Wildlife Conservation and Land Development Risk in Virginia, USA

Ying Xu and Gwenlyn M. Busby

Dept. of Forest Resources and Environmental Conservation, College of Natural Resources, Virginia Tech, Blacksburg, VA

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

Abstract: There is rich literature in reserve site selection for wildlife conservation, but little has investigated the spatial correlation of risks presented by hazards. This paper contributes to the literature by applying the modeling framework developed in Busby et al. (2011), which incorporates spatially correlated risk into the reserve site selection problem, to a Virginia landscape where fine-scale species data is available. In this context, we consider both homogeneous and heterogeneous on-site land development risks. Finally, we apply a budget constraint to our maximal covering species problem to investigate how land cost impacts optimal reserve design and the level of species protection. Using fine-scale species data in the analysis, we identify the types of settings where incorporating spatially correlated risk into conservation reserve design can lead to significant improvements in species protection.

Key words: reserve site selection, spatially correlated risk, maximal covering species problem, Virginia

Introduction

Biodiversity is deteriorating at an unprecedented rate throughout the world. It is estimated that between 150 and 200 species go extinct every 24 hours (United Nation Environment Programme). Land conservation is one major strategy to address biodiversity loss, and is widely implemented in the form of a system of protected areas, or natural reserves (Noss and Cooperrider, 1994, Pimm and Lawton, 1998). Cost effectiveness is of first priority in the design of natural reserves. However, due to the complexity of the ecological system and the evolving knowledge of conservation planners, no simple concensus has been reached and how to optimally design the natural reserves has been under active debates for decades.

Most literature on land conservation aims to minimize the risks of potential hazards that threaten species' survival. Previous literature observes a rich record that seeks the best solution of reserve site selection (RSS) problem (Kirkpatrick, 1983; Margules et al., 1988; Possingham et al., 1993; Pressey et al., 1993; Church et al., 1996; Camm et al., 1996), but little has investigated the spatial correlation of risks presented by hazards due to modeling difficulties. In the real world, most hazards such as wildfire, pest outbreak, invasive species and land development appear to be spatially correlated since they are more likely to spread to adjacent regions. Recognizing this, Busby et al. (2011) develop a simple static model of the expected maximum species covering problem incorporating spatially correlated risk.

Similarly we model spatially correlated risk in the context of the maximum species covering problem. We compile comparative results drawn by varying the probabilities of risk spread. To be more realistic, we allow for heterogeneous probabilities of risk occurrence on individual parcels. To derive policy-oriented applications, we further consider budget constraint in the more general case of heterogeneous risk where discussion on the cost effectiveness of the RSS solution is straightforward. We extend the analysis in Busby et al. (2011) by applying a fine-scale species dataset from Virginia. Using this fine-scale data allows us to identify settings where spatially correlated risk affects species protection and conservation planning might be improved to better protect species in these risky landscapes.

Literature

The first question that comes to the conservation planner's mind is whether a single large reserve or several small reserves work better for wildlife protection. One school of thoughts suggests that a single large reserve is preferable to several smaller reserves with the same aggregate area (MacArthur and Wilson, 1967). The philosphy is that since species richness increases with habitat area, a larger block of habitat would support more species than any of the smaller blocks (Diamond, 1975). This idea has gained popularity in the 1960s and 1970s and been standardized in many ecological textbooks (Williams et al., 2005). However, there is neither theoretical nor empirical evidence for the proposed advantages a single large reserve, and if the smaller reserves had unshared species, it is possible that several smaller reserves could have protected more species than a single large reserve (Simberloff and Abele, 1982). This is later referred to as the SLOSS debate (a single large or several small reserves), or more recently the FLOMS debate (a few large or many small reserves) (Williams et al., 2005).

Recent researchers are more interested in several small reserves than a single large one (Ando et al., 1998; Polasky et al., 2001; Hamaide et al., 2009). This makes sense because of the uneven distribution of species as well as a wide range of socioeconomic constraints such as land price and predetermined land use pattern. Another consideration that favors several small reserves is that, once certain hazards occur to some reserves, species may still be protected given their existence in other reserves. To design the natural reserve system that consists of several small reserves, reserve site selection (RSS) problems are formed and empirically applied, which take into consideration different constraints under which the species' survival is optimized (Kirkpatrick, 1983; Margules et al., 1988; Possingham et al., 1993; Pressey et al., 1993; Church et al., 1996; Camm et al., 1996).

