26, wet tundra: 36, sedge meadow: 41, upland tundra: 35) and water (0) in relation to distance from simulated infrastructure.

the fractional reduction (pre and post development) in use by caribou calves within four distance bins (i.e., 0–1, 1–2, 2–3, and 3–4 km). From these data, we calculated a logistic curve for the proportional reduction in use as a function of distance from simulated development, outwards to 4 km:

$$w(x) = \frac{\exp(-2.974 + 1.079 \times x)}{1 + \exp(-2.974 + 1.079 \times x)}$$

To ensure that areas beyond 4 km had no reduction in use, we scaled $w(x)$ by $w(4)$ (i.e., $w(x)/\ w(4)$). As an underlying map of habitat value during calving, we used the results of a resource selection function (RSF) quantifying the relative probability of use for parturient females in the Teshekpuk Herd during calving (1–15 Jun) from data spanning 2004–2010 (120 m resolution; Wilson *et al.* 2012). We overlaid the simulated roads and production facilities onto the RSF map and discounted pixel values based on the minimum distance to any simulated infrastructure and the logistic function detailed earlier. We then determined the number of RSF map pixels remaining having a high relative probability of use (>0.75) similar to Johnson *et al.* (2005).

## Passerine disturbance

To determine the potential impact to passerine nest survival of oil and gas development, we simulated nests across the study area based on empirical studies of passerine nest density in the Teshekpuk Lake Special Area (Figure 1). Between 2005 and 2011, two sites within the Teshekpuk Lake Special Area were systematically searched for passerine nests (Liebezeit *et al.* 2011, J. Liebezeit unpublished data). We used nest locations and a vegetation map of the area (Bureau of Land Management & Ducks Unlimited, Inc. 2002) to obtain vegetation-specific estimates of passerine nest density across years (Figure 2B). There were originally 13 vegetation classes in the Teshekpuk Special Area, but we consolidated them into four: flooded tundra, wet tundra, sedge meadow, and upland tundra. Each pixel (30 m resolution) of the vegetation map received a unique nest density drawn

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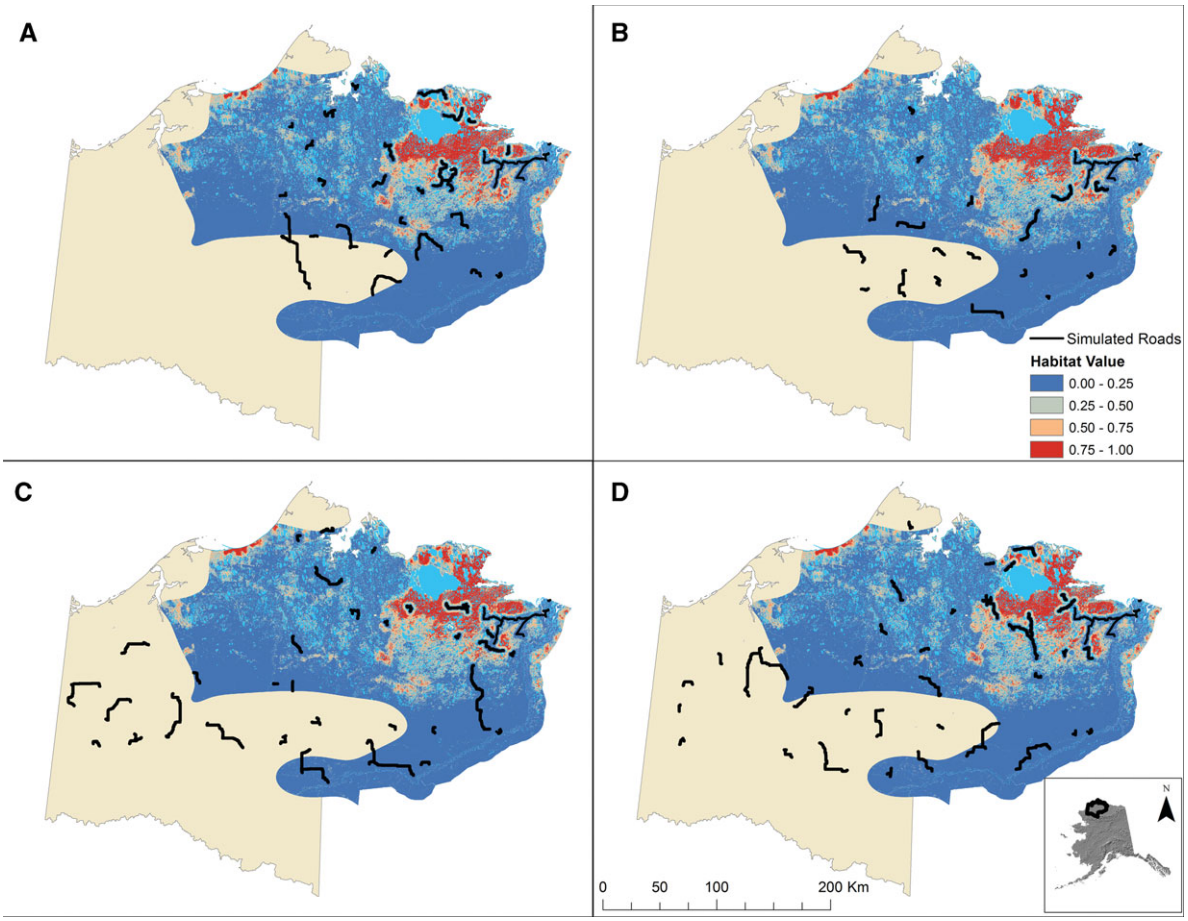


