DEVELOPING AN ECOLOGICAL FRAMEWORK TO EVALUATE THE IMPACTS OF RELEASES AT UPSTREAM EXPLORATION AND PRODUCTION SITES: THE EFFECT OF SIZE AND DISTRIBUTION

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INTRODUCTION

This project, FEAB321, began in July of 2000 with support from the U. S. Department of Energy (Fossil Energy Program, National Petroleum Technology Office, Tulsa, OK; Nancy Comstock, Project Manager). The framework and ecological modeling are collaborative research between Lawrence Livermore National Laboratory (Tina Carlsen, Principal Investigator) and Oak Ridge National Laboratory. The project has several long-term goals: (1) to quantify the effects of habitat removal and fragmentation from petroleum exploration and production (E&P) activities on population densities and extinction probabilities of vertebrates, (2) to develop an ecological framework for evaluating impacts of brine and/or oil spills at E&P sites, utilizing population models based on patchiness of landscapes and/or trophic transfer; and (3) to develop early exit criteria from the ecological risk assessment process (if possible), based on size and distribution of spills in the context of potentially patchy habitat. In late FY03, additional funds were received from DOE at the request of the Petroleum Environmental Research Forum (PERF). The primary task of the past year has been to generalize the spatially-explicit, individual-based model that was developed for American badger *(Taxidea taxus*) at the Tallgrass Prairie Preserve (TPP) near Pawhuska, Oklahoma. With remaining funds, we will: (1) continue to generalize the habitat model for new classes of species, (2) summarize how the model can be adjusted to consider impacts of roads, (3) consider how to test impacts of increasing road density, and (4) summarize minimal data needs for the models. Essentially, this project is intended to inject ecology into ecological risk assessment, a field that has been dominated by conservative assumptions about exposure and toxic responses. The project will contribute to PERF project 99-01, "Ecological Evaluations for Upstream Site Remediation Programs." Improved methods for ecological risk assessment should lower costs of remediation by decreasing the need for conservative assumptions in estimates of ecological exposure.

BACKGROUND

The exposure of ecological receptors to chemical contaminants has a spatial context. Wildlife exposure models include dietary uptake but rarely the habitat preferences that also determine exposure. The premise of this project is that organisms experience the environment spatially, as a patchwork. Patches may be beneficial, as in the case of suitable habitat for the animal, or patches may be detrimental, as in the case of some hydrocarbon or brine spills. In addition, background processes, such as controlled burns and grazing by bison, can contribute to patchiness of habitat. Areas denuded of vegetation are non-habitat for most vertebrates. The integrated effect of the patchwork landscape on a particular species will depend on the spatial arrangement of those patches of varying quality.

DISCUSSION OF CURRENT ACTIVITIES

Case study site. The subject of the case study for this project is the Tallgrass Prairie Preserve (TPP) in Pawhuska, OK. The TPP is approximately 37,000 acres of mostly intact prairie grassland with approximately 600 historic wells (about 120 in current production) and isolated spills of hydrocarbons and brine. The Nature Conservancy, which owns the site, has attempted to restore ecosystem function through controlled burns and grazing by introduced bison. Tallgrass prairie vegetation forms comprise about seven percent of oil and gas well locations in the U. S., and prairie generally comprises 32 percent (Fig. 1). Thus, our case study site is representative of about one out of three upstream oil and gas locations.