Most RSS models can be categorized into either the species set covering problem (SSCP) or maximal covering species problem (MCSP). SSCP is first developed by Possingham et al. (1993). The idea is to choose the least number of parcels in such a way that each species is protected, i.e. represented in at least one parcel. An integer linear program solvable by multiple algorithms, SSCP can be easily extended to account for real world complexities such as heterogeneous land costs (Possingham et al., 1993). While SSCP presents an ideal image of reserve system design assuming sufficient resources, it is hardly applicable as in the real world limited resources may constrain what can actually be protected in a reserve system.

MCSP, in contrast, recognizes the resource constraints in the real world and solves instead the maximal number of species under these constraints (Church et al., 1996; Camm et al., 1996). These constraints include the number of reserve sites as well as governmental budget. As governmental budget can hardly protect all species of interest, land prices become a natural consideration. Using a MCSP, Ando et al. (1998) make comparative analysis under both site and budget constraints, respectively, and show how the results vary. The cost-optimal solution is found to achieve efficiency by avoiding costly sites and selecting nearby sites as reserves which have slightly fewer species but are much less costly.

Literature observes further development of both MCSP and SSCP. Polasky et al. (2001) introduce a probability measure of species into MCSP with either site or budget constraints. Similar to Ando et al. (1998), their empirical analysis also shows that budget-constrained solution that incorporates land costs results in far more cost-effective reserve system than site-constrained solution. Hamaide et al. (2009) develop an SSCP in which species are categorized as either critical (e.g. rare, threatened or endangered) and noncritical. Spatial structure of reserve sites are considered. Specifically, selected sites to protect critical species are required to be core areas that have surrounding buffering areas, which is intended to protect the core area from spreading hazards. Hamaide et al. (2009) has a primary idea of hazard prevention by imposing the core-buffer structure, while it only helps in the case of on-site hazards. In the real world, most hazards such as wildfire, pest outbreak, invasive species and land development can either occur on-site or spread from neighboring areas, and these types of spatially correlated risks are considered in Busby et al. (2011).

Among all the risks that threaten wildlife, land development is most commonly seen as a growing proportion of land resources is devoted to human uses throughout the world. As the remaining land resources become scarcer, the debate over economic development and resource conservation sharpens. There are scientific and public concerns that the loss of habitat due to land development causes the greatest extinction of species (Luniak 1994, Kowarik 1995, Savard et al., 2000, Stein et al., 2000, McKinney 2002). Noticeable deterioration in wildlife diversity has been observed along the urban to rural gradient that observes the most drastic landscape change as urban areas sprawl (Denys and Schmidt, 1998; McInyre, 2000; Blair, 2001; McKinney 2002). Snyder et al. (2004) apply the MCSP framework to land development risk in wildlife conservation. A two-period site-constrained model that accounts for uncertainty in land development is built and solved using a linear-integer formulation. However, there is a growing gap between scientific literature and the increasing impacts of land development on wildlife conservation.

This paper tries to bridge these gaps by developing a MCSP which directly accounts for the spatial correlation of risks. The procedure is empirically implemented using data from Virginia where the land area is partitioned into a grid system. A general risk that is homogeneous across landscape is modeled at the state level. Land development risk as a specific example is further investigated with both heterogeneity and spatial correlation of such risk carefully considered, which is implemented to a landscape of four adjacent counties for accuracy and the implementability of detailed conservation policies. Results are also drawn by replacing site number constraints with budget constraints, and the tradeoff between the protection of species and conservation cost are presented. Multiple policy applications are derived and discussed.

Model

In the real world, each individual species has a unique distribution, making it difficult to select natural reserve sites so as to protect as many species as possible in a comprehensive manner. Thus, we specify a grid system covering the landscape where each species is either present or absent within a land parcel, and a binary indicator suffices the measurement needs of species' existence in each parcel. The grid system consists of individual square parcels, which are the basic units in our analysis. The smallest square grid set (with the same row and column number) that covers the whole irregularly shaped landscape is considered. The grid system is built in a GIS environment.

A few assumptions are made that allow us to incorporate real-world characteristics of the RSS problem into a solvable modeling framework. Following literature, it is first assumed that the existence of species is spatially independent, i.e. the existence of species in one parcel is not related to their existence in other parcels (Possingham et al., 1993; Church et al., 1996; Camm et al., 1996). Second, we assume that when a hazard occurs in a parcel, all existing species will be wiped out. This assumption is necessary as it largely represents reality and enables our modeling of spatially correlated risk using a probability measure. For example, in the case of land development risk, when a parcel is urbanized, the habitat of species would be altered to such a degree that species survival on the parcel would no longer be possible.

