

# Wildlife winners and losers in an oil sands landscape

Jason T Fisher<sup>1,2\*</sup> and A Cole Burton<sup>1†</sup>

Energy development and consumption drive changes in global climate, landscapes, and biodiversity. The oil sands of western Canada are an epicenter of oil production, creating landscapes without current or historical analogs. Science and policy often focus on pipelines and species-at-risk declines, but we hypothesized that differential responses to anthropogenic disturbances shift the entire mammal community. Analysis of data collected from 3 years of camera trapping and species distribution models indicated that anthropogenic features best explained the distributions of the ten mammal species included in the study. Relative abundances of some mammals were positively correlated with anthropogenic feature density, and others were negatively correlated. Effect sizes were often larger than for natural features. Increasing anthropogenic spatial complexity, access to multiple habitats, and new forage sources favor generalist predators and browsers, to the detriment of specialists, likely altering ecological processes. This issue has far-reaching implications: as the oil sands landscape changes so too does its mammal community, serving as a bellwether of future change for energy landscapes worldwide.

*Front Ecol Environ* 2018; 16(6): 323–328, doi: 10.1002/fee.1807

**A**nthropogenic changes to the quantity, structure, and distribution of native vegetation communities (“landscape change”) eclipse even climate change as an immediate stressor on biodiversity (Maxwell *et al.* 2016). Anthropogenic activities leading to landscape change are often economically important (Czech *et al.* 2000) and therefore politically popular. Among these, oil extraction ranks as a major activity fueling modern economies, but is also driving much of the global change in climate, landscapes, and biodiversity. In North America, oil pipeline development projects, such as Dakota Access and Keystone XL, are at the front lines of disagreements over issues pertaining to social change and conservation (Green *et al.* 2017). Canada’s oil sands, which rank among the world’s largest hydrocarbon deposits, are the headwaters of these “rivers of oil”, and are therefore the epicenter of much debate. They represent a key component of the Canadian and global economy, and are a major issue in North American geopolitics (Bayoumi and Mhleisen 2006).

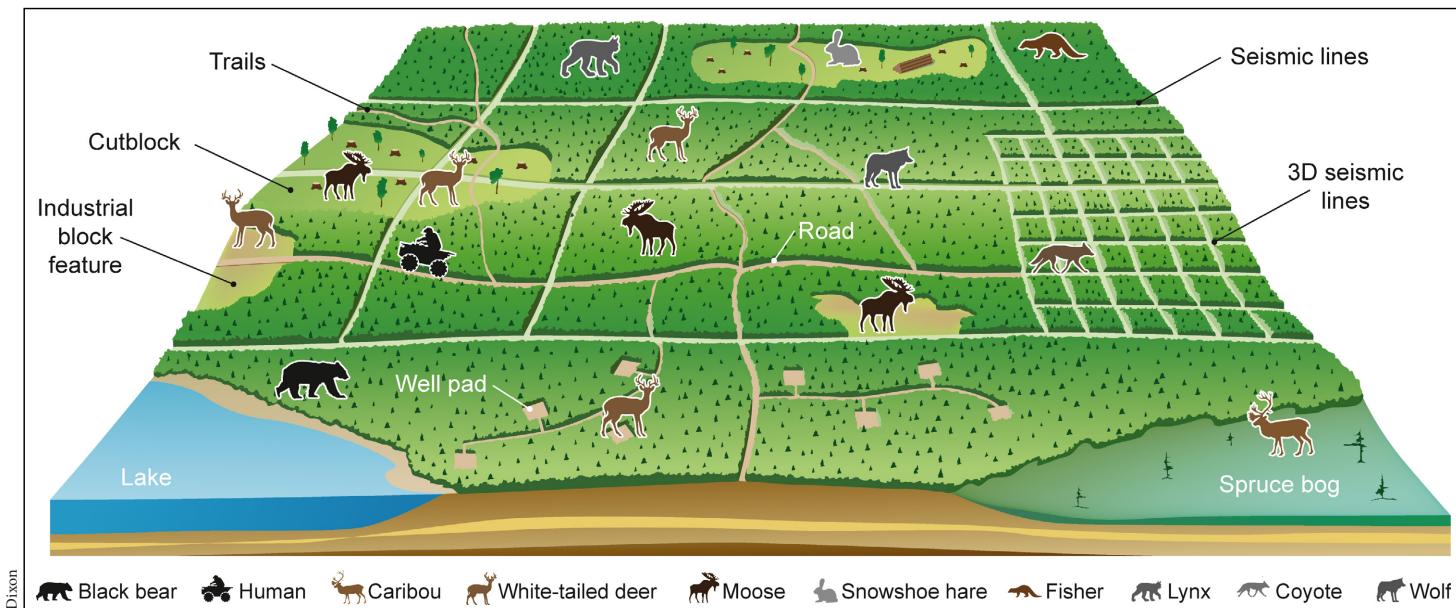
Although open-pit bitumen mines are an oil sands icon, they are relatively small compared to the footprint of in-situ drilling, which spans most of northern Alberta and parts of British Columbia and Saskatchewan. This footprint includes long linear petroleum exploration (“seismic”) lines; intensively clustered, crossed three-dimensional (3D) seismic lines; well sites; and polygonal industrial features (Figure 1). Petroleum extraction, timber harvesting, and road infrastructure have cumulatively and rapidly increased disturbance rates in Canada’s boreal forests. Spatial disturbance patterns are now well outside the

