OPEN SPACE AS AN ARMATURE FOR URBAN EXPANSION: A FUTURE SCENARIOS STUDY TO ASSESS THE EFFECTS OF SPATIAL CONCEPTS ON WILDLIFE POPULATIONS

by

HOMERO MARCONI PENTEADO

A DISSERTATION

Presented to the Department of Landscape Architecture
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

March 2014

DISSERTATION APPROVAL PAGE

Student: Homero Marconi Penteado

Title: Open Space as an Armature for Urban Expansion: A Future Scenarios Study to Assess the Effects of Spatial Concepts on Wildlife Populations

This dissertation has been accepted and approved in partial fulfillment of the requirements for the Doctor of Philosophy degree in the Department of Landscape Architecture by:

David Hulse	Chairperson
Bart Johnson	Core Member
Robert Ribe	Core Member
John Bolte	Core Member
Mark Gillem	Institutional Representative

and

Kimberly Andrews Espy	Vice President for Research and Innovation; Dean of the Graduate School

Original approval signatures are on file with the University of Oregon Graduate School.

Degree awarded March 2014

DISSERTATION ABSTRACT

Homero Marconi Penteado

Doctor of Philosophy

Department of Landscape Architecture

March 2014

Title: Open Space as an Armature for Urban Expansion: A Future Scenarios Study to Assess the Effects of Spatial Concepts on Wildlife Populations

Urbanization is one of the biggest threats to biodiversity. To address this problem, landscape planners have increasingly adopted landscape ecology as a theoretical basis for planning. They use spatial concepts that express principles of landscape ecology in diagrammatic form to create frameworks for planning. This dissertation presents a quantitative approach to evaluate the application of spatial concepts developed to create an armature of open space in areas subject to urbanization. It focuses on the predicted urban expansion of Damascus, Oregon, as a case study. An alternative futures study was used to test three open space spatial concepts for patches, corridors and networks in combination with compact and dispersed urban development patterns. The resulting eight scenarios of land use and land cover were then modeled for the year 2060 to evaluate their effects on habitat quantity, quality and configuration and to identify tradeoffs between urban development and conservation for three focal wildlife species: Red-legged frog, Western meadowlark, and Douglas squirrel. Open space spatial concepts strongly influenced habitat quantity and quality differences among future scenarios. Development patterns showed less influence on those variables. Scenarios with no landscape ecological spatial concept provided the most land for urban development but reduced habitat

quantity and quality. Greenway scenarios showed habitat increases but failed to provide sufficient habitat for Western meadowlark. Park system scenarios showed habitat increases, but high-quality habitats for Western meadowlark and Red-legged frog decreased. Network scenarios presented the best overall amount of habitats and high-quality habitats for the three species but constrained urban development options.

Next, I used an individual-based wildlife model, *HexSim*, to simulate the effects of habitat configuration and to compare and contrast resulting wildlife population sizes among the eight future scenarios with the ca. 2010 baseline landscape. Network scenarios supported the largest number of Red-legged frog breeders. Park scenarios performed best for meadowlarks, while greenway scenarios showed the largest populations of squirrels. Four of the eight scenarios sustained viable populations of Western meadowlarks. Compact development scenarios performed best for most indicators, but dispersed development scenarios performed better for Western meadowlarks.

This dissertation includes both previously published and unpublished material.

CURRICULUM VITAE

NAME OF AUTHOR: Homero Marconi Penteado

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene
University of Guelph, Guelph, ON, Canada
Universidade de Sao Paulo, São Carlos, SP, Brazil

DEGREES AWARDED:

Doctor of Philosophy in Landscape Architecture, 2014, University of Oregon
Master of Landscape Architecture, 2004, University of Guelph
Master of Architecture, 2000, Universidade de Sao Paulo
Bachelor of Architecture and Urbanism, 1995, Universidade de Sao Paulo

AREAS OF SPECIAL INTEREST:

Landscape design and planning, landscape ecology, urban open space systems, waterfronts.

PROFESSIONAL EXPERIENCE:

Professor, Universidade Federal do Espirito Santo, 2004 to present
Graduate Teaching Fellow, Department of Landscape Architecture, University of Oregon, 2009 - 2012
Professor, Faculdades Integradas Espirito-santenses, 2004
Teaching Assistant, University of Guelph, 2002 - 2003
Professor, Universidade Sao Francisco, Brazil, 2001
Professor, Pontificia Universidade Catolica de Minas Gerais, Brazil, 2001

GRANTS, AWARDS, AND HONORS:

CAPES-Fulbright PhD Scholarship, CAPES Foundation, 2008 - 2012
Facitec Research Grant, Green corridors, City of Vitoria, Brazil, 2006
Honour Award, Environmental Research Center for the Universidade Federal do Espirito Santo, Brazilian Institute of Architects, 2005
Certificate of Honour, American Society of Landscape Architecture, 2003
Arthur D. Latornell Graduate Scholarship, University of Guelph, 2002
Soden Memorial Scholarship, University of Guelph, 2002
Taffy Davison Memorial Research Travel Grant, University of Guelph, 2002
University Graduate Scholarship, University of Guelph, 2002
CNPq Graduate Scholarship, National Council of Scientific Development, 1998
CAPES Graduate Scholarship, CAPES Foundation, 1996 - 1998

PUBLICATIONS:

Penteado, H. (2013). Assessing the effects of applying landscape ecological spatial concepts on future habitat quantity and quality in an urbanizing landscape. Landscape Ecol, 28, 1909-1921.

Penteado, H. M., & Alvarez, C. E. (2007). Corredores verdes urbanos: estudo da viabilidade de conexao das areas verdes de Vitoria. Paisagem e Ambiente, 24, 57-68.

ACKNOWLEDGMENTS

I wish to express my gratitude to my advisor, David Hulse, for his guidance and uncountable insights. His work was a key influence to the development of my research. I also thank my committee members for their contribution: Bart Johnson (also for his help with non-academic matters) and Rob Ribe, for their thoughtful insights and revisions, from the early versions of manuscripts to the thorough review of this dissertation; John Bolte for his assistance with modeling; and Mark Gillem. Nathan Schumaker helped me with modeling dispersal with his software, Hexsim. And special thanks to Chris Enright, for her assistance with the mysteries of GIS.

I am also grateful to the many new friends I have made in my four years in Eugene, especially Evandro, Valter, and Heliane, who helped me feel a little closer to home.

This research was supported by the CAPES Foundation – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior. I also acknowledge the financial and institutional support I received from the Fulbright Program, from my home university – Universidade Federal do Espírito Santo, and from the Department of Landscape Architecture at the University of Oregon.

TABLE OF CONTENTS

Chapter Page

Chapter Page

LIST OF FIGURES

Figure Page

Figure Page

LIST OF TABLES

Table Page

CHAPTER I

INTRODUCTION

RESEARCH PROBLEM

The traditional process of landscape planning and design is a sequence of stages that starts with a site or landscape and a program, and develops toward implementation (Lynch 1972; Swaffield 2002; Reid 2007). Within this process, landscape architects elaborate landscape concepts - also referred to as design concepts or concept plans - to investigate alternative prescriptions for that landscape based on key organizing ideas (Figure 1). Such concepts often serve as an armature for proposed forms and patterns in prescriptions for landscape change. Over the last two decades, landscape ecology theory has increasingly become a resource of ideas for linking landscape planning to biodiversity protection. Among other sources of inspiration, landscape architects find the foundations for landscape concepts in landscape ecological principles (Dramstad et al. 1996; Botequilha Leitão and Ahern 2002; Ahern 2002; Forman 2004; Opdam et al. 2006). Authors often refer to landscape concepts based on landscape ecological principles as “spatial concepts”. A spatial concept provides a narrative and a graphic expression “of a planning issue and the actions considered necessary to address the issue" (Ahern 2005).