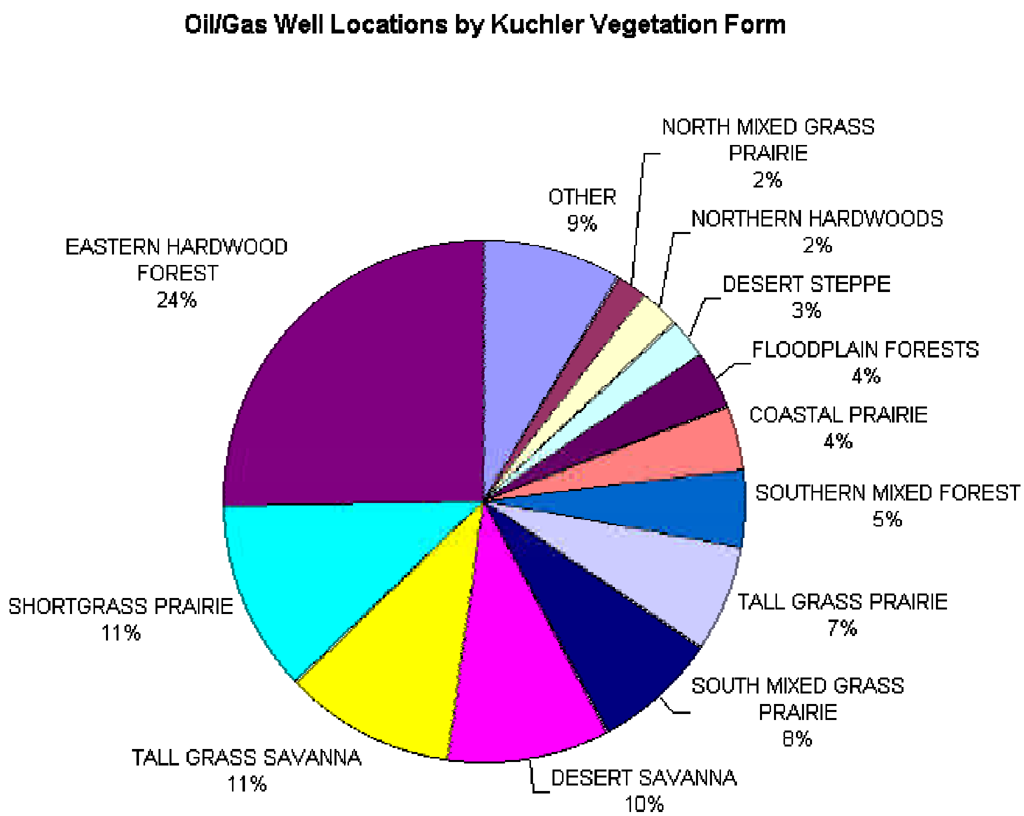


Fig. 1. **Predominant vegetation forms in _ mile by _ mile cells in which productive and unproductive oil and gas wells in the U. S. are located.** Data on well locations in USGS (1995) were obtained from David Ferderer at USGS.

Geographic Information System (GIS). A web-based interface for the GIS, that includes map layers provided by ORNL, was released by Lawrence Livermore National Laboratory (LLNL). The web site, entitled "Managing Ecological Impacts at Exploration and Production Sites" is accessible at http://gis.llnl.gov/mei/ to project team members, DOE sponsors, and PERF 99-01 partners. The GIS includes the following types of data, described more fully in the 2001 *Fossil Energy Program Annual Progress Report*: (1) soil survey, (2) vegetation type, (3) digital ortho quarter quadrangle photos, (4) Landsat Multispectral Scanner data (North American Landscape Characterization data from USGS/EPA/NASA), (5) Normalized Difference Vegetation Index for six years, (6) prescribed burn history (annual 1991-1999), (7) management usage and years of bison grazing, (8) bison pastures with dates opened, and (8) land ownership. Most of these layers are available on the web site. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) hyperspectral data have been obtained from the USGS, and these have been radiometrically corrected by USGS and georectified. Two journal articles are being written based on the GIS data at the Tallgrass Prairie Preserve, one on a hyperspectral detection method for brine scars, and another on a rapid assessment method for disturbance at E&P sites using LandSat data.