historical range of natural variation (Pickell *et al.* 2015), and, for the time being at least, are without global analogs. As demand for oil continues, consumers will increasingly rely upon unconventional oil sources (Rosa *et al.* 2017); as such, the impacts of oil extraction in the Canadian oil sands will soon occur with greater frequency elsewhere around the globe.

Landscape disturbance is typically synonymous with habitat loss and fragmentation, with well-known impacts on species diversity (Tscharntke *et al.* 2012). In the oil sands, seismic lines and other linear features are implicated in dramatic and persistent declines in woodland caribou (*Rangifer tarandus caribou*) populations through a complex of direct and indirect effects (Hebblewhite 2017). Expanding white-tailed deer (*Odocoileus virginianus*) populations exploit the conversion of mature forest to early seral vegetation, and rising deer populations support growing gray wolf (*Canis lupus*) populations; similarly, seismic lines facilitate caribou predation (Boutin *et al.* 2012). However, we contend that this story does not end with caribou predators and shared prey. Landscape disturbance affects the population sizes, distributions, and persistence of many species in myriad and complex ways (Tscharntke *et al.* 2012). Differential responses to disturbance allow populations of some species to increase (or invade) whereas others decrease; the ranges of some species shrink while others expand. Many modern North American mammal distributions are artifacts of human land-use patterns integrated over the past two centuries (Laliberte and Ripple 2004). However, the northern boreal forest has been extensively disturbed only in the past two decades, producing an opportunity to examine large-scale spatial distributions of multiple mammal species in response to rapid, contemporary, and spatially extensive landscape change (Pickell *et al.* 2015).

We hypothesized that seismic lines, roads, and trails increase access to dense forest for multiple carnivores in addition to

<sup>1</sup>InnoTech Alberta, Vegreville, Canada; <sup>2</sup>University of Victoria, School of Environmental Studies, Victoria, Canada \*([fisherj@uvic.ca](mailto:fisherj@uvic.ca)); <sup>†</sup>current address: University of British Columbia, Department of Forest Resources Management, Forest Sciences Centre, Vancouver, Canada