In the real-world, hazards such as land development, wildfire, pest outbreak and invasive species are more likely to affect nearby areas than distant areas. Thus, it is assumed that the probability of hazard spread decreases over space. Specifically, in each direction, a hazard is allowed to spread to directly adjacent parcels and then to a further one, which is the double-level queen contiguity structure (Anselin and Rey, 2010). Figure 1 illustrates the total affected area when a hazard occurs on a core parcel, which can be any individual parcel in the grid system. For simplicity, we assume that for the core parcel, the probability of hazard spread to the outer-belt (O) parcels is one-half of the probability of hazard spread to the inner-belt (I) parcels. As illustrated in the empirical application below, once we vary the probability of hazard spread from inner-belt parcels to the core parcel from 0, 0.5 to 1, the probability of spread from outer-belt parcels to the core parcel will be 0, 0.25 and 0.5, respectively. As each individual parcel can be considered as the core parcel, the total risk of hazard occurence on a parcel includes the on-site risk as well as the aggregate risk of hazard spread from both inner-belt and outer-belt parcels.

Based on the assumptions above, we specify a nonlinear mixed integer optimization model to select a number of land parcels that maximizes the expected number of species, subject to the budget constraint (or site constraint) and a total risk constraint. Formally, there are n parcels indexed by j (J = 1,2,…,n) and m species indexed i (I = 1,2,…,m). On parcel j, species i is absent with probability q_{ij}. The computation of q_{ij} depends on the initial presence or absence of species and on the aggregate probability of hazard's occurence on parcel j, p_j:

$$(1) \qquad q_{ij} = \begin{cases} p_j, & \text{for all } N_i \\ 1, & \text{otherwise} \end{cases}$$

where N_i is the set of parcels that contain species i. The model is formalized as (2a) - (2d) below:

$$\begin{aligned}
&(2\mathrm{a}) && \max && \sum_{i\in I}(1-\prod_{j\in J} q_{ij}^{x_j}) \\
&(2b) && \text{s.t.} && \sum_{\mathrm{j\in J}} c_j x_j \le B \\
&(2c) && && p_j \le \alpha, \ \text{for all } j \\
&(2d) && && p_j = p_{j0}x_j + \sum_{k\in H_j} p_k f_k x_k + \sum_{l\in O_j} p_l t_l x_l, \ \text{for all } j
\end{aligned}$$

Additional notations include the following. x_j, a selection indicator of parcel j is added to q_{ij} as a superscript, which is equal to 1 if parcel j is selected to form the reserve system; or $x_i = 0$ if not. c_j is the land cost of parcel j and B is the given budget in monetary terms. α is the maximal allowable risk set by the planner. H_j is the set of inner-belt neighboring parcels of parcel j, and O_j is the set of outer-belt neighboring parcels. For the risks of hazard on parcel j, p_{j0} is the on-site probability of hazard; p_k is the probability of its occurence on inner-belt parcel k; and p_l is the probability of its occurence on outer-belt parcel l. For hazard that occurs in nearby parcels and spreads to parcel j, f_k is the probability of hazard spread from inner-belt parcel k and t_l is the probability of hazard spread from inner-belt parcel l.

The objective function in (2a) is solved by deciding if x_j (the decision variable) equals 0 or 1 for each parcel j such that the reserve system includes a group of parcels (sites) so that the expected number of species is maximized. Two constraints are presented in the model: (2b) and (2c). (2b) is the budget constraint. However, it is a general setting which can also represent site number constraint. In that case, c_j is set to 1 for all j and B is set to the maximum number of parcels allowed in the reserve system.

(2c) differentiates risk components with p_j further specified in (2d): the probability of on-site hazard within parcel j and the aggregate risks of hazard spreads from inner-belt and outer-belt parcels. The total risk on each parcel is the sum of all the three types of risks above. (2c) states that the aggregate probabilities of hazard, i.e. the total risk, should be no greater than a maximum allowable risk, α. Intuitively, the maximum allowable risk α can be interpreted as the threshold above which a parcel shall not be selected as a reserve. In practice, this risk threshold may come from past conservation studies and planning experiences, and we may expect α to decrease as the size of a single parcel increases or the total number of reserve sites decreases. The valuation of α, however, can be arbitrary if no solid support is found either theoretically or empirically, and the overall solution can be biased. To avoid such risk, we assign α a comparatively large value so the constraint is not binding and does not influence the optimal reserve design. Thus, α is mainly for illustration purposes in our case. Admittedly, sensitivity analysis with respect to α may be important when the constraint is binding. However, we leave that for future work as no solid information on the maximal allowable risk in our example is currently available.