**Figure 3** Example of road networks simulated under each of four management alternatives (A–D) outlined for the National Petroleum Reserve-Alaska. Each map shows the underlying calving habitat value estimated for the Teshekpuk Caribou Herd discounted based on the area's proximity to simulated roads. Each map represents one realization from 100 simulations obtained for each management alternative.

from a random distribution with mean and standard deviation (across years 2005–2011) specific to the vegetation type of the pixel: flooded tundra (26.3 ± 11.4), wet tundra (36.0 ± 13.4), sedge meadow (41.0 ± 9.3), and upland tundra (34.9 ± 28.0). We used these values to simulate spatially explicit passerine nests across the study area with an Inhomogeneous Poisson Process (Schabenberger & Gotway 2005) using the "rpoispp" function in the "spatstat" package (Baddeley & Turner 2005).

We initially assigned all simulated nests an 80% probability of survival based on the annual estimated passerine nest survival around Teshekpuk Lake in the absence of industrial development (Liebezeit *et al.* 2009). Passerine nest survival was shown, however, to decrease within 5 km of oil and gas production facilities in northern Alaska (Liebezeit *et al.* 2009). Thus, we used the logistic equation from Liebezeit *et al.* (2009, p. 1637) to proportionately reduce a nest's baselines survival given its proximity to simulated production facilities. In addition, if a nest was located on a simulated road, or within the boundary of a production facility, we gave it a 0% probability of survival. We then performed a Bernouli trial for each nest, based on its probability of survival, to determine the number of nests surviving a given year in the presence of simulated industrial infrastructure.

## Results

### Development simulations

There were significant differences in the size of simulated footprints between the different management alternatives (Table 3; Figure 3). Alternative D had the largest simulated footprints, although Alternative C did not differ significantly from D. Alternative D also had the greatest footprint for all infrastructure types. Conversely, Alternative B had the smallest overall footprint, but did not differ significantly from Alternative A due to restricted leasing

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**Table 3** Results from 100 model runs for each of four management alternatives for the National Petroleum Reserve-Alaska. Means and 95% Confidence Intervals (C.I.) are presented for the footprint size of simulated gas pads, oil pads, roads, and all infrastructure summed

| | Management Alternative | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | | B | | C | | D | |
| Infrastructure | $\bar{x}$ | 95% C.I. | $\bar{x}$ | 95% C.I. | $\bar{x}$ | 95% C.I. | $\bar{x}$ | 95% C.I. |
| Gas Pads ($km^2$) | 3.7 | 3.1–4.2 | 6.8 | 5.6–7.9 | 10.5 | 9.3–11.9 | 11.7 | 10.3–13.1 |
| Oil Pads[a] ($km^2$) | 2.4 | NA | 1.9 | NA | 4.0 | NA | 4.2 | NA |
| Roads (km) | 700 | 600–818 | 527 | 460–613 | 980 | 820–1148 | 1037 | 934–1157 |
| Total Footprint[b] ($km^2$) | 20.1 | 18.5–22.5 | 19.3 | 18.1–20.3 | 32.6 | 29.9–35.5 | 35.1 | 33.5–36.8 |

[a]The number of oil pads per oil accumulation remained fixed, so there was no variability in their overall footprints across runs.
[b]Assumes roads are 0.02 km wide.

in the southwest section of the reserve. In addition, Alternative B had the smallest footprints for each of the infrastructure types across alternatives, except for gas pads, which were significantly lower under Alternative A.

### Caribou disturbance

Prior to any simulated development, 3,200 $km^2$ of high value calving habitat was available. Of the four alternatives (Figure 3), Alternative B conserved on average (95% CI), 91% (89–93%) of high value calving habitat after simulated oil and gas development. This was significantly greater than that observed under any of the other three alternatives (Figure 4), with the Alternative D having as low as 66% of high value habitat remaining after development.