**Figure 1.** Anthropogenic features are expected to affect the suite of mammal species in Alberta's boreal forest, based on known habitat associations. Large and small herbivores benefit from early seral vegetation in cutblocks, and perhaps also in industrial block features and well sites. Predators use linear features such as seismic lines for travel, but may avoid active road networks due to mortality risk. These hypothesized relationships overlay habitat associations with natural landscape features (upland and lowland forest, water, and bogs).

wolves (McKenzie *et al.* 2012). Juxtaposing thousands of small, early seral patches – oil well sites, harvested forest patches (cut-blocks), and industrial block features (areas of cleared mature forest now vegetated with young trees, shrubs, grasses, or forbs) – within a mature forest matrix provides forage subsidies for multiple herbivores (Fisher and Wilkinson 2005). The expected outcomes for other species are less clear, but we hypothesized that the shifting vegetation communities, successional trajectories, and spatial configuration of this industrializing landscape will manifest as broad-scale spatial patterns, and that anthropogenic features play primary roles in determining the geographic distributions of all mammal species in the region. We tested these hypotheses using camera trapping (Steenweg *et al.* 2017) in the boreal forest of northeastern Alberta (WebFigure 1) and species distribution models. We assessed the influence of natural and anthropogenic features (Figure 2; WebVideo 1) on the distribution of ten mammal species, representing most of the larger mammal community in the Canadian boreal forest (Figure 3; WebFigure 2): gray wolf, white-tailed deer, moose (*Alces alces*), American black bear (*Ursus americanus*), coyote (*Canis latrans*), Canada lynx (*Lynx canadensis*), fisher (*Pekania pennanti*), red fox (*Vulpes vulpes*), snowshoe hare (*Lepus americanus*), and American red squirrel (*Tamiasciurus hudsonicus*).

## Methods

The boreal forest northeast of Lac La Biche, Alberta, Canada (WebFigure 1), is composed primarily of white spruce (*Picea glauca*), black spruce (*Picea mariana*), and aspen (*Populus tremuloides*). There are roads, trails (accessible to off-road

vehicles), petroleum exploration and extraction, extensive forestry, and other types of development throughout the study area (WebVideo 1). We selected a 3000-km<sup>2</sup> landscape within the oil sands region that contained all of the anthropogenic features representative of these resource extraction sectors, as well as natural heterogeneity representative of the boreal forest of northeastern Alberta (WebFigure 1; WebVideo 1).

## Sampling design

Inferences from species distribution models vary among landscapes (Fisher *et al.* 2005). To provide a broad inference space, we adopted a stratified random design based on reclassified digital forest inventory (AVI) data (WebTable 1). In ARCGIS 10.2 Spatial Analyst (ESRI Inc, Redlands, CA) we imposed a 1-km × 1-km cell grid and randomly selected grid cells (a minimum of 2 km apart) within strata defined by canopy cover, tree species, and topography. In each cell, we selected a sampling site on active game trails to maximize detection probability, with one unbaited Reconyx PC900 Hyperfire infrared remote digital camera (Holmen, WI) deployed at each sampling site. "Site" was defined as the area of the camera detection zone used by a species during the survey; "study area" was defined as the ~3000-km<sup>2</sup> minimum convex polygon around all of the camera sites (Burton *et al.* 2015). We sampled 62 sites in total from October 2011–October 2014.

## Landscape analysis

We quantified percentage cover of (1) natural landscape patches, derived from AVI data; (2) polygonal anthropogenic

features (forest harvest cutblocks, well sites, industrial sites, and mines) from the Alberta Biodiversity Monitoring Institute (ABMI) 2010 Human Footprint Map Ver 1.1; and (3) linear features buffered to create polygons from polylines (seismic lines, roads, and trails) from a 2012 ABMI linear features layer based on manual interpretation of *Satellite Probatoire d'Observation de la Terre* (SPOT) imagery (WebTable 1). Landscape data were static; although disturbances continued throughout the study period, the degree of site-specific change was marginal.