A nonlinear programming problem with a binary decision variable, the MCSP built above cannot be solved using traditional optimization techniques. We employ a simulated annealing heuristic which seeks to identify a good approximation to the global optimum to the problem by iteratively identifying candidate solutions (the set of *J* where $x_j = 1$) that increase the value of the objective function (Kirkpatrick, Gelatt and Vecchi,1983; Černý, 1985). Simulated annealing algorithm comes from annealing in metallurgy, which is a technique to reduce the defects of a material by heating and controlled cooling. Analogically, the basic idea of the algorithm is to approximate the global optimum via iteration (the "cooling" process). Specifically, in search of the best available solution (an approximation with a small error), a slow decrease in the probability of accepting worse solutions is implemented as the algorithm explores the solution space, analogical to the decrease of temperature in the metallurgical annealing process. Simulated annealing is suitable for situations where the search space is large and discrete. For many problems unsolvable by exhaustive enumeration and the best available solution is acceptable, simulated annealing may significantly increases computing efficiency.

To investigate how the spatial correlation of risks plays a role in RSS, the spatial distribution or proximity of individual reserves needs to be carefully measured. One such commonly used measure is connectivity (Kirkpatrick, 1983; Margules et al., 1988; Pressey et al., 1993; Tischendorf et al., 2000; Williams et al., 2005). In our double-level queen contiguity structure, we develop a simple connectivity index (*CI*) to quantify the spatial patterns of selected reserves. For each reserve, we count the number of inner-belt reserves and assign them a weight of 1, and count the number of outer-belt reserves and assign them a weight of 0.5. Then the connectivity index is a weighted sum of the nearby parcels of each reserve. For example, if a certain selected reserve j has k inner-belt reserves and l outer-belt reserves nearby, then $CI_j = k + 0.5l$ and $CI = \Sigma_j CI_{j.}$ Reserves that are highly connected will have higher CI values than reserves that are more dispersed.

Data Description

Multiple data sets are jointly employed in the empirical analysis. The species information in terms of habitat distribution comes from the Natural Heritage GIS data from Virginia Department of Conservation and Recreation. Species are originally documented as rare, threatened or endangered. However, we do not differentiate these slightly different concepts for modeling simplicity, which does little harm to the illustrative application of our methodology, and term all these three categories as "rare species". The species data is retrieved in the form of GIS files where the distributions of species are mapped in a GIS environment. These distributions are further projected into the grid system also developed in the same environment, which enables the measurement of the existence of species i on parcel j. A total of 821 rare species are included in the empirical analysis, including plants and animals. The grid system consists of 625 square parcels (25×25), Figure 2 graphs the distribution of these rare species (the top half of the grid system which is out of the boarder of Virginia is not presented). Rare species cluster in two regions: the mountainous region in the west and the coastal plain.

As a specific and more realistic example, we analyze land development risk with both heterogeneity and spatial correlation of the risk carefully considered. The whole Virginia landscape is of so large a magnitude that any ignorance of within-parcel heterogeneity in either land development risk or land price can hardly yield any applicable results or policy implications at the local level. Thus, we switch to a smaller landscape of four adjacent counties for accuracy and local implementability. The focal area include Sussex County, Brunswick County, South Hampton County, Greensville County and Emporia City in Southeast Virginia. It is representative as one half of it locates in the coastal plain where species cluster and the other half locates in the central area that is less rich in species. For modeling simplicity, 20 rare species widely distributed across this landscape are randomly selected. Figure 3 maps the distribution of these species in the grid landscape of the focal area where species clusters are presented in colors.

In modeling land development risk, every parcel has a different risk value based on the specification of Virginia Conservation Lands Needs Assessment's Natural Heritage Program. Land development risk in every Virginia county (city) is originally evaluated on a 1-8 scale, in which counties scored 1 are the least likely to be developed and those scored 8 are the most likely to be developed. Figure 4 graphs the heterogeneous land development risk, which generally decreases from the north of the landscape, which is closer to urban areas, to the south which is more rural. In the empirical application, we divide these scores by 100 for modeling feasibility, which generates probabilities of land development valued from 0.01 to 0.08 (the acual risk in the focal area of our analysis varies from 0.03 to 0.08).

In the budget-constrained optimization with heterogeneous and spatially correlated risk, land value is approximated using farm land value data from the National Agricultural Statistical Service, United States Department of Agriculture (USDA, 2007). Using the Quick Stats web tool, we retrieve the county-level average farm real estate value from the electronic tables. These county-level values are then assigned to individual parcels within the focal area. For parcels located across county boarders, the assigned land values are averaged county-level real estate value weighted by area shares within relative counties.