In this dissertation, I argue that that there is a direct relationship between the choice of spatial concept and the consequences of landscape prescriptions for landscape patterns, and consequently, to the persistence of wildlife populations of concern. I approached this project as a landscape architect seeking defensible processes for evaluating alternative urban open space plans. I sought more evidence that one spatial concept is better than another in ensuring that landscapes maintain viable populations of wildlife species and, with this evidence in hand, to enhance landscape architectural practice. I explore social-ecological relationships in a newly urbanizing landscape within a metropolitan region. In so doing, my intent is to advance open space planning theory, drawing attention to its ecological dimensions.

Figure 1. Example of spatial concept. Study of urban corridors for the City of Vitoria, Brazil (Penteado and Alvarez 2007). Green areas represent the major open spaces; orange lines are the major potential connections between open spaces; red lines are secondary connectors.

Planning new urban expansion areas is a complex multidisciplinary process that should consider various factors and include many stakeholders. Here, I focus on the ecological consequences of urbanization for three native wildlife species: Northern Red-legged frog (*Rana aurora aurora*, henceforth Red-legged frog), Western meadowlark *(Sturnella* neglecta) and Douglas squirrel (*Tamasciurus douglasii*) in areas of metropolitan expansion near Portland, Oregon.

PURPOSE OF THE STUDY AND RESEARCH QUESTIONS

The purpose of this study is to explore and test the efficacy of landscape ecological spatial concepts as tools for planning better open space systems where the goal is to sustain wildlife populations in areas facing urban expansion. I am particularly interested in examining modeling tools to understand how landscape change affects the viability of wildlife populations as metropolitan regions expand and urbanization intensifies.

Landscape ecology offers a foundation for landscape planning that aims for sustainability, innovation and biodiversity protection (Botequilha Leitão and Ahern 2002; Ndubisi 2002; Corry and Nassauer 2005; MacKenzie and Barnett 2006). Ahern argues that "landscape ecology can assist in the conception and evaluation of spatial concepts, and that the implementation of spatial concepts in landscape plans represents a basis for field experimentation which can, in turn, generate new knowledge" (Ahern 2002). Therefore, this dissertation proceeds on the assumption that landscape ecology, when used as a knowledge base for design and planning, can generate spatial concepts concerning both natural and cultural variables that can inform the planning of urban open space systems (Dramstad et al. 1996; Ahern 1999; Forman 2008b). I here test the effects of spatial concepts by addressing one over-arching question:

What are the effects of different landscape ecological spatial concepts, when applied to the design of urban open spaces, on wildlife population viability, expressed by habitat quality, quantity and spatial configuration, for representative amphibian, bird and mammal species as they experience urbanization?

I used two sub-questions to answer to this question, which represented two separate phases of research. The first phase aimed to answer the following question:

What landscape ecological spatial concepts applied to urban open space plans provide the most and the best habitats for the target species?

I addressed this question at the study area extent (Figure 4 in Chapter II) using geographic information system (GIS) data, peer-reviewed literature, and computational simulation modeling. I adopted a scenario-based research framework to investigate ecological impacts of various open space and urban development patterns. I used the computer model *Envision* as an experimental tool to depict a set of landscape ecological spatial concepts and their effects through multiple alternative future urbanization scenarios. I used a GIS to compute the habitat quantity and quality for each of three species (one bird, one mammal, one amphibian) in the resulting scenarios.

The second phase answered the following question:

What landscape ecological spatial concepts perform best in sustaining viable populations for the indicator species from a movement perspective?

The answer to this question came from an investigation of the peer-reviewed literature and modeling. I addressed this question at the urban reserve extent (Figure 8c in Chapter III) using an individual-based wildlife simulation model, *HexSim*, to test the effects of the scenarios' landscape patterns on species' life events, with focus on movements and resulting populations. I evaluated which spatial concepts performed best for the selected species collectively and individually.

SIGNIFICANCE OF THE STUDY

Research in landscape architecture aims to advance both theory (i.e., explanations) and practice by creating deeper linkages between the two. To accomplish this, I looked for explanations to serve as a basis for practical action, and to contribute to what Swaffield calls an instrumental theory (Swaffield 2002).

Several authors have proposed a bridge between landscape architecture and landscape ecology that results in planning principles and spatial concepts based on landscape ecology theory (Ahern 1991; Collinge 1996; Dramstad et al. 1996; Ahern 1999; Botequilha Leitão and Ahern 2002; Ahern 2002; Forman 2008b). However, the lack of studies that test those principles and spatial concepts in urban environments indicates a need for frameworks that support decisions and help put in practice a metropolitan plan that preserves viable wildlife populations. I seek to 1) contribute to the understanding of how spatial concepts that express broad landscape ecological principles perform if applied to address specific spatial needs of the chosen species in a metropolitan region and, 2) clarify the long-running debate between having enough habitat versus sustaining viable populations within some patterns of habitat – the influence of habitat configuration. My research aims to contribute to incorporating reliable and defensible quantitative evaluation methods that indicate the effects of different landscape patterns on wildlife populations. I propose to address this by linking the science of landscape ecology to landscape architectural open space planning.

RESEARCH DESIGN

A deductive approach starts with a formal hypothesis that is then tested experimentally (Swaffield 2002). My hypothesis is that the choice of landscape ecological spatial concept in urban open space planning produces landscape patterns that diversely affect the persistence of wildlife population in areas of urban expansion. I adopt a modeling-based approach to explore a) the relationship between spatial attributes of open space and patterns of urbanization (originated in spatial concepts), and b) their combined effects on wildlife species that use urban open spaces as habitats and conduits for moving across the landscape.

I conceptualize two strands of research. The first consists of developing an alternative future scenario-based research framework (Hulse et al. 2009) to produce scenarios of open space and land use to serve as a basis for investigating future landscape configurations. The second involves two phases of evaluations of future scenarios. The first phase evaluates the resulting amount and quality of wildlife habitats. The second phase focuses on population dynamics using a computer model to simulate the target species' life cycles. I use multiple methods and phases to develop individual components of the framework approach (Figure 2), described in the following sections.

STUDY AREA

I apply this framework to a study area in the southeastern portion of the metropolitan region of Portland, OR (see Figure 4 in Chapter II). Oregon's state-wide land use planning system requires cities to rationalize their expansion through the delineation of Urban Growth Boundaries (UGBs) (Goal 14: Urbanization/OAR 660-015-0000(14), 2006). Periodic reviews attempt to guarantee a buildable land supply within UGBs based on a 20-year population forecast. In order to plan the expansion of its UGB, Metro (greater Portland's regional government) established urban reserves – large areas designated for future urban expansion where comprehensive planning must occur prior to urbanization. In February 2010, Metro and the counties within the metropolitan region approved new urban and rural reserves. Urban development during the following 50 years (until 2060) should occur only within existing UGBs and the urban reserves (see **Error! Reference source not found.** in Chapter II). I chose Damascus's urban reserves because of its metropolitan context, appropriate scale, and availability of information (GIS files) and an expected high population growth that will cause rapid urbanization. The study area comprises the existing UGB of Damascus, OR, urban reserves adjacent to that UGB, and a half-mile (800m) buffer that surrounds them (Figure 4). The focal urban reserves for this dissertation total approximately 19 km^2 (4,644 acres, 1,879 ha).