We used variance inflation estimation to explore data (Zuur *et al.* 2007, 2010) and omitted correlated variables ( $r > 0.7$ , variance inflation factor [VIF]  $> 3$ ). Our effective design retained almost all variables; we combined sparse features (<1–2% of area) into single variables (WebTable 1) and rescaled each (mean = 0, standard deviation = 1) to compare effect sizes.

### Statistical analysis

The 60,937 trap-days yielded 164,519 photographs, from which we visually identified 141,140 images containing animals. From these continuous data, we calculated a proportional binomial response variable (Zuur *et al.* 2007) in which the species was detected (1) or not (0) monthly, prorated for camera failures ( $>0.5$  month) or winter hibernation (black bear, December–March). This “occurrence frequency” variable measured the number of months (0–36) a site supported a species, minimized the temporal heterogeneity imposed by frequent animal movements at a site during a month, and assumed that sites with more resources (and less risk) are more frequently used. We assumed zero detections to be true zeros in this case and opted against dynamic occupancy models, which seek to estimate the proportion of zeros that result from imperfect detections (MacKenzie *et al.* 2003); these assume closure within surveys and can conflate missed detections with temporary emigration from study sites (common for vagile mammals), treating each as error (Efford and Dawson 2012). Variability in occurrence frequency is due (in part) to movement and temporary emigration from the site (Neilson *et al.* 2018), but this was the very signal we wanted to measure in order to test our hypotheses (Burton *et al.* 2015), and more closely correlates with density than does occupancy (Parsons *et al.* 2017).

Species distribution models assume that use of a site by a species is related to surrounding landscape features, but the extent of this area is unknown. As per the methodology described in Fisher *et al.* (2011), we quantified landscapes at 20 spatial scales consisting of circular buffers ranging from 250 m to 5000 m in radius, in 250-m increments. At each scale we modeled each species’ occurrence frequency against all landscape features using generalized linear models (binomial errors, logit link) in R v3.2.2. Models included additive linear effects for all non-correlated predictor variables. We reduced this global model with the step-AIC function in R package “MASS” (Ripley *et al.* 2013), which ranks models’ Akaike



**Figure 2.** Anthropogenic features are densely distributed across the study area landscape, as illustrated by a 3D visualization. Well sites are small gray squares, block features are center bottom and top, cross-hatched lines are 3D seismic lines, long lines are traditional seismic lines and roads, and irregular polygons are cutblocks.

information criterion (AIC) scores (Burnham and Anderson 2002) to produce the most parsimonious, best-supported model at the best-supported spatial scale (WebFigure 3). We tested for overdispersion, and calculated model deviance explained. We used 10-fold cross-validation in R package “boot” (Canty and Ripley 2012) to assess model fit. For each species we calculated mean parameter estimates of anthropogenic variables, with net directionality an indicator of “winners and losers”.

### Results

The influence of anthropogenic disturbance was pervasive across the entire mammal community in this region (Figure 4), and variables describing anthropogenic landscape features were retained in best-supported models for all of the mammal species included in the study (WebTables 1 and 2). Notably, 3D seismic lines – pervasive features in oil sands landscapes – were retained in top models for eight of the 10 species, more than any natural land-cover feature (Figure 4). Block features and trails (linear features accessible by off-road vehicles) explained as many species’ distributions as did the most dominant natural land covers.

The mean effect sizes of anthropogenic variables on species distributions rivaled or exceeded those of natural land-cover variables (Figure 4). The direction and magnitude of these effects demonstrated marked variation in responses across species and footprints (Figure 4); for instance, strong positive associations between occurrence frequency and industrial block features were detected for four species, whereas three species showed strong negative associations with 3D seismic lines. In general, large herbivore distributions were positively



**Figure 3.** We used camera traps to survey the relative abundance of ten boreal mammal species, including (a) black bear (*Ursus americanus*), (b) gray wolf (*Canis lupus*), (c) white-tailed deer (*Odocoileus virginianus*), and (d) moose (*Alces alces*).

related to disturbance patches providing early seral forage subsidies and negatively related to linear features. Large canids were positively related to linear features, although roads were avoided by wolf but selected by coyote. Mixed positive and negative responses were found for black bear, lynx, fisher, fox, hare, and squirrel (WebTable 2).