Spill Generator. The TPP case study relied on artificial maps of disturbance features. Artificial spills are necessary to identify potential spill area or fragmentation thresholds that result in population-level effects. Maps with different spill patterns also aid in understanding causes of declines. Two spill generators were developed, one theoretical, and one more realistic and dependent on pipeline distribution. The theoretical model generates point patterns of spills and assumes that oil well placement is random across a two-dimensional space. A random walk algorithm simulates diffusion to neighboring cells until the specified spill area is disturbed. The well-complex model simulates spills in locations of well complexes that are assumed to be rectangular grids (based on many of the well arrangements at the TPP) of gather lines and tank batteries. The user specifies the number and dimensions of well complexes. The model assumes that the likelihood of encountering a spill along any segment of pipe of a specified length is constant, so that the likelihood of a spill within a cell increases with the length of pipe located within its boundaries. A manuscript summarizing these tools is in review: Jager, H. I., Efroymson, R. A., Sublette, K., Carr, E. A., and T. L. Ashwood. 2004, submitted. Unnatural landscapes in ecology: Generating the spatial distribution of oil spills.

Ecological Modeling. The presence of oil or brine spills may affect population density and persistence of animal populations through several mechanisms. Patches of spills may impact animal movement, food availability, shelter availability and availability of refuge from predators. Habitat loss may lead to local extinction at low population densities ("Allee effect") because of the inability to find mates or breeding territories.

The structure of the object-oriented model template for ORNL and LLNL models is described in Figure 2. The cell, as well as its immediate surroundings, is conceived as the source of food resources and shelter for individual animals. The model will simulate population changes over time in response to disturbances by brine spills.