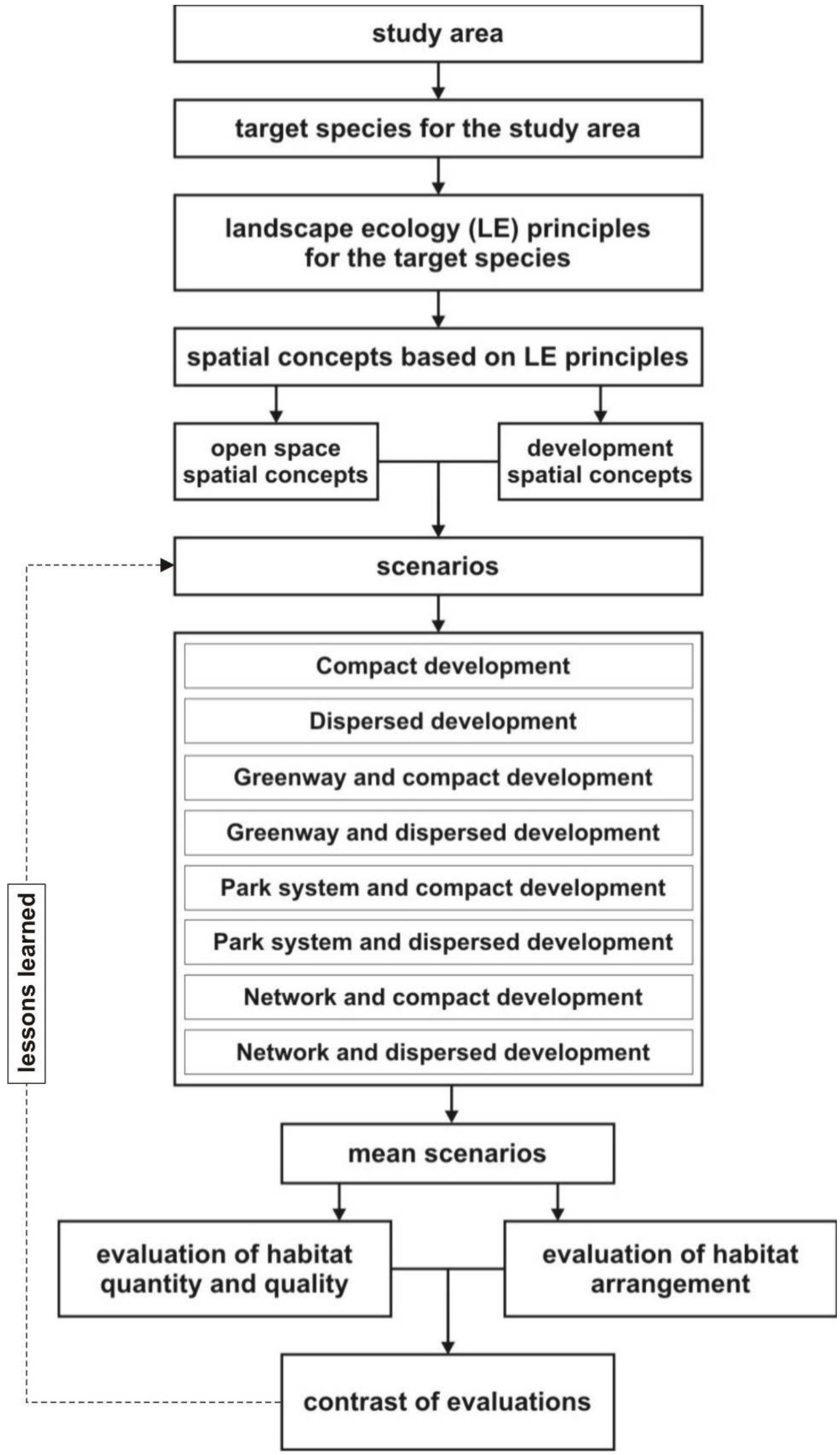


Figure 2. Research framework.

POPULATION PROJECTION

Projections for the Willamette River Basin, in which greater Portland is found, point toward a population increase from 2 million in 2000 to 3.9 million people in the year 2050 (Payne 2002; Baker et al. 2004), most of which is likely to occur in enlarged or densified urban areas. In December of 2010, the City of Damascus approved a Comprehensive Plan to guide development within the existing UGB until 2028. Damascus's Plan projects a population between 19,979 and 34,979, an increase of 10,000 - 25,000 people, and an expected density of between 1.94 and 3.4 people/acre. This projection does not include the urban reserves population. To estimate population and employment demands for the urban reserves, I calculated proportional quantities from the highest projections present in the Damascus Comprehensive Plan. The existing population in the urban reserve is approximately 2,600 people (2010 Census). The population projection adopted for the 4,644 acres (1,879 ha) urban reserves used the density for the highest growth scenario (3.4 people per acre), resulting in a population increase for Damascus of 13,400 people and a total population of approximately 16,000 people for the year 2060. The total projected 2060 population, including Damascus's and the urban reserves, is approximately 51,000 people, which was used in this study for all modeled future scenarios.

WILDLIFE SPECIES

I selected three species that occur in the study area (Figure 3), the Northern red-legged frog, the Western meadowlark and the Douglas squirrel. They require various habitat types that may be affected by urbanization. By selecting a suite of target species, planning measures to support them may also influence viability of other species with similar requirements (Rubino and Hess 2003). For example, the Red-legged frog may share habitats with Northwestern salamanders, Long-toed salamanders, Pacific chorus frog, and Rough-skinned newts (Lannoo 2005). The Western meadowlark may coexist with other grassland birds such as Western bluebird, Oregon vesper sparrow, Horned lark, Grasshopper sparrow, and Common nighthawk (Oregon Department of Fish and Wildlife 2006). Douglas squirrels share habitats with other tree squirrels such as the Northern flying squirrel and the Townsend chipmunk, and may indicate the presence of their predators (Northern spotted owl, goshawk, weasel) (Duncan 2004). Appendix B contains descriptions of each species' life history and parameters adopted for simulations.

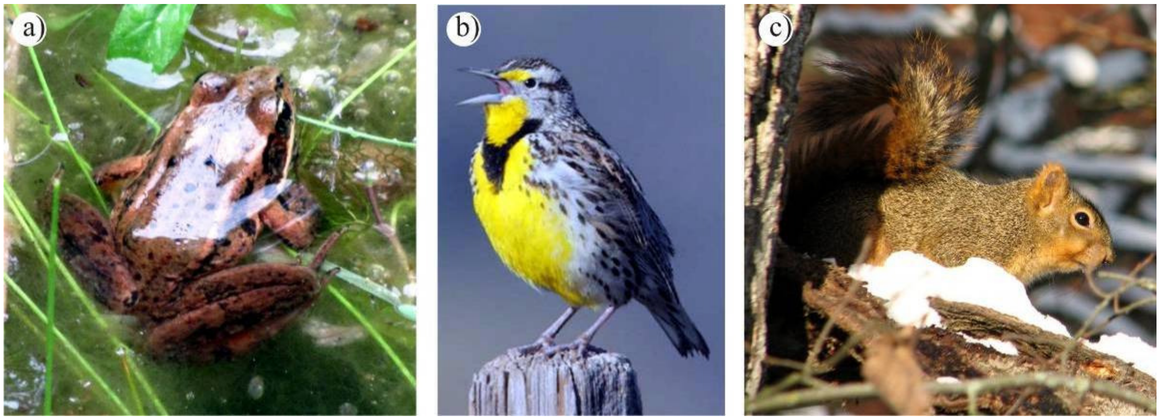


Figure 3. Target species: a) Northern red-legged frog (Rana aurora aurora); b) Western meadowlark (Sturnella neglecta) (Altman et al. 2011); and c) Douglas squirrel (Tamiasciurus douglasii).