Mean parameter estimates for anthropogenic variables – interpretable as mean change in species occurrence frequency per unit change in proportion of anthropogenic disturbance – varied in directionality among species (WebTable 2). White-tailed deer exhibited a net positive mean response, whereas moose showed a net negative response, and small herbivores had a net positive response. Among carnivores, wolf, coyote, and lynx showed positive responses, but black bear, fox, and fisher showed net negative responses to disturbance.

## Conclusions

Landscape disturbances create “winners and losers” (McKinney and Lockwood 1999) among the entire oil sands mammal community. Disturbances in this region lead to increasing white-tailed deer populations at the expense of moose, and an increase in the abundances of large canids (ie wolf and coyote) and Canada lynx with a concomitant reduction in black bear, red fox, and fisher populations. Differing responses within the community are due to varying responses to linear features and conversion of mature forest to early seral vegetation.

The widespread intrusion of permeating linear features into a forest matrix – predicted by connectivity theory (Taylor *et al.* 1993) to affect landscape function and biodiversity – affects

the entire boreal mammal community. Linear features increase connectivity for wolf populations, facilitating their predation on caribou (McKenzie *et al.* 2012), but our data suggest that multiple species exploit these features. In addition, the extremely high density of small polygonal features provides early seral forage subsidies; these are far more abundant and widespread than in natural boreal forests (Pickell *et al.* 2015), and are exploited by multiple herbivores (Fisher and Wilkinson 2005). We contend that the accumulation of hyper-connectivity and high-density resource subsidies have the potential to create synergistic, antagonistic, or additive effects (Côté *et al.* 2016) on the mammal community. Future research should be aimed at forming and testing hypotheses about these effects, to better understand the ecological mechanisms behind the broad spatial patterns we observed.

There is marked potential for complex indirect effects, as predator–prey and competitive interactions will likely be further altered by species’ differential responses to disturbance.

Spatially mediated predator–prey dynamics (Kareiva *et al.* 1990) and competition (Amarasekare 2003) may change with landscape disturbance, altering interspecific interactions within herbivore and carnivore guilds. Negative effects on top carnivores can trigger a mesopredator release and the possibility of trophic cascades (Terborgh and Estes 2010). Adaptable “winners”, such as coyote, may be released and gain a competitive edge over other mesopredators (eg fox, fisher) that “lose” in a developed landscape. Such dynamics within the predator guild are likely to interact with the dynamics of herbivore “winners and losers”, causing additive ecosystem changes. The observed correlations between mammal distributions and anthropogenic features do not necessarily imply causation; however, widespread correlation repeated across an entire community certainly does invite a search for, and test of, causality and the proximal mechanisms creating those patterns. Our research points solidly toward an emerging community-level shift in relative abundance and distribution, and a large-scale restructuring of spatial ecological processes.

The current policy and regulatory focus on mitigating species-at-risk declines in energy landscapes (Hebblewhite 2017) – and the societal debate focused on pipelines – falls short of recognizing that community change, as well as altered landscape function, is both an outcome and a cause of biodiversity loss. Conservation science should refocus to include a community approach. Moreover, broadening the global societal debate from pipelines and climate change to explicitly include the many energy landscapes at the headwaters of the “rivers of oil” is long overdue. The Canadian oil sands are currently distinctive in their rapid pace and the extent of the disturbance they are creating, but the economic advantages of