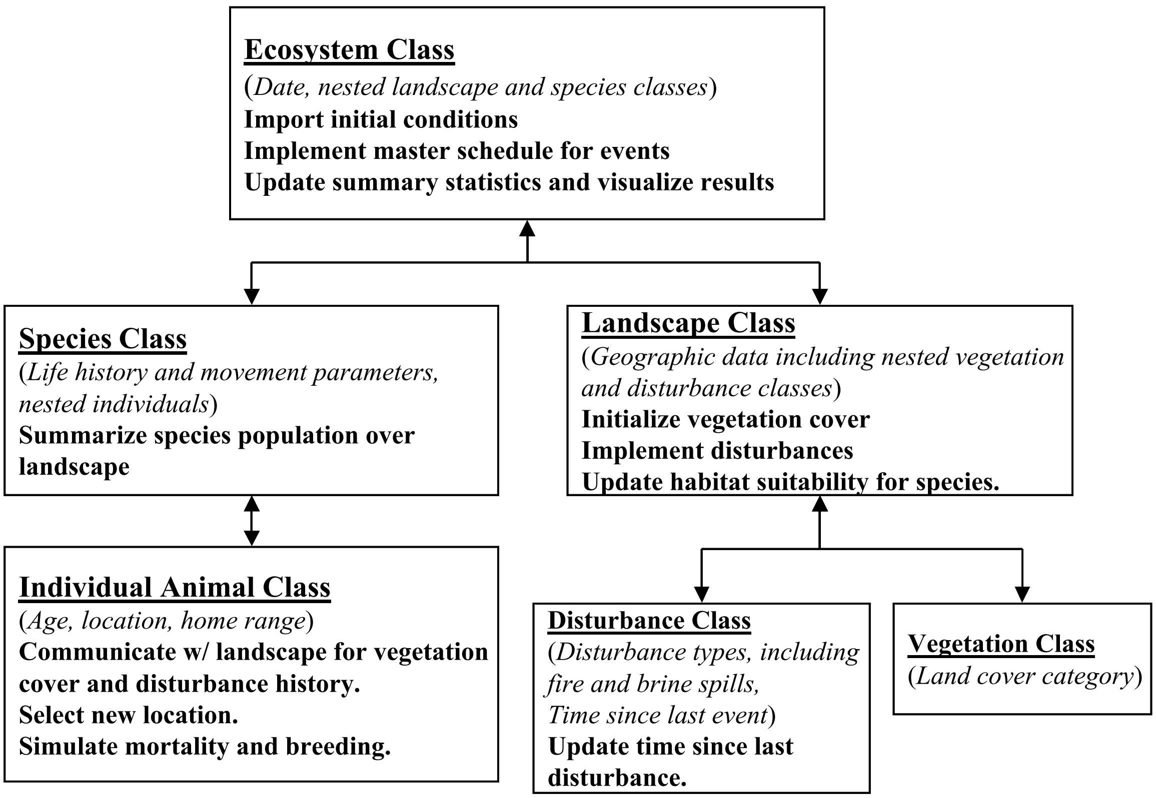


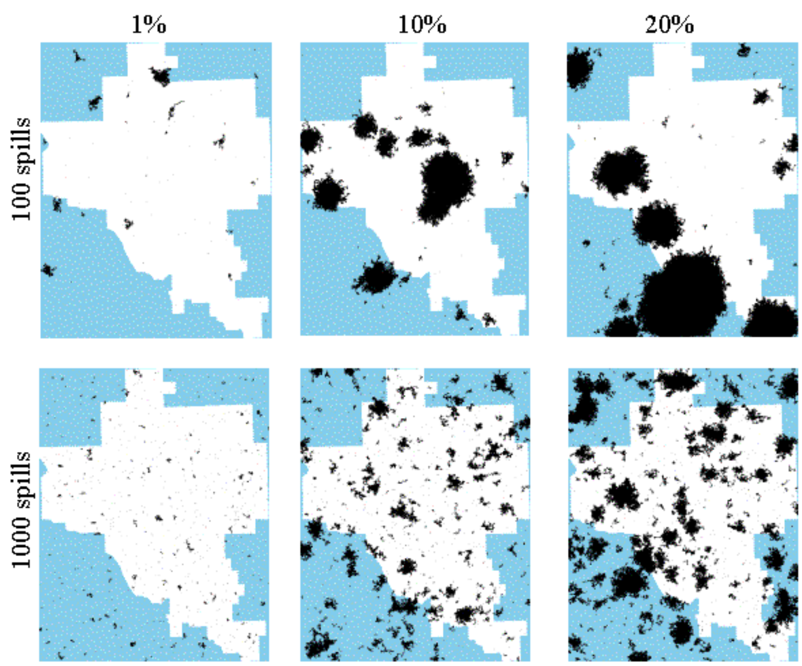
Fig. 2. Diagram of the proposed model template. Objects in the model are defined by classes that include data members (*italics*) and member functions (**bold**). Each class is represented by a box in the diagram.

Trophic interactions (e.g., vegetation growth and reduction due to grazing, herbivory, and bioenergetics) are a focus of the model in development by LLNL. The prairie vole (*Microtus ochrogaster*), a monogamous herbivore, feeds on grassland vegetation and is preyed upon by predators such as owls and badgers.

Habitat individual-based models are well suited for studying the differential susceptibility of species with different life histories and habitat requirements to habitat loss from brine spills. We implemented a habitat-based model for the American badger (*Taxidea taxus*), a voracious, solitary predator with low tolerance for other individuals. We assigned habitat suitability indices to various vegetation categories at the TPP based on known compatibilities with the presence of small, fossorial mammals or burrowing requirements. Brine spills, structures, and streams are designated as unsuitable habitat. Habitat quality of cells influences reproduction simulations through acquisition of territory used for breeding and survival via movement costs and habitat-related mortality. This model does not explicitly represent foraging or predation.