SPATIAL CONCEPTS: OPEN SPACE AND URBAN DEVELOPMENT

I produced spatial concepts that combine patterns of open space with patterns of development. For the urban reserves, I based the open space spatial concepts on landscape ecology principles from the literature, have the potential to protect, restore and enhance habitats for the selected species. The principles focus on habitat patches, corridors and networks. Principles for patches generated open space spatial concepts for habitat conservation and restoration areas, parks, and other vegetation-dominated urban land use types with high interior:edge ratios. Principles for habitat corridors guided spatial concepts for greenways and stream corridors. Combinations of patches and corridors produced spatial concepts for networks, which are large-area open space patterns integrating patches with corridors. Urban development spatial concepts, in contrast to open space concepts, followed two patterns, compact and dispersed. Chapter II contains a summary of principles and illustrations of these spatial concepts (Figure 5a & b in Chapter II).

Scenarios

Scenarios are narratives that describe and quantify plausible future landscape characteristics. They are envisioned through maps of land use and land cover (Nassauer and Corry 2004; Swart et al. 2004; Kok et al. 2007; Mahmoud et al. 2009; Kok and van Delden 2009). Here, eight scenarios represent different configurations of open space and urban development in the urban reserves.

Scenario Simulation: Alternative Futures

An alternative future is a spatially explicit representation of a scenario's land use and land cover. I use a computer model called *Envision* (Bolte et al. 2007; Bolte 2009b) to model landscape change over 50 years of urbanization. *Envision* uses policies to produce alternative futures to model biophysical and socio-cultural goals (Bolte 2009b). For each scenario, I used *Envision* to model 20 alternative futures, each of which was consistent with the assumptions of that scenario, to depict future patterns of land uses and open space.

Spatial concepts and assumptions formed the basis for writing policies that guided scenario simulations. Policies operationalized the assumptions to achieve goals that resulted in the future scenarios. Sets of policies (Appendices D and E) determined by scenario assumptions (Appendix A) drove landscape change. Policies in this project are divided in theme groups: open space policies (conservation; creation of corridors - improvement of habitat corridors; protection of habitats; restoration of habitats; active recreation opportunities and amenities); and urban development policies (allocation of population and employment zones). Combinations of policies determined differences among scenarios (Appendix D).

Evaluation of Habitat Quantity and Quality

Because the goal of this analysis was to evaluate quantity and quality of habitats, I used two indicators means, weighted habitats and mean weighted breeding habitats, as criteria for selecting mean scenarios. Mean scenario is the alternative future representation in maps and numbers that is closest to the mean weighted habitats and weighted breeding habitats among the 20 *Envision* runs conducted for each scenario. Mean scenarios were used for comparing and contrasting total amount of suitable habitats and breeding habitats across the three species, and high-quality habitats for individual species. Chapter 2 presents specific methods.

Evaluation of Habitat Configuration

Using the mean scenarios, I modeled the target species life-events to evaluate the effects of landscape patterns on wildlife populations. I used a spatially-explicit wildlife population model - *HexSim* - to simulate species' life events. The *HexSim* analysis tested mean scenarios in providing the conditions necessary for the wildlife species to breed, feed and disperse, using population size ca. 2060 as an indicator of species viability. The study area for this evaluation was reduced to the urban reserves and an 800m buffer that surround them (see Figure 8 in Chapter III).

Comparison of Evaluation Methods

My first evaluation contrasted mean scenarios for their amount and quality of habitats. The second assessment considered the influence of habitat pattern on populations. *HexSim* tests if the results for quantity and quality of habitats obtained in the first assessment remain the same from a dispersal perspective. Because debate continues regarding the relative importance of habitat quantity, quality, and spatial pattern in determining species viability (Hodgson et al. 2011), the results from the two different evaluation methods were then compared.

DEFINITION OF TERMS

Open Space

The term "open space" has multiple and at times contrasting meanings. Some consider open space as exclusive natural areas, some as spaces for people that do not contain buildings, yet others consider combinations of both. Maruani and mit-Cohen consider open spaces as natural areas where a low level of human intervention allows ecosystem functioning and survival of nature and landscape values (Maruani and mit-Cohen 2007). For Lynch, open space is a metropolitan outdoor area where city people are free to choose what to do (Lynch 1972). Girling and Helphand's more inclusive definition embraces public and private landscape, including streets, sidewalks, yards, and driveways, and vacant and natural lands that provide public access and activity and promote the relationship between nature and community (Girling and Helphand 1997). Arendt et al. consider open space as areas with preserved vegetation and recreational uses such as hiking, biking, and trail systems for the specific cases of suburbs, subdivisions, and new towns (Arendt et al. 1994). Bengston includes "natural resource lands such as farmland and timberland, environmental resources such as wildlife habitat and wetlands, and a variety of other socially valued landscapes such as scenic sites, wilderness areas, historic and cultural resources, and recreation areas" (Bengston et al. 2004).

I use the term “open space” in the context of my urbanizing study area to mean agricultural land or forestland, conservation areas and fragments of native ecosystems that are soon-to-be urbanized, as well as non-built areas in cities including parks and plazas. A similar term – greenspace – has been used to describe open spaces that offer high ecological value (Forman 2008b). The two terms have been used interchangeably (Erickson 2006).

I define *urban* open space here as vegetated areas in a city that provide habitat for native wildlife comprised of riparian forests, patches of native vegetation, and woodlots, and the connections among them. As urban places, these areas also offer opportunities for people. They provide recreational opportunities and amenities, including parks, greenways, plazas, and streets. Parks and greenways are major types of urban open space that may support/sustain wildlife. Open space in this usage can be either public or private.

URBANIZATION

Urbanization is densification and outward spread of the built environment, the transformation of rural landscapes into urban regions (Forman 2008b). It is a maximization in the use of landscapes for human needs where strategies for protecting natural landscapes are, most times, an afterthought of master plans (Rodiek 2008). My scenarios represented two patterns of urbanization, compact and dispersed development.

There is a direct relationship between urban design and preservation of open space (Arendt et al. 1994). I used compact development patterns to maximize the area of open space. Urbanization causes large agricultural parcels and forestlands to subdivide into smaller lots for residential, commercial, industrial, or other urban uses. Decisions about density set the framework for other urban design features and have far-reaching implications (Girling and Kellett 2005). When cities expand, densification, clustering, buffering, and land acquisition may prevent excessive consumption of land and reduce impact on and protect open space (Arendt et al. 1994; Calthorpe and Fulton 2001; Calthorpe Associates et al. 2002). Arendt et al. defend adopting clustering and open space development design (OSDD), which requires developers to develop only a small portion of the parcel (Arendt et al. 1994), maintaining the largest part as open space. In open space communities, developers site homes on smaller lots than normally required if they preserve specified amounts of the natural land as open space to include trails, pathways and recreational sites, owned communally by the residents of the development. (Kaplan et al. 2004; Kaplan and Austin 2004).

Change in the mix of housing densities and types is another strategy, reducing single family development, and increasing the percentage of town-homes, small-lot single family homes, and denser commercial development (Calthorpe 2010). Concentrating rather than dispersing development greatly increases the protection of natural systems and reduces the dependence on vehicular usage (Forman 2008b). Public transit can also support compact settlements that adopt a hierarchy of neighborhoods, organized around an urban center and connected to other neighborhood and urban centers (Calthorpe Associates et al. 2002; Lukez 2007).