Empirical results

We first evaluate the impact of spatially correlated risk which is homogeneous. This is implemented on a statewide landscape partitioned into parcels using a 25×25 grid system. A total of 821 rare species are included in the analysis. Due to computational difficulties caused by data magnitude, we only consider risk spread from inner-belt parcels, and make full consideration of risk spread from both inner-belt and outer-belt later in the smaller landscape of four counties. We use simulated annealing algorithm to select 30 parcels from a total of 625 to form the reserve system that maximizes the expected number of species. The probability of on-site risk, p_{j0}, is assigned a value of 0.05 and α is equal to 20 in both the statewide and four-county analysis.

We first set the probability of hazard spread f_k=0 and selected the reserves. This is the classical MCSP with no spatially correlated risk. Selected reserves are mapped in Figure 5(a). Most selected reserves are located on the western and eastern parts of Virginia, with only a few located in the central part of the state. This pattern is consistent with the species distribution (see Figure 3). The connectivity index (*CI*) of reserves is 75. When f_k is increased to 0.5, the distribution of reserves changes slightly, though most selected parcels remain concentrated in the western and eastern areas. *CI* decreases to 65. Finally, we increase the probability of hazard spread to 1. *CI* further falls to 53, indicating that the parcels selected for reserve are more dispersed. Table 1 reports the decreasing trend of *CI* as well as the expected number of species, which also shows a decreasing trend as the spatial correlation of risk increases. These comparative results imply not only that the spatial correlation of risk alters optimal reserve site distribution, as reserves get further from each other to offset increasing risk of hazard spread, but also that the number of species protected decreases as the risk of hazard spread increases. Thus, in the case of homogeneous risk, spatially correlaed risk plays an important role in RSS, the ignorance of which will bias the optimal solution. Failing to consider spatially correlated risk will result in an overestimation of more than 50 protected species, or nearly 10% of the total, using our parameters.

We further extend our analysis to land development risk on a four-county landscape where the on-site risk of hazard is heterogeneous and risk spread from both inner- and outer-belt parcels are considered. The focal area in Southeast Virginia

(Sussex County, Brunswick County, South Hampton County, Greensville County and Emporia City) are partitioned into a 20×20 grid system. 20 randomly selected rare species are included[1]. We apply the site-constrained MCSP where 15 parcels are selected. The probability of land development spread varies from inner-belt parcels (f_k) from 0, 0.5 to 1; and the probability of land development spread from outer-belt parcels (t_l) is then equal to 0, 0.25, and 0.5, respectively. Figure 6(a), 6(b) and 6(c) present the select reserves in these three cases, respectively. It is observed that the distribution of selected reserves changes as spatially correlated risk is introduced and varies. Detailed results are presented in Table 2. Similar to the statewide analysis, reserves get further from each other as spatially correlated risk increases, and the expected number of protected species slightly goes down. It is seen that in general selected parcels are more likely to locate in areas with lower probabilities of land development as such risk increases. Some parcels in areas with higher levels of development risk are selected, but the connectivity level is low among these selected parcels. This again confirms the impact of spatially correlated risk on RSS solution.

As most conservation practice is implemented under certain budget constraint rather than site-number constraint, we further apply the MCSP with spatially

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[1] [1] The species included are Atlantic pigtoe, Bachman's Sparrow, Bald eagle, Barking treefrog, Blackbanded sunfish, Dwarf wedgemussel, Green floater, Henslow's sparrow, Loggerhead shrike, Mabee's salamander, Dwarf Crabgrass, Easter big-eared Bat, Eastern Lampmussel, Golden Colicroot, Lined Topminnow, Virginia Thistle, Round-leaved Goldenrod, Southern Bladderwort, Oak Toad and Reniform Sedge.

correlated risk to the same four-county landscape using a budget constraint. The tradeoff between habitat conservation and the cost of land protection is always a major concern, and is presented here by solving the MCSP multiple times with different budget constraints. Table 3 shows detailed results, where the cost per species is also included as a measure of conservation efficiency. As the conservation budget tightens, both the number of protected species and the number of parcels selected for reserve decrease. When the budget constraint drops below $23.4 million, the selected reserves and the expected number of species decreases to 0. The most cost-efficient solution is reached with a budget of 24.3 million US dollars where 6 species are protected. It is also seen that species are clustered in small areas. When there are 4 selected parcel, the number of protected species is 14.43. But even when the number of reserves further decreases to 1, there are still 5 species under protection. This information is of practical use as policy makers usually follow a priority list of species and choose reserve parcels in certain order.

Concluding remarks

This analysis aims to find optimal conservation strategies in the presence of spatially correlated risk. We first introduce homogenous spatial risk in a MCSP framework and solve the RSS problem in a whole state landscape of Virginia. We then examine a specific type of heterogeneous spatial risk, land development risk, in a MCSP framework and solve the RSS problem in a four-county area in Virginia. We contribute to the literature by applying fine-scale species data to a model of spatially correlated risk in the context of the RSS problem as outlined in Busby et al. (2011). Although incorporating spatial risk into the MCSP framework makes the programming process much more complicated and computationally intensive, it allows for a more realistic analysis particularly with the application of fine-scale data.