Individuals pass through five periods of pre-breeding, mating, post-mating, birthing, and rearing of young. They establish a permanent home range, equivalent to the breeding territory. Following dispersal and territory establishment, within-range movement is simulated. Movement depends on seasonal and gender-based parameters. Mating is assumed to occur for any mature female with a home range overlapping the home range of at least one mature male. Sources of mortality include: baseline, age-related mortality; habitat-related mortality; mortality based on movement; and emigration from the study area. Sensitivity analyses are in progress. We conducted a simulation experiment to investigate the effects of loss of habitat area and fragmentation (represented here by increasing numbers of spills). We used the Poisson-gamma statistical model described above to generate spill landscapes with a specified target percentage of area covered by spills (1%, 10%, 20%, 30% or 50%), and a specified number of spills (100 or 1000). Six of these maps are depicted in Figure 3. Effects of spills on final average population sizes and the proportion of potential breeding females that successfully mated were compared. In addition, Allee effects were noted.

Figure 3. Example landscapes generated by the Poisson-gamma model, with different numbers of spills and spill areas.



Results showed a decrease in the average, simulated badger population size with increasing area of habitat loss, and a similar decline in the proportion of replicate populations that persisted (Figure 4). Population persistence declined to 80% (100 spills) or 40% (1000 spills) when 10% of land area was covered by spills. Thus, extreme landscape fragmentation led to increased effects on population densities. Similarly, the fraction of populations persisting decreased with the area of disturbance, but the threshold for this effect was apparently higher than 10% disturbance. These declines were accompanied by declines in the proportion of females mating. The area thresholds are higher than the 0.1% of the TPP covered with brine scars and the less than 1% of the TPP that is directly disturbed by wells, roads or spills.