In this study, the highest densities used in the simulations are relatively low if compared to the ones defended in the literature (Calthorpe 2010). I adopted the densities present in Damascus's Comprehensive Plan, which were determined through a long discussion involving city planners and citizens (City of Damascus 2010).

In North America, dispersed development patterns that reduce the amount of open space prevail over more compact patterns (Girling and Helphand 1997). They produce zones of relatively low-density development, or sprawl, around the city (Bengston et al. 2004; Forman 2008b). Dispersed development results in large lots with large lawns, that result in low-density suburbs and require an extensive automobile-oriented transportation network, and specialized/segregated urban zones, big box development along major arterials with large parking areas and impervious surfaces (Vogt and Marans 2004; Kaplan and Austin 2004). The consequences of sprawl are well known: elimination of forests or agricultural lands, habitat elimination and fragmentation, increase of impervious surfaces and introduction of chemicals in watersheds, loss of open space, among others (Vogt and Marans 2004; Kaplan and Austin 2004). Disturbance by roads and pets cause consequences on bird populations (Hilty et al. 2006). However, suburbs on the fringe of urban areas are still the most desired residential development (Bengston et al. 2004). Nevertheless, low-density residential areas may provide habitats for some species (Bryant 2006) and support more diversity of species than more compact urbanization models (Steinitz et al. 1996).

The simulations produced relatively small differences of total area of urban development between compact and dispersed development scenarios. However, the spatial patterns are very distinct. Compact development scenarios showed cohesive urban patterns, while dispersed development scenarios presented scattered patterns of residential and employment areas (maps in Appendix F).

ALTERNATIVE FUTURE SCENARIOS

Future scenario studies integrate science, planning and information management to confront issues of public land use policy. They allow the formulation and comparative analysis of alternative futures for large areas (Steinitz et al. 2005). "Alternative future scenario studies explore possibilities for the future of a place, an organization or a community and the effects of choices on resources of concern" (Hulse et al. 2009). They allow decision-makers to anticipate their reactions to different future possibilities, to anticipate time-frames beyond the immediate future, and to make choices (Nassauer and Corry 2004). Alternative future scenarios permit experiments with landscape patterns and are particularly useful as planning tools to test landscape ecological spatial concepts, integrating the science of landscape ecology with landscape planning (Botequilha Leitão and Ahern 2002; Nassauer and Corry 2004). Such studies generally comprise four components: a) a landscape representation; b) a definition of assumptions or visions that guide the scenarios; c) modeling the scenarios; and d) an evaluation of scenarios with a synthesis of lessons learned (Steinitz et al. 1994; Ahern 1999; Hulse et al. 2000; Nassauer and Corry 2004; Hulse et al. 2004; Baker et al. 2004; Hulse et al. 2009).

Assumptions about future use and allocation of key resources of concern drive scenario modeling. Those assumptions are expressed by the arrangement of land use and land cover types in a digital map (Hulse et al. 2004). The digital map contains the characteristics (attributes) of the landscape that allow the representation of the landscape in various ways (land uses and habitat types, among others). Scenario assumptions translate into policies that drive the modeling of future alternatives. Assumptions are operationalized through policies that either directly alter the landscape or create conditions for future change (Steinitz et al. 2002; Ahern 2002; Hulse et al. 2009).

ORGANIZATION OF THE DISSERTATION

This dissertation contains three chapters prepared as journal articles. These individual works have been conceived, prepared, and published to be included as chapters of this dissertation.

Chapter II develops a quantitative approach to evaluating design concepts used by landscape architects to apply theory to landscape design and planning. An alternative futures study is used to test the effects on three target wildlife species of 8 alternative future scenarios, which combine open space spatial concepts with compact or dispersed urban development patterns. This chapter has been previously published (Penteado 2013).

Chapter III uses dispersal modeling to depict the effects of scenario landscape patterns on the three target species' life events. I evaluate scenarios by quantifying the number of each species supported in each scenario in the year 2060 and contrasting with ca. 2010 populations.

Chapter IV contrasts the two evaluation methods and results - habitat quantity and quality versus total population of each species - identifying agreements and discrepancies between results of the two methods.

Chapter V presents a summary of findings, as well as research limitations, recommendations for planning urban open space systems, and future research.

CHAPTER II

ASSESSING THE EFFECTS OF APPLYING LANDSCAPE ECOLOGICAL SPATIAL CONCEPTS ON FUTURE HABITAT QUANTITY AND QUALITY IN AN URBANIZING LANDSCAPE

This chapter has been previously published as:

Penteado, H. (2013). Assessing the effects of applying landscape ecological spatial concepts on future habitat quantity and quality in an urbanizing landscape. *Landscape Ecol, 28*(10), 1909-1921.

INTRODUCTION

Landscape architects and planners have a longstanding tradition of basing proposals for landscape change on key ideas for organizing space, often referred to as "design concepts" or "concept plans". Such design concepts typically serve as an armature for proposed landscape forms and spatial patterns. This article presents a quantitative approach for testing certain types of design concepts at the regional scale, which I refer to as "spatial concepts". I used a modeling approach to test the application of spatial concepts in landscape plans. It focuses on some biodiversity effects of varying open space patterns in a rapidly urbanizing landscape driven by a few landscape ecological principles. An alternative futures study was used to test three open space spatial concepts for patches, corridors and networks contrasted with compact and dispersed urban development patterns. Eight scenarios of land use and land cover were defined based on different spatial design concepts to evaluate their effects on habitat quantity and quality and analyze the tradeoffs between urban development and conservation of three focal wildlife species.

For the purposes of this study, spatial concepts are plan-view diagrams that accomplish three tasks: 1) they apply key organizing ideas to specific locations, 2) they order two-dimensional relationships and 3) they express design or planning goals in spatial form and pattern (Dramstad et al. 1996; Ahern 2002; Ahern 2005). In this regional-scale study, spatial concepts bridge landscape ecological theory to landscape planning practice on the ground.

Recent research shows that urbanization causes habitat loss, fragmentation, and loss of biodiversity (Pickett et al. 2001; Hilty et al. 2006; Wu 2008). Spatial concepts can be used to illustrate how open space and settlement patterns may merge to form distinct future scenarios that meet human needs while minimizing conflicts with biodiversity conservation as metropolitan regions expand. They can assist in demonstrating how changes to landscape patterns may affect habitat quantity and quality. This can in turn influence the viability of target wildlife populations.

The term “open space” was used in this study broadly to mean agricultural land, conservation areas and fragments of native ecosystems that are soon-to-be urbanized. I define *urban* open space here as vegetated areas in a city that provide habitat for native wildlife comprised of riparian forests, patches of native vegetation, woodlots, and the ecologically functional connections among them. As urban places, these support a diversity of human uses including parks, greenways, community gardens, plazas, and streets (Lynch 1972; Marcus and Francis 1998; Bengston et al. 2004; Girling and Kellett 2005), and provide multiple benefits to ecosystems and urban residents (Tzoulas et al. 2007).

Landscape ecology is often argued to be a useful and appropriate perspective for planning landscapes and for promoting urban sustainability (Botequilha Leitão and Ahern 2002; Ahern 2005; Girling and Kellett 2005; Wu 2008). The concept of land mosaics (Forman 1995) captures the spatial distribution of three components of landscape pattern: patches, corridors, and the matrix. The patch-corridor-matrix model provides a taxonomy of open space systems that organizes an understanding of open spaces in relation to each other and to people (Forman 2008b). The patch-corridor-matrix model is a bridging concept useful to "translate the knowledge of patterns and processes into spatial frameworks and principles for creating sustainable spatial arrangements of the landscape" (Ndubisi 2002). Systems of interconnected patches and corridors woven into a landscape matrix and connected to external and internal source areas form habitat networks (Cook 1991). Land mosaics (Forman 1995) and networks (Cook 1991) provided a basis for creating open space spatial concepts. Key urban form principles, in turn, provided a basis for development of spatial concepts that have the potential to improve protection and connectivity of open spaces and habitats (Arendt et al. 1994; Calthorpe and Fulton 2001; Calthorpe Associates et al. 2002; Dunham-Jones and Williamson 2009).