We find that spatially correlated risk plays an important role in determining optimal reserve design. Using species fine-scale species data we find that parcels selected for protection are more dispersed when spatially correlated development risk is considered. Thus, conservation planning that fails to incorporate information about spatially correlated risk may not effectively protect species.

This paper applies fine-scale data to the RSS problem with spatially correlated risk, as outlined in Busby et al. (2011), and empirically tests the significance of this approach in a Virginia landscape. Extensions of this research might explore weighting systems for various classifications of species (endangered, threatened, sensitive, etc.) to prioritize conservation efforts. Implementation of such conservation planning will require spatial data describing ownership parcels and more advanced computational tools.

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Table 1 Connectivity Index and Expected Number of Species in Statewide Analysis

Probability of Hazard Spread from Inner-Belt (f_k)	Reserve Connectivity	Expected No. of Species
0	75	565
0.5	65	538
1	53	514

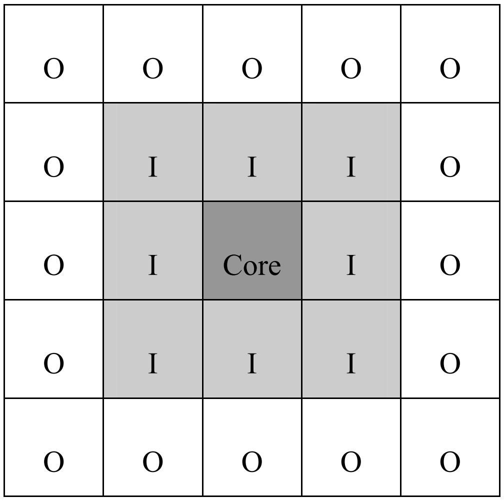
Table 2 Connectivity Index and Expected Number of Species in Four-County Analysis

Probability of Hazard Spread from Inner-Belt (f_k)	Probability of Hazard Spread from Outer-Belt (t_l)	Reserve Connectivity	Expected No. of Species
0	0	25	19.69
0.5	0.25	18.5	19.53
1	0.5	16	19.33

Table 3 Conservation Efficiency under Budget Constraint with Heterogeneous Risk

Budget Constraint (million USD)	Expected Number of Species	Cost per Species (million USD)	Number of Parcels in Reserve
1,056	19.79	53.36	46
633.6	19.65	32.24	34
352.0	17.6	20.00	19
211.0	16.74	12.62	11
168.2	15.55	10.82	7
112.1	14.43	7.77	4
74.8	11.66	6.41	3
56.1	9.55	5.87	2
46.7	6	7.79	1
24.3	6	4.05	1
23.4	5	4.67	1
< 23.4	0	-	0

Fig. 1 A Graphical Illustration of Inner-Belt (I) and Outer-Belt Parcels (O)