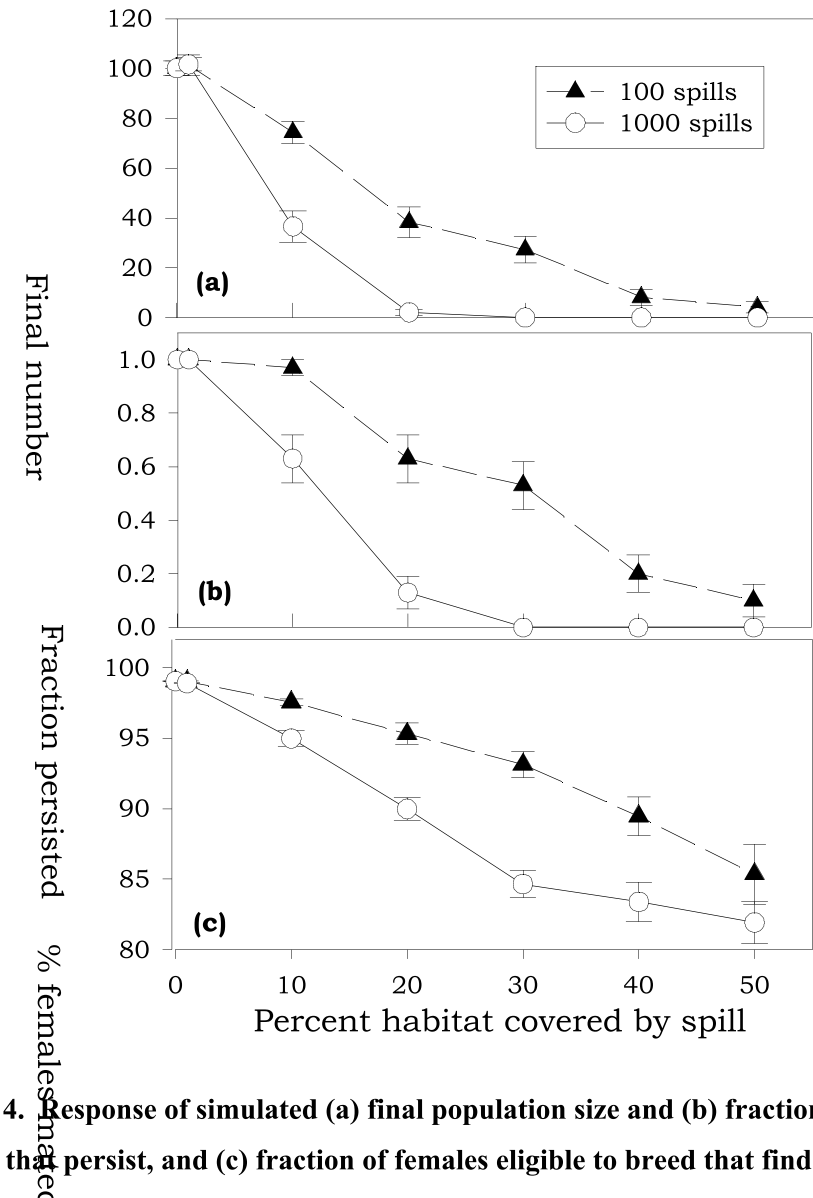


Fig. 4. Response of simulated (a) final population size and (b) fraction of replicate populations that persist, and (c) fraction of females eligible to breed that find mates to habitat loss. Error bars show 1 standard error surrounding the mean of 30 replicate simulations for landscapes with 100 and 1,000 spills.

Model results will contribute to generalizations about the effect of the size and distribution of brine and oil spills on the demographics of wildlife populations. Exclusion criteria and/or mitigation measures for E&P sites may be recommended, based on results of population modeling.

A manuscript describing the badger model is in review, Jager, H. I., Carr, E. A., and R. A. Efroymson. 2003b manuscript. A simulation study to evaluate the effects of habitat loss and fragmentation on the American badger (*Taxidea taxus*). *Conservation Biology*.

In the past year we have focused on: (1) generalization, (2) streamlining, and (3) implementation of Monte Carlo features in the habitat model. With respect to generalization, the model now has the capability to simulate either synchronized breeders or sequential breeders, to permit more than one clutch or litter per year, and to allow either a male or female parent, or both, to remain with and to defend offspring. Another generalized feature of the new version is flexibility in fidelity to a given breeding territory. It is assumed that migratory animals give up their territories each year. Non-migratory animals may give up their territories only in the event of breeding failure, if the average quality drops, or never. Depending on the species, animals may adjust the size of their territories if quality drops (centered on the same location), or not. Animals may now include poor habitat (zero quality) in a territory, or avoid it.

The second activity undertaken in the past year has been to streamline the habitat model. For example, the model was reorganized to remove one level of the hierarchy (no Simulation Class). Most movement functions were moved to the Individual Class from the Population class by giving Individuals access to the Habitat. A general Landscape template class was created that can be used for landscape variables of any type, to replace separate classes. The input parameters are now stored in a globally available Singular class (that can only be defined once). These modifications improve communication among the various classes, while protecting data that should remain unchanged.

The third activity undertaken in the past year was the implementation of Monte Carlo runs for sensitivity analysis using parameters generated by Latin-hypercube algorithm outside of the model. Preliminary sensitivity analysis for the badger showed three results: (1) effects of habitat fragmentation on populations were more negative when movement-related mortality was important; (2) high mobility did not increase badger populations because they were more likely to encounter each other and fight; and (3) site fidelity and avoidance of poor habitat increased simulated badger numbers when habitat loss was high, both for landscapes with high and low fragmentation.

Ecological framework. A preliminary ecological framework for evaluating terrestrial vertebrate populations at E&P sites is presented in Figure 5. Assessment endpoint populations are chosen using a site conceptual trophic model and other management criteria. The potential for exposure to contaminants is determined by contaminant bioavailability and animal behavior. The threshold for conducting a toxicological risk assessment may be lower for threatened and endangered populations than for other populations. The spatial regulatory criteria (contaminated area thresholds) and scientific exclusion criteria that determine whether an exposure to habitat disturbance may be significant and may require a spatial ecological assessment are described below. Species life history information, trophic relationships, and habitat suitability may be explicitly or implicitly modeled in an IBM. This framework is scheduled for publication in August 2004, Efroymson, R. A., T. M. Carlsen, H. I. Jager, T. Kostova, E A. Carr, W. W. Hargrove, J. Kercher, and T. L. Ashwood. 2004. Toward a Framework for assessing risk to vertebrate populations from brine and petroleum spills at exploration and production sites, In *Landscape Ecology and Wildlife Habitat Evaluation: Critical Information for Ecological Risk Assessment, Land-Use Management Activities, and Biodiversity Enhancement Practices, ASTM STP 1458*, L. Kapustka, H. Galbraith, M. Luxon, and G. R. Biddinger (eds.), ASTM International, West Conshohocken, PA, 2004