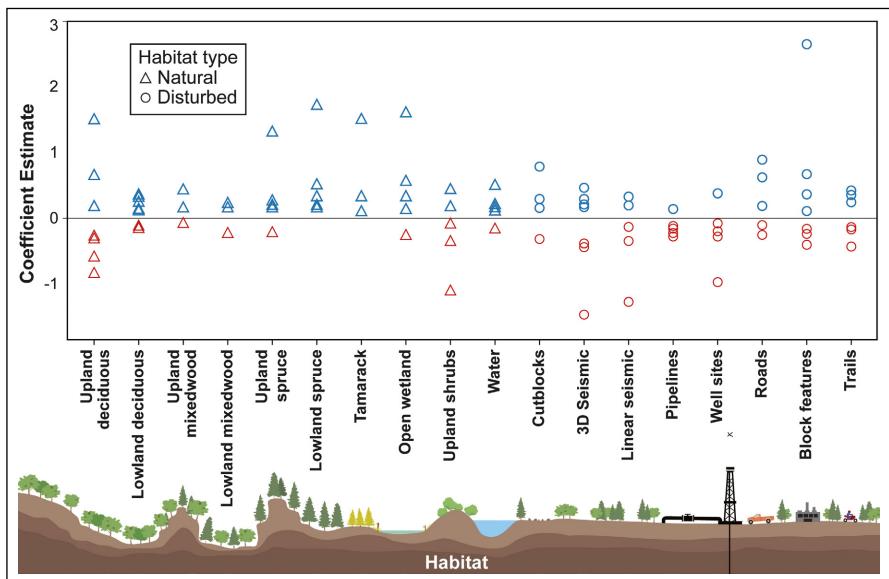
petroleum extraction are spurring global increases in extraction and deforestation (Rosa *et al.* 2017). The Canadian oil sands therefore provide an early warning: as oil and gas extraction continues to drive national and global economies, the biodiversity effects we observed are a precursor of the potential future of landscape change in unconventional petroleum regions around the globe. As world leaders contemplate continental-scale pipelines and international climate-change agreements (Rockström *et al.* 2017), the regional-scale impacts of oil sands development take on global relevance, and the future of boreal ecosystems hinges on global decisions.

## Acknowledgements

Research was conducted by InnoTech Alberta (IA), and funded by IA and Alberta Environment and Parks (AEP), the Petroleum Technology Alliance of Canada AUPRF, MEG Energy, and the Alberta Conservation Association. We thank M Hiltz, L Roy, L Nolan, S Melenka, S Heckbert, D Pan, B Eaton, K Richardson, K Tereschyn, S Eldridge, J Dennett, J Watkins, and T Zembal at IA, as well as B Maile, G Chapman, P MacMahon, C Dockrill, and K Norstrom (deceased) at AEP. JP Volpe, L Burke, N Ban, AC Fisher, C James, and FEC Stewart provided valuable comments.