The goal of this study is to evaluate the effectiveness of using various landscape ecological spatial concepts in providing enough habitats for the three target species. The goal of scenarios was to depict a wide range of alternative futures and test various spatial configurations for the year 2060 in the urban reserve, with a focus on patterns that protect or improve the diverse habitats needed by the target species in the several stages of their life cycles. This work does not assess population viability, but instead the spatial conditions provided by the area and quality of habitats as they are correlated to wildlife population viability.

METHODS

In this study, spatial concepts are central as a planning and communication tool to address biodiversity conservation in urban areas. Spatial concepts serve as a link between landscape ecology theory and prescriptions for landscape change. The life cycles and habitat requirements for selected target species provided some of the basic requirements for alternative future planning prescriptions, along with human population projections and the resulting housing, employment, and recreation land uses. Landscape ecological principles to address target species' needs were identified from the literature, as were urban development strategies that accommodate the growing human population. Spatial concepts that express landscape ecological principles and urban development strategies were developed as the foundation for different scenarios. Sets of policies that capture rules, regulations, incentives, and other strategies were developed to operationalize spatial concepts and drive landscape change in scenario modeling (Bolte et al. 2007).

This study employed an alternative future scenarios modeling-based approach to urban open space planning. Scenarios have been adopted by governments, corporations, and scholars to systematically frame uncertainties about political, economic, and sustainability issues (Swart et al. 2004). Alternative future scenarios were used to explore landscape ecological spatial concepts as a design and planning technique for protecting biodiversity (Dramstad et al. 1996; Botequilha Leitão and Ahern 2002; Nassauer and Corry 2004; Ahern 2005; Nassauer 2012; Thompson et al. 2012).

Eight future scenarios were defined and modeled by combining landscape ecological and urban development spatial concepts. The eight scenarios are thus comprised of a fully crossed 4 x 2 factorial combination of four open space scenarios (none, greenway, park system, and network), and two development scenarios (compact and dispersed). Resulting patterns were then compared for the amount and quality of habitat for the target species.

A computer program, *Envision* (Bolte et al. 2007; Bolte 2009b) was used to simulate 50 years of landscape change and to depict alternative futures for eight scenarios of land use and land cover. These were generated for an area designated for future eastward urban expansion of Damascus, Oregon, a newly incorporated city in Portland's metropolitan region. *Envision* also provided a modeling environment to evaluate how the resulting landscape patterns could affect habitat quantity and quality for three sensitive wildlife species: Northern red-legged frog *(Rana aurora aurora*, henceforth Red-legged frog), Western meadowlark *(Sturnella neglecta*), and Douglas squirrel *(Tamiasciurus douglasii*).

STUDY AREA

I applied this framework to urban reserves adjacent to Damascus, OR, in the southeastern portion of the Portland metropolitan region (Figure 4a,b). In Oregon, urban reserves are large areas designated for future urban expansion where comprehensive planning must occur prior to urbanization. The urban reserves total approximately 1,879 ha. Land use changes from pre-Euro-American settlement conditions (ca. 1851) to the present (ca. 2010) produced a highly fragmented landscape of agricultural, forest and suburban patches, with significant alteration of aboriginal habitats (Figure 4c,d). The present Damascus limits and an 800 m buffer are included in the study area to provide spatial and ecological context. However, spatial concepts are applied exclusively to the urban reserves.

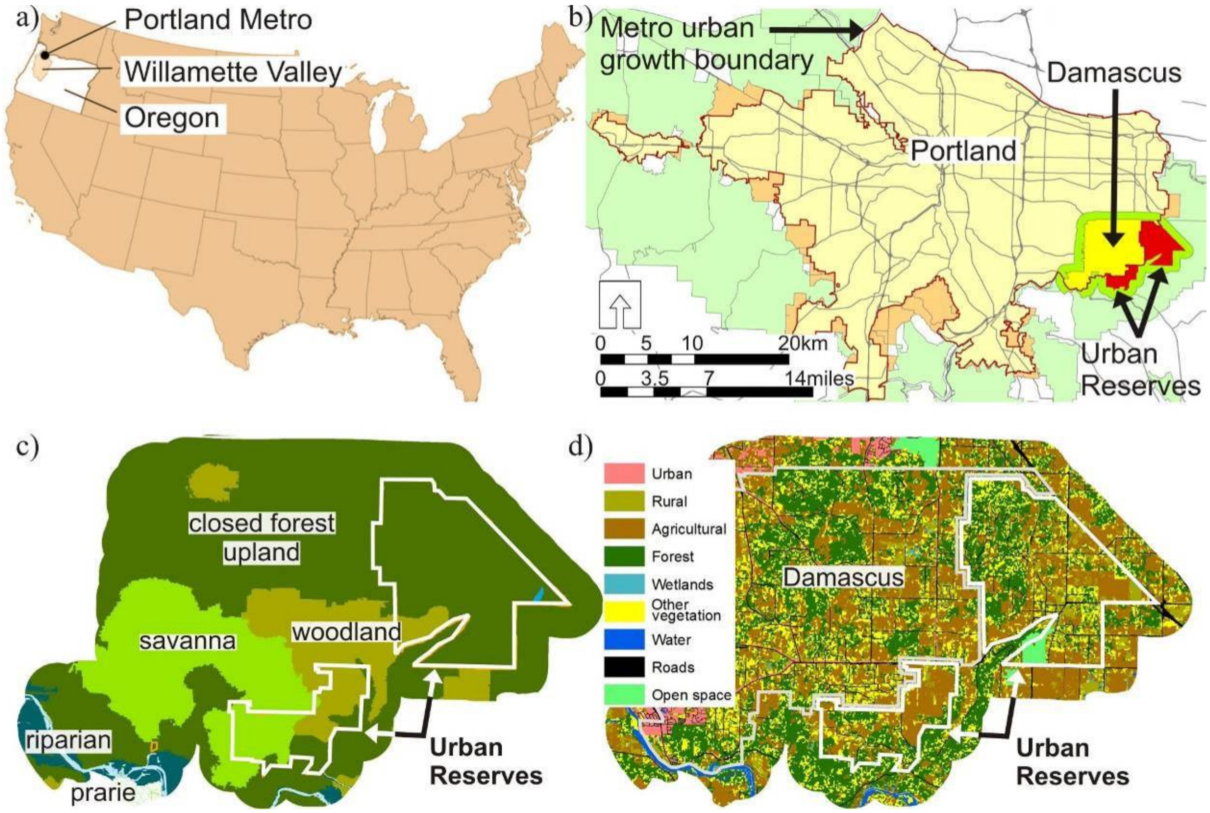


Figure 4. a) Study area within continental United States; b) the study area located southeast of Portland's metropolitan area. c) Pre-Euro American settlement vegetation (ca. 1851). Presence of large, homogeneous, contiguous land cover types; d) ca. 2010 land cover. Rural uses prevail. The highly pixelated map demonstrates the high degree of habitat fragmentation.