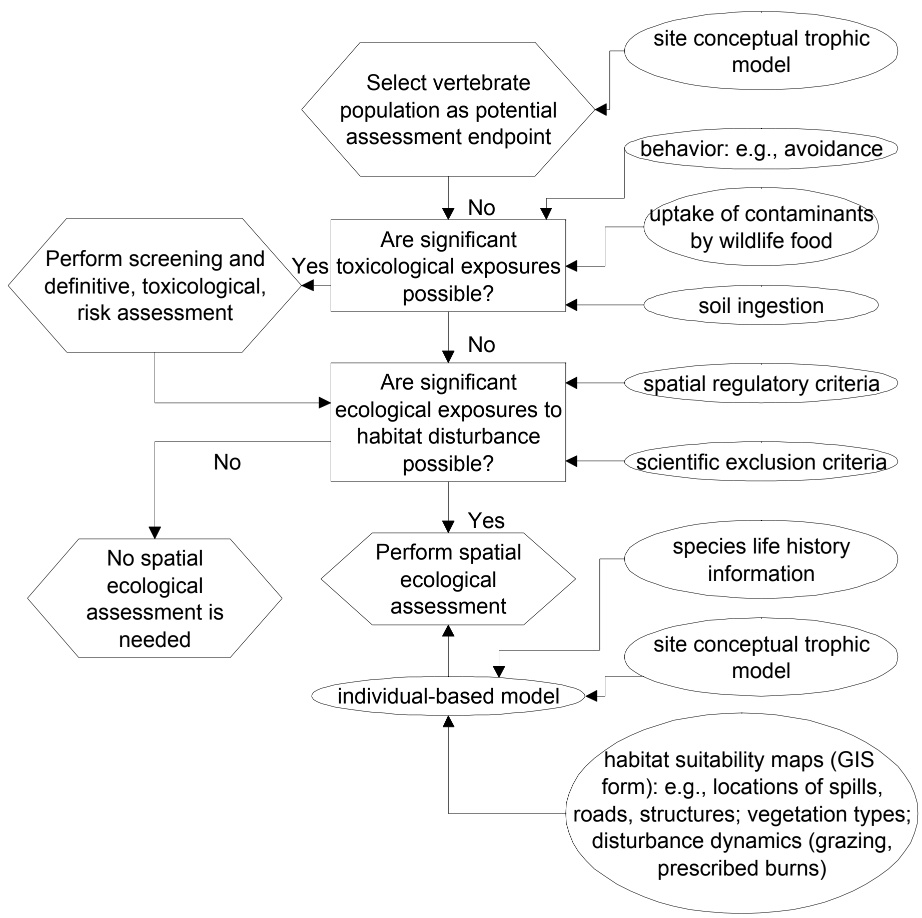


Fig. 5. A preliminary ecological framework for evaluating terrestrial vertebrate populations at E&P sites.

Presentations. This project was presented this year at the 19th Annual Symposium of the United States Regional Association of the International Association for Landscape Ecology, Las Vegas, NV, March, 2004: H. I. Jager and R. Efroymson, "Spatial life history influences the risks associated with habitat loss and fragmentation." Also, Tina Carlsen of LLNL presented this project at the November 2003 meeting of PERF99-01 in Richmond, CA.