O	O	O	O	O
O	I	I	I	O
O	I	Core	I	O
O	I	I	I	O
O	O	O	O	O

Fig. 2 The Distribution of Rare Species in Virginia

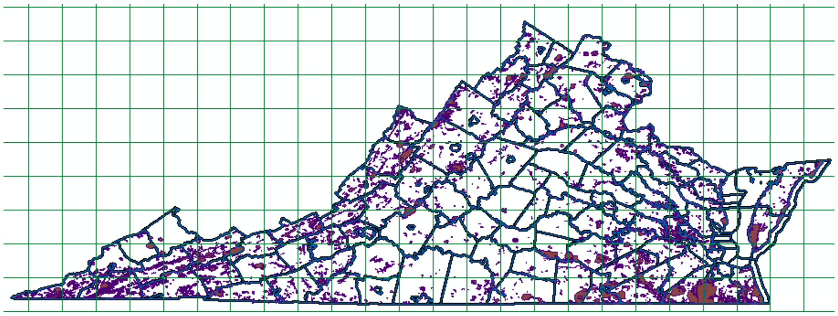


Fig. 3 The Distribution of Rare Species in the Four-County Area

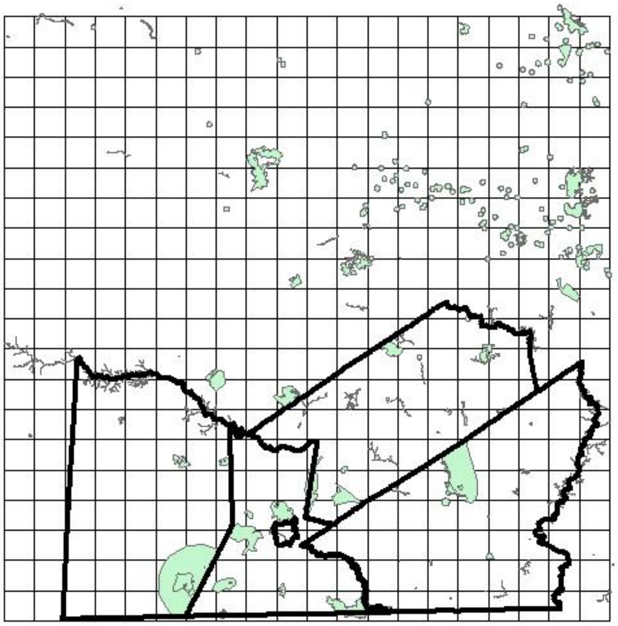


Fig. 4 Heterogeneous Land Development Risk in the Four-County Area

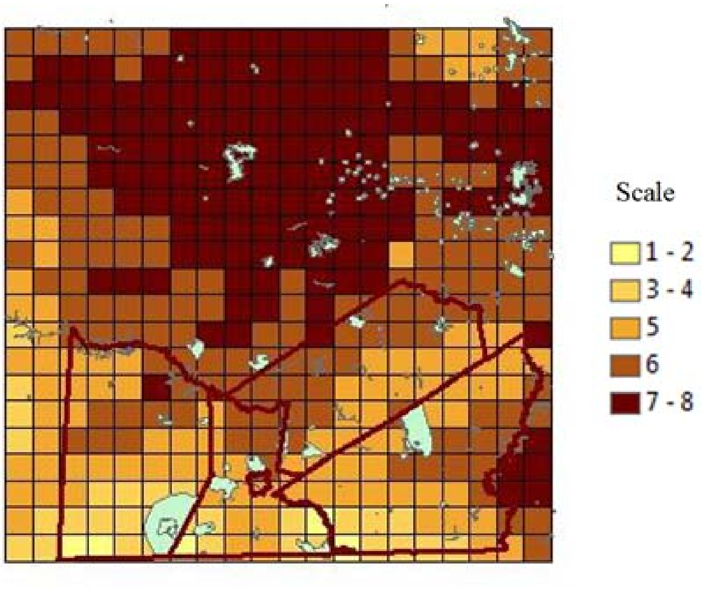
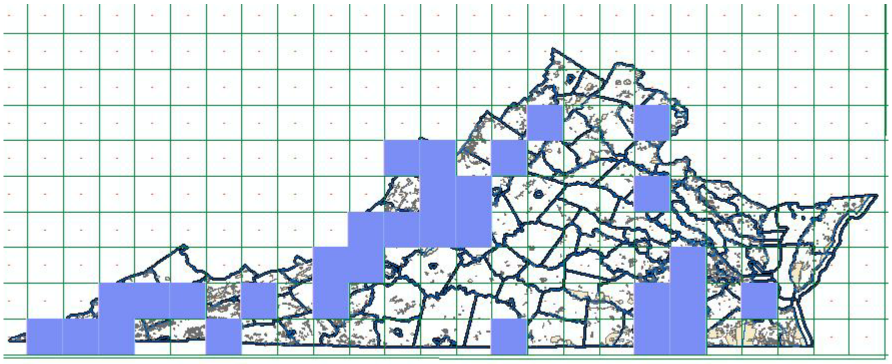
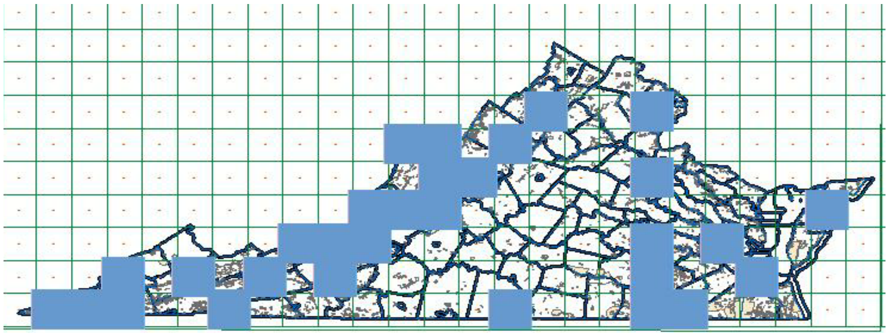