TARGET WILDLIFE SPECIES

Three indicator wildlife species were chosen for their presence in the study area, their susceptibility to the habitat fragmentation that typically results from urbanization, their conservation status, and as a means to represent the potential effects on other species that may be affected by urbanization.

The Red-legged frog breeds in vegetated shallows of wetlands, ponds, ditches, springs, marshes, margins of large lakes, slow-moving portions of rivers where emergent vegetation is abundant, and occasionally in house yards, neighborhood parks, and small stormwater storage areas (O'Neil 2001; Davidson et al. 2001; COSEWIC 2004; Lannoo 2005; Chelgren et al. 2006). They migrate seasonally between forested areas and wetland breeding sites (Kiesecker and Blaustein 1998; COSEWIC 2004; Lannoo 2005; Chelgren et al. 2006). The Red-legged frog shares habitats with Northwestern salamanders, Long-toed salamanders, Pacific chorus frogs, and Rough-skinned newts (Lannoo 2005).

The Western meadowlark forages and nests in large areas of grasslands and prairies (> 6 ha) that may be comprised of several patches (Davis et al. 2006), uses scattered shrubs, trees or posts for singing perches (Morrison 1993; Oregon Department of Fish and Wildlife 2006) and is more abundant in grassland interiors (Haire et al. 2000; Jones and Bock 2002). Golf courses may also contribute to conservation of bird communities (LeClerc and Cristol 2005). The Western meadowlark may coexist with other grassland birds, such as Western bluebird, Oregon vesper sparrow, Horned lark, Grasshopper sparrow and Common nighthawk (Oregon Department of Fish and Wildlife 2006).

The Douglas squirrel is abundant in the Willamette Valley, but urbanization may significantly reduce its coniferous forest habitats and increase road mortality. Douglas squirrels are associated with old-growth conifer stands, but may be abundant in second-growth or mature stands (Ransome and Sullivan 2004). Their home range is less than 0.6 ha (O'Neil 2001). They compete for the same habitats as other tree squirrels (Northern flying squirrel and Townsend chipmunk) and may indicate the presence of their predators (Northern spotted owl, goshawk, weasel) (Duncan 2004).

Landscape Ecological Principles

Three landscape ecological sets of principles were adopted in the open space plans: patches (variation in form size, distribution, and diversity), corridors (riparian and greenways) and networks. Dramstad et al. (1996) have published an illustrated handbook with key principles derived from landscape ecological theory that are applicable to landscape design and planning. These principles have been widely adopted in the practice and education of landscape architects. Other authors have also addressed the adoption of the land mosaic theory as a basis for planning (Ahern 1999; Botequilha Leitão and Ahern 2002). The principles for patches, corridors and networks focused on patterns that are likely to affect the target species. Grasslands, oak savannas, conifer and riparian forests, and wetlands are the major habitat patches and corridors for the target species addressed. Networks are combined arrangements of corridors and patches (Cook 1991).

2060 Human Population Projection

Projections for the Willamette Valley, in which the greater Portland area is located, point toward a population increase from 2 million ca. 2000 to 3.9 million people ca. 2050 (Baker et al. 2004), most of which is likely to occur in enlarged and/or densified urban areas. The City of Damascus projects a maximum density of 8.4 people/ha within its existing urban limits (City of Damascus 2010), resulting in a total population of approximately 35,000 in year 2028. To estimate population and employment demands in the urban reserves for the modeled year 2060 (a 50 year planning horizon), this highest density projection was adopted to explore the most challenging open space protection scenario. According to this projection, the study urban reserves can be expected to have 13,400 new inhabitants added to the existing 2,600 people (2010 Census), resulting in a population of approximately 16,000 people. The total projected 2060 population, including Damascus's and the urban reserves, is approximately 51,000 people, which was used in this study for all modeled future scenarios.

Urban Development Principles

Key urban development principles were adopted in the scenarios. Development decisions to protect open space in the urban reserves should consider both regional and local scales:

a) Metropolitan regions offer opportunities to accommodate development with reduced impact on natural resources than historic or unplanned patterns. Planning at the regional scale should direct development to areas of low ecological value, while gaps in urban patterns of building-dominated land use can allow vegetation in natural areas that may provide a potential network of open space and habitats (Forman 2008b).

b) There is a direct relationship between urban design decisions about density, where buildings dominate, and preservation of open space, where vegetation dominates (Arendt et al. 1994). Compact patterns of urbanization prevent excessive consumption of land, reduce infrastructure expense and protect open space. Strategies include densification, clustering, enhancing the mix of housing densities and types, reducing single-family development, and increasing town-homes, small-lot single-family homes, and denser commercial development (Arendt et al. 1994; Calthorpe and Fulton 2001;

Calthorpe Associates et al. 2002; Bengston et al. 2004; Kaplan et al. 2004; Kaplan and Austin 2004; Forman 2008b; Calthorpe 2010).

c) Areas near key intersections with higher density and transit stops can provide a walkable, attractive and pedestrian-friendly environment (Beyard et al. 2001).

d) A high proportion of single-family development and large lots predominate in more dispersed patterns of urbanization. Some wildlife species may be supported in these dispersed urban areas.

SPATIAL CONCEPTS

I developed five spatial concepts, three for open space and two for settlement patterns, which were used as the basis for defining a suite of eight scenarios in the urban reserves. The *Stream network as an armature for habitats and connectivity* spatial concept (Figure 5a), with an emphasis on corridors, provides corridors for Red-legged frog and Douglas squirrel. Riparian vegetation and greenways function as corridors. The *Stepping-stones for habitats and connectivity in a fragmented landscape* spatial concept (Figure 5b), with an emphasis on patches, protects and improves habitat patches such as wetlands, mature forests, oak savannas and grasslands. Patches are present in the form of parks for active and passive recreation, conservation areas (forest, grassland, wetlands), agricultural land managed for wildlife, small parks, rain gardens, stormwater structures, community gardens, urban farms, and low-density residential areas. The *Open space network for maximum connectivity* spatial concept (Figure 5c) spatially integrates corridors and patches to form the most comprehensive open space system.

Development spatial concepts express settlement patterns to meet housing and employment demands. The *Compact development for open space conservation* spatial concept (Figure 5d) emphasizes compact communities, public transit, and urban centers with higher densities and mixed-use, concentrate development to protect open space in areas that produce lower impact on habitats. Higher densities consume less land, demand fewer roads, produce a smaller physical footprint, and protect more habitat area. The *Dispersed development for spacious living* spatial concept (Figure 5e) is based on lower densities and single-family development. It maintains the current desire among urban migrants for more spacious living. This spatial concept reflects recent market trends of low-density suburban development with the attendant pattern of open space and leftover rural patches.