## References

- Amarasekare P. 2003. Competitive coexistence in spatially structured environments: a synthesis. *Ecol Lett* **6**: 1109–22.
- Bayoumi T and Mhleisen M. 2006. Energy, the exchange rate, and the economy: macroeconomic benefits of Canada's oil sands production. Washington, DC: International Monetary Fund.
- Boutin S, Boyce MS, Hebblewhite M, *et al.* 2012. Why are caribou declining in the oil sands? *Front Ecol Environ* **10**: 65–67.
- Burnham KP and Anderson DR. 2002. Model selection and multi-model inference: a practical information-theoretic approach. Berlin, Germany: Springer-Verlag.
- Burton AC, Neilson E, Moreira D, *et al.* 2015. Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. *J Appl Ecol* **52**: 675–85.
- Canty A and Ripley B. 2012. Boot: Bootstrap R (S-Plus) functions. R package v1. Vienna, Austria: The R Foundation.
- Côté IM, Darling ES, and Brown CJ. 2016. Interactions among ecosystem stressors and their importance in conservation. *P Roy Soc Lond B Bio* **283**: 20152592.
- Czech B, Krausman PR, and Devers PK. 2000. Economic associations among causes of species endangerment in the United States. *BioScience* **50**: 593–601.
- Efford MG and Dawson DK. 2012. Occupancy in continuous habitat. *Ecosphere* **3**: art32.
- Fisher JT and Wilkinson L. 2005. The response of mammals to forest fire and timber harvest in the North American boreal forest. *Mammal Rev* **35**: 51–81.
- Fisher JT, Anholt B, and Volpe JP. 2011. Body mass explains characteristic scales of habitat selection in terrestrial mammals. *Ecol Evol* **1**: 517–28.
- Fisher JT, Boutin S, and Hannon SJ. 2005. The protean relationship between boreal forest landscape structure and red squirrel distribution at multiple spatial scales. *Landscape Ecol* **20**: 73–82.
- Green SJ, Demes K, Arbeider M, *et al.* 2017. Oil sands and the marine environment: current knowledge and future challenges. *Front Ecol Environ* **15**: 74–83.
- Hebblewhite M. 2017. Billion dollar boreal woodland caribou and the biodiversity impacts of the global oil and gas industry. *Biol Conserv* **206**: 102–11.
- Kareiva P, Mullen A, and Southwood R. 1990. Population dynamics in spatially complex environments: theory and data (and discussion). *Philos T Roy Soc B* **330**: 175–90.
- Laliberte AS and Ripple WJ. 2004. Range contractions of North American carnivores and ungulates. *BioScience* **54**: 123–38.
- MacKenzie DI, Nichols JD, Hines JE, *et al.* 2003. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology* **84**: 2200–07.
- Maxwell SL, Fuller RA, Brooks TM, *et al.* 2016. The ravages of guns, nets and bulldozers. *Nature* **536**: 143–45.
- McKenzie HW, Merrill EH, Spiteri RJ, *et al.* 2012. How linear features alter predator movement and the functional response. *Interface Focus* **2**: 205–16.
- McKinney ML and Lockwood JL. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends Ecol Evol* **14**: 450–53.



**Figure 4.** Estimated parameter coefficients (effect sizes) for the relationships between species relative abundances and landscape features, from species distribution models. Some species relationships were positive (blue) and others were negative (red) for both natural features (triangles) and anthropogenic features (circles). The number of plotted estimates is the number of mammal species for which a landscape feature significantly explained relative abundance.

- Neilson EW, Avgar T, Burton AC, *et al.* 2018. Animal movement affects interpretation of occupancy models from camera-trap surveys of unmarked animals. *Ecosphere* **9**: e02092.
- Parsons AW, Forrester T, McShea WJ, *et al.* 2017. Do occupancy or detection rates from camera traps reflect deer density? *J Mammal* **98**: 1547–57.
- Pickell PD, Andison DW, Coops NC, *et al.* 2015. The spatial patterns of anthropogenic disturbance in the western Canadian boreal forest following oil and gas development. *Can J Forest Res* **45**: 732–43.
- Ripley B, Venables B, Bates DM, *et al.* 2013. Package “MASS”. CRAN-R. Vienna, Austria: The R Foundation.
- Rockström J, Gaffney O, Rogelj J, *et al.* 2017. A roadmap for rapid decarbonization. *Science* **355**: 1269–71.
- Rosa L, Davis KF, Rulli MC, *et al.* 2017. Environmental consequences of oil production from oil sands. *Earth's Future* **5**: 158–70.
- Steenweg R, Hebblewhite M, Kays R, *et al.* 2017. Scaling-up camera traps: monitoring the planet's biodiversity with networks of remote sensors. *Front Ecol Environ* **15**: 26–34.
- Taylor PD, Fahrig L, Henein K, *et al.* 1993. Connectivity is a vital element of landscape structure. *Oikos* **68**: 571–73.
- Terborgh J and Estes JA. 2010. Trophic cascades: predators, prey, and the changing dynamics of nature. Washington, DC: Island Press.
- Tscharntke T, Tylianakis JM, Rand TA, *et al.* 2012. Landscape moderation of biodiversity patterns and processes – eight hypotheses. *Biol Rev Camb Philos* **87**: 661–85.
- Zuur A, Ieno EN, and Smith GM. 2007. Analysing ecological data. Berlin, Germany: Springer Science+Business Media.
- Zuur AF, Ieno EN, and Elphick CS. 2010. A protocol for data exploration to avoid common statistical problems. *Methods Ecol Evol* **1**: 3–14.