### Passerine disturbance

An average of 127,027 (SD = 373) passerine nests survived within the Teshekpuk Lake Special Area during each model iteration before simulated development. There were significant differences in the percent of nests that survived between development scenarios (Figure 4). The number of nests lost annually under Alternative B did not differ significantly from the number lost annually in the absence of development and was less than any other management alternative (Figure 4). The remaining alternatives did not differ from each other in the number of nests lost annually, but all were significantly greater than in the absence of infrastructure (Figure 4).

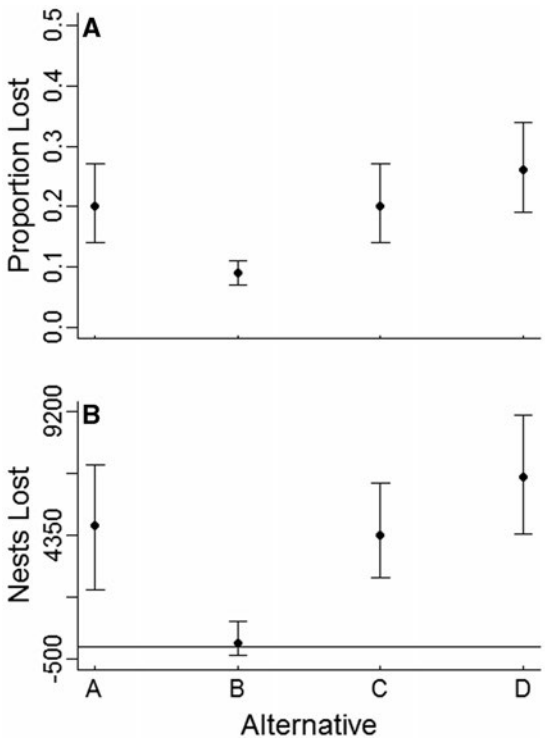


**Figure 4** Estimated differences in the proportion (± 95% C.I.) of caribou calving habitat lost (A) and the number of passerine nests lost (B) between each of four management alternatives for the National Petroleum Reserve-Alaska. For the number of passerine nests lost (B), the number represents the difference in nests lost compared to if no infrastructure was simulated, represented by the solid line in the graph.

## Discussion

Techniques to model the potential impacts of future energy development on wildlife populations are uncommon (Copeland *et al*. 2009) even though they can be severe (Festa-Bianchet *et al*. 2011; Gilbert & Chalfoun 2011; Beckmann *et al*. 2012). We developed a flexible model to quantify potential impacts of development on wildlife when the actual location of development is unknown. Integration of a stochastic development model with existing habitat value maps allowed us do this for calving caribou and nesting birds in NPRA. We were able to

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objectively compare management alternatives in a reproducible methodology that is flexible enough to accommodate multiple species and various demographic metrics simultaneously.

Our analysis revealed that oil and gas development under Alternative D (the most development intensive) could diminish high value calving habitat for the Teshekpuk herd by >30% and cause a loss of >9,000 passerine nests annually. Conversely, under Alternative B, >50% of the NPRA would remain available for oil and gas development but would limit further losses of caribou calving habitat beyond the 6% lost developing existing leases with oil and gas discoveries. The variability in estimates of nest survival and habitat loss for each alternative highlight the importance of our stochastic approach. Variability between iterations was largely driven by where the oil and gas accumulations were simulated (Figures S1–S4), and the underlying habitat value at those sites. The similar level of impacts to wildlife under Alternatives A and C, resulted from the main areas off-limits to development in A not overlapping with the habitat maps used for analysis.

With large increases in energy development projected in the coming decades (McDonald *et al*. 2009), it is important that we determine how large an impact this will have on wildlife populations (Bayne & Dale 2011). Our modeling approach allowed us to better anticipate how populations might be affected. We should note that our results for nest survival did not account for changes in nest density as a function of distance to infrastructure. This could potentially reduce the impact we estimated if birds nested successfully away from infrastructure. We are unaware, however, of any published research in northern Alaska suggesting such a change in density in areas adjacent to infrastructure but a study in northern Canada (Smith *et al*. 2005) found limited changes to ground-nesting bird density within 1 km a diamond mine. We believe our results reflect a reasonable outcome of potential development but more complex simulations of nest density could be included in future models if sufficient information is available. For caribou, our results for caribou are not directly relatable to population-level impacts, but are precautionary based on previously documented reductions in survival and recruitment when females are displaced from calving grounds (Cameron *et al*. 2005). If our results were combined with information on thresholds of habitat loss required to see population effects from development (e.g., Sorensen *et al*. 2008), we could produce similar population-level impacts for caribou.