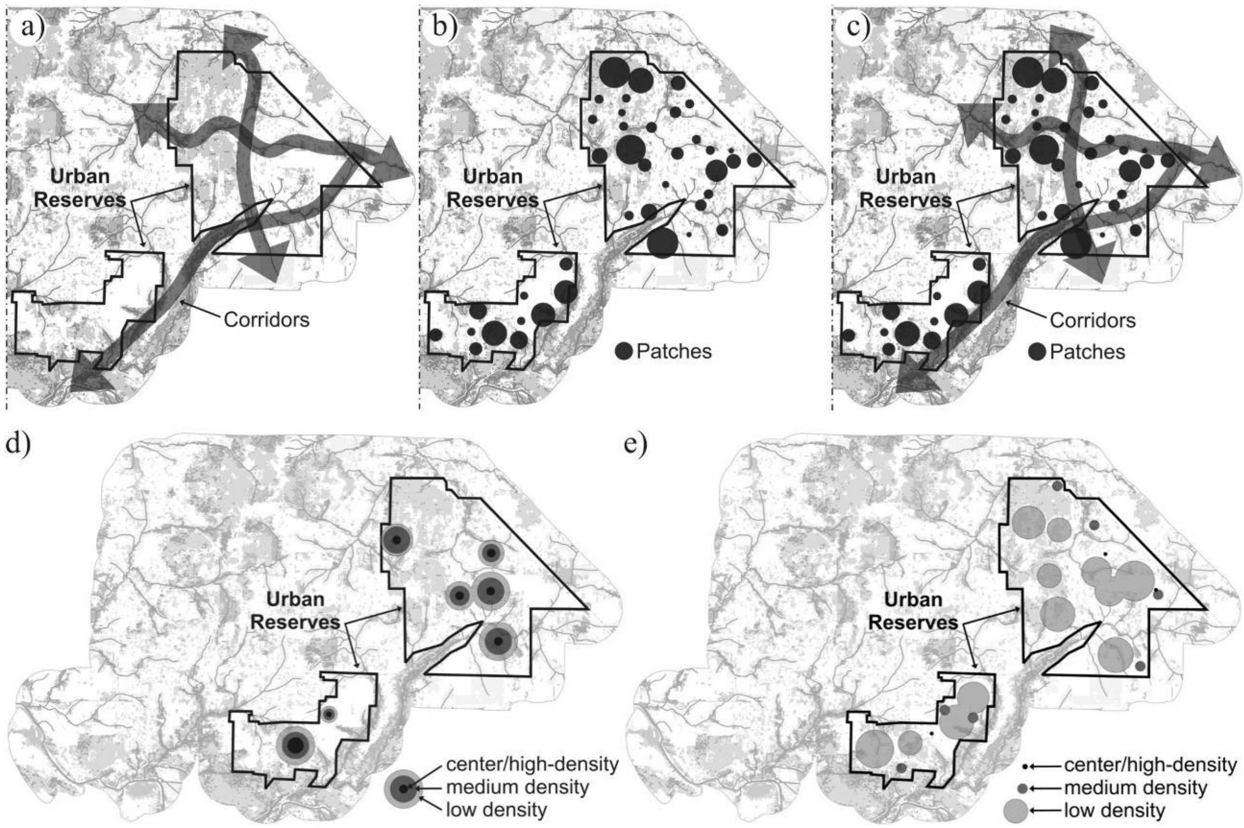


Figure 5. Open space spatial concepts: a) Stream network as an armature for habitats and connectivity; b) Stepping-stones for habitats and connectivity in a fragmented landscape; and c) Open space network for maximum connectivity. Urban development spatial concepts: a) Compact development for open space conservation; b) Dispersed development for spacious living.

SCENARIOS THAT COMBINE OPEN SPACE AND URBAN DEVELOPMENT SPATIAL CONCEPTS

The scenario-based research framework for alternative futures consisted of the following parts (Hulse et al. 2004; Hulse et al. 2009): 1) assumptions about open space and urban development for some bounded place over some period of time; a logically coherent group of these assumptions comprise a scenario; 2) changing landscape conditions representations of each scenario including narratives and maps for year 2060; 3) an evaluation of effects of alternative futures on habitat quantity and quality for the target species as a group, and for high-quality habitats for individual species; and 4) a summary of lessons.

Eight scenarios that combine open space and urban development spatial concepts illustrate alternative futures for the urban reserves (Table 1). Each open space spatial concept adopts a prevailing open space type as a planning strategy. A null scenario concept of no open space plan was also included. Urban development spatial concepts contrast compact and dispersed development strategies. All scenarios assume the same population projection.

Table 1. Scenarios across the rows combine open space and development spatial concepts.

SCENARIO	OPEN SPACE SPATIAL CONCEPT	OPEN SPACE EMPHASIS	OPEN SPACE TYPES	URBAN DEVELOPMENT SPATIAL CONCEPT	DEVELOPMENT EMPHASIS
CD: Compact Development	---	---	---	Compact development for open space conservation	Mixed use Higher densities
DD: Dispersed Development				Dispersed development for spacious living	Single family Lower densities
GCD: Greenway and Compact Development	Stream network as an armature for habitats and connectivity	Core habitats and corridors	Riparian vegetation and buffers, greenways, trails	Compact development for open space conservation	Mixed use Higher densities
GDD: Greenway and Dispersed Development				Dispersed development for spacious living	Single family Lower densities
PCD: Park System and Compact Development	Stepping-stones for habitats and connectivity in a fragmented landscape	Patches and stepping-stones	Low-density residential areas, parks, urban farms, community gardens	Compact development for open space conservation	Mixed use Higher densities
PDD: Park System and Dispersed Development				Dispersed development for spacious living	Single family Lower densities
NCD: Network and Compact Development	Open space network for maximum connectivity	Corridors and patches	Combination of the above	Compact development for open space conservation	Mixed use Higher densities
NDD: Network and Dispersed Development				Dispersed development for spacious living	Single family Lower densities

Assumptions

Assumptions and visions of the future define each scenario (Hulse et al. 2004). Because planning goals were to provide habitats for the target species and to accommodate future human population growth, general assumptions concerning habitat protection and urban development patterns were made; specific assumptions described open space and urban form emphasis for each scenario (Appendix A).

Scenario Representation: Alternative Futures

The simulation software *Envision* was used to produce 20 spatially explicit representations of each scenario. Each of these representations is an alternative future represented by a polygonal map in a geographic information system (GIS). Each polygon contains a set of attributes needed for modeling the scenarios. *Envision* creates dynamic spatial maps by probabilistically selecting qualifying polygons for different land use change policies at each time step of each alternative future land use and land cover scenario. The software performs a random selection among valid candidate polygons.

Each alternative future simulation starts with a representation of ca. 2010 conditions built on available data from the Pacific Northwest Ecosystem Research Consortium (Hulse et al. 2000; Hulse et al. 2002; Hulse et al. 2004; Baker et al. 2004; Hulse et al. 2009) and from the Metro Portland RLIS Geographic Information System (Metro 2011). The urban reserves have the finest grain to allow simulations to represent future urban structure, with a maximum polygon area of 0.9 ha. Damascus and a 800 m-buffer were included in the simulation to connect the urban reserves, provide source areas for wildlife, and simulate the totality of the projected population (51,000 people). These areas have a coarser grain because the spatial concepts apply exclusively to the urban reserves. Color scenario maps are shown in Appendix F.

Scenario Evaluation

This evaluation focused on interpreting how the choice of spatial concepts determined landscape patterns - determined by the arrangement of open space and urban development - as they influence habitat quantity and quality in the future scenarios. The quantity and quality of habitats for the three species were examined both as a group and individually, along with the area of urban development as an indicator of settlement goals achievement.

To assess the landscape-level habitat value for each target species at year 50 of each alternative future and compare the quantity and quality of habitats across scenarios, I multiplied the area of each polygon (in hectares) by its Adamus Resource Assessment (ARA) score for each species (Schumaker et al. 2002; Baker et al. 2004; Schumaker et al. 2004). The ARA score indicates habitat suitability for each species ranging from zero to ten. The ARA score, as used here, does not address structure or connectivity. I constructed two metrics: *weighted habitats* is the sum of ARA x hectares of all polygons across all three species; weighted breeding habitats is the sum of ARA x ha of highly-scored polygons used for breeding by each species. Each metric produced one single number for each scenario run. The mean weighted *habitat* was selected among 20 alternative futures produced for each scenario to compare and contrast the eight scenarios. I used a two-way ANOVA to analyze the influence