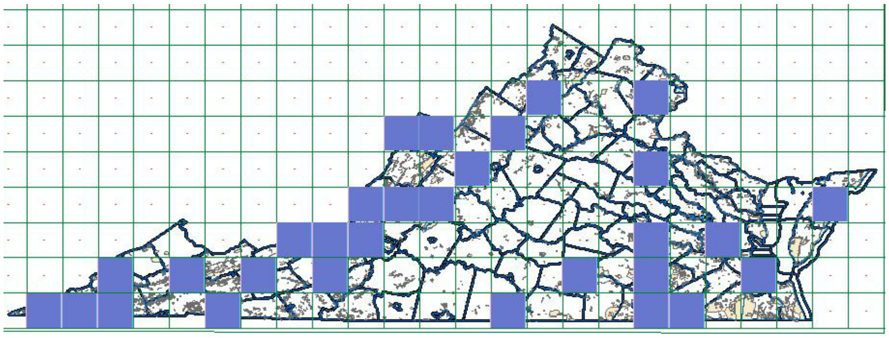
Fig Error! No text of specified style in document. **Reserve Site Distribution of Statewide Analysis**



(a) $f_k = 0$

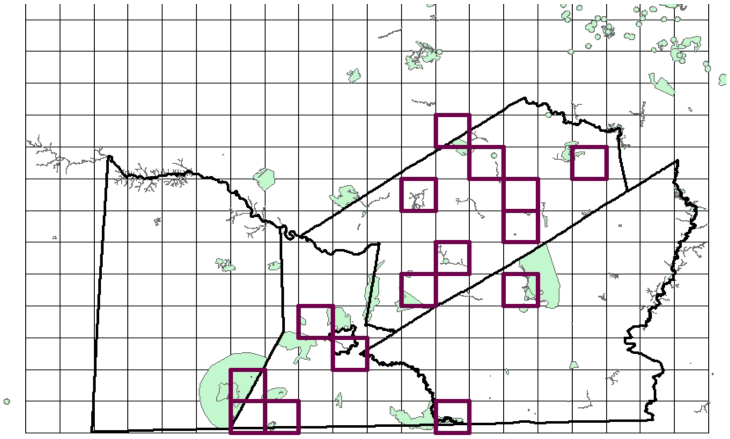


(b) $f_k = 0.5$

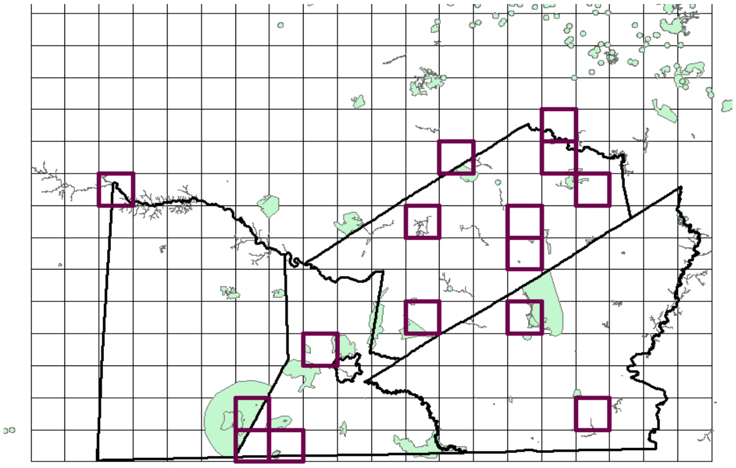


(c) $f_k = 1$

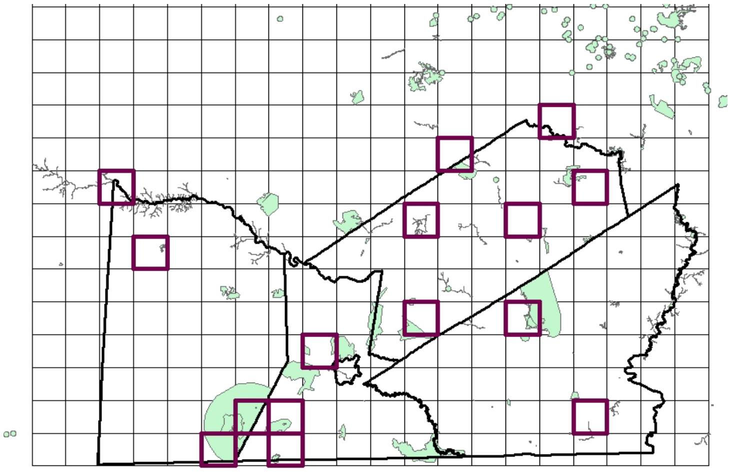
Fig 6 Reserve Site Distribution of Four-County Analysis



(a) $f_k = 0$, $t_l = 0$



(b) $f_k = 0.5$, $t_l = 0.25$



(c) $f_k = 1$, $t_l = 0.5$