There is currently a vast literature on designing reserve networks to meet conservation and economic objectives (Kiesecker *et al*. 2010; Smith *et al*. 2010; Delavenne *et al*. 2012). Development of management alternatives for the NPRA could have been guided by conservation planning algorithms such as MARXAN (Ball *et al*. 2009) or ZONATION (Moilanen *et al*. 2009), however, the Bureau of Land Management used their knowledge of wildlife habitat, oil and gas, and public comments to derive the alternatives. Since our goal was to evaluate how these management alternatives would impact wildlife habitat and account for uncertainty in where oil and gas might be developed, we chose to use methods more similar to Copeland *et al*. (2009).

In their study, Copeland *et al*. (2009) estimated which areas of the landscape had the highest probability of oil and gas and used this to simulate pads across the landscape at two different levels of development to provide a range of impacts to sage-grouse (*Centrocercus urophasianus*). They did not take a stochastic approach but instead produced a deterministic model that placed well pads sequentially from the area with the highest estimated potential for oil and gas to the next highest, and so on, until the anticipated level development was simulated. This was an important step in helping land managers to anticipate development impacts on wildlife but missed important information on the range of possible impacts. This is a key difference with our study and we believe that accounting for uncertainty in the location of future development is necessary when attempting to compare the relative impacts to wildlife of various management plans.

A stochastic approach is also important when one considers that the probability of an accumulation being developed is dependent on an accumulation's size and its proximity to other accumulations and existing infrastructure (Powell 1991). Given that there is uncertainty where accumulations are located on the landscape (Gautier *et al*. 2009), it would be impossible to represent the level of disturbance from only one realization. In addition, the spatial distribution of oil and gas accumulations can affect the type of drilling operation employed. This not only affects the size of development footprint, but potentially the impacts to wildlife (Sawyer *et al*. 2009).

We relied on assumptions presented in the NPRA DEIS (Bureau of Land Management 2012) for this analysis, but the model framework can be easily modified to accommodate more detailed assumptions. For example, the NPRA DEIS assumed that oil and gas accumulations were equally probable across an economic zone. Accumulations, however, are probably spatially correlated. The model could easily be modified by simulating the locations of oil and gas accumulations as inhomogeneous point patterns with varying degrees of autocorrelation. In the future, this stochastic model could be used to quantify impacts to other natural and cultural values such as

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the loss of area for subsistence hunters who are deterred by the presence of industrial infrastructure (National Research Council 2003). Additional variables could be included to provide more comprehensive cumulative effects analysis, including aircraft over-flights, ports, and landscape response to climate change. Overall, we believe this is a unique approach for assessing the range of potential impacts on wildlife habitat from an uncertain future of oil and gas development.

## Acknowledgments

We thank D. Yokel, M. Smith, and N. Walker for providing insightful discussion prior to developing the model. K. Pietrzak and many other field assistants help collect nesting data. Funding was provided by grants from the Wilburforce Foundation, the Neotropical Migratory Bird Conservation Act (U.S. Fish and Wildlife Service), the Liz Claiborne/Art Ortenberg Foundation, Alaska Department of Fish and Game, the Bureau of Land Management, the National Fish and Wildlife Foundation, and the Disney Wildlife Conservation Fund. We thank R. Suydam at the North Slope Borough for logistic support and A. Bontrager for GIS assistance.

## Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

**Figure S1.** Examples of simulated road networks for Alternative A, representing various levels of impact from 100 iterations: (A) scenario with highest impact, (B) scenario with impact at the 66% quantile, (C) scenario with impact at the 33% quantile, (D) scenario with lowest impact. Each map shows the underlying calving habitat value estimated for the Teshekpuk Caribou Herd discounted based on the area's proximity to simulated roads.

**Figure S2.** Examples of simulated road networks for Alternative B, representing various levels of impact from 100 iterations: (A) scenario with highest impact, (B) scenario with impact at the 66% quantile, (C) scenario with impact at the 33% quantile, (D) scenario with lowest impact. Each map shows the underlying calving habitat value estimated for the Teshekpuk Caribou Herd discounted based on the area's proximity to simulated roads.

**Figure S3.** Examples of simulated road networks for Alternative C, representing various levels of impact from 100 iterations: (A) scenario with highest impact, (B) scenario with impact at the 66% quantile, (C) scenario with impact at the 33% quantile, (D) scenario with lowest impact. Each map shows the underlying calving habitat value estimated for the Teshekpuk Caribou Herd discounted based on the area's proximity to simulated roads.

**Figure S4.** Examples of simulated road networks for Alternative D, representing various levels of impact from 100 iterations: (A) scenario with highest impact, (B) scenario with impact at the 66% quantile, (C) scenario with impact at the 33% quantile, (D) scenario with lowest impact. Each map shows the underlying calving habitat value estimated for the Teshekpuk Caribou Herd discounted based on the area's proximity to simulated roads.

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