## ■ Supporting Information

Additional, web-only material may be found in the online version of this article at <http://onlinelibrary.wiley.com/doi/10.1002/fee.1807/suppinfo>

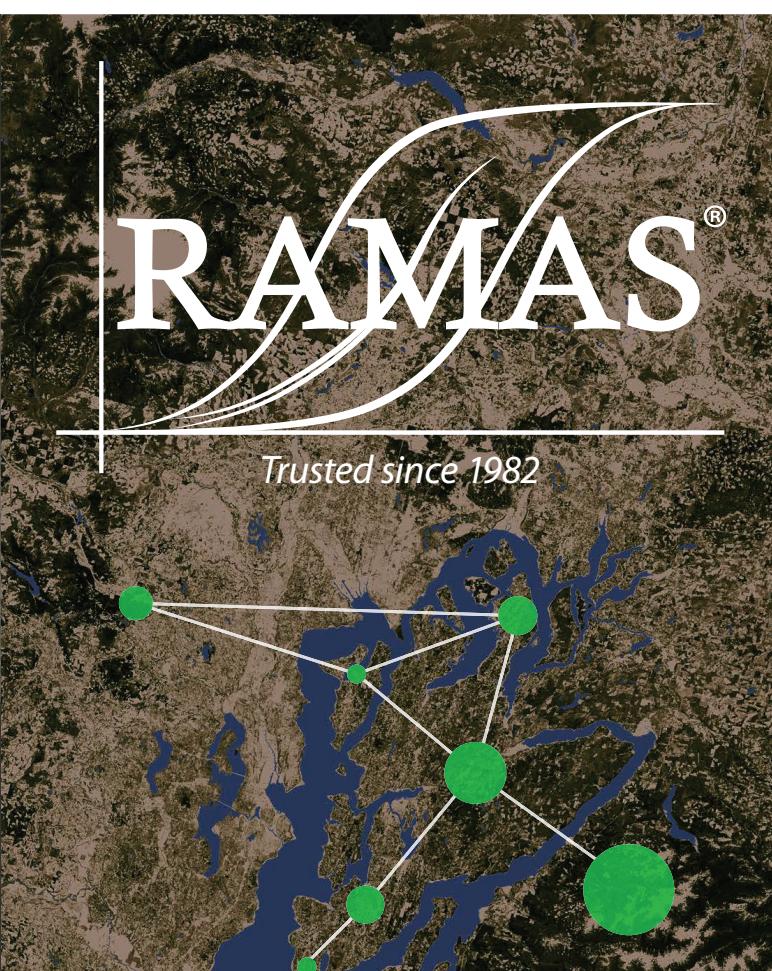
**Ecological software  
for rapid risk assessment**

**Who uses RAMAS software?**

*Thousands of researchers in 60 countries*  
*Hundreds of university classroom licenses*  
*Government agencies around the world*

**Visit [ramas.com/ESA](http://ramas.com/ESA)**  
**special discounts and free new tools**

RAMAS is a registered trademark of Applied Biomathematics, Inc.



The RAMAS logo features the word "RAMAS" in a large, bold, white sans-serif font, with a registered trademark symbol (®) at the top right. The letters are partially enclosed by two white curved lines forming an arc. Below the logo, the text "Trusted since 1982" is written in a smaller, italicized white font. The background of the entire advertisement is a dark gray image of a forested landscape with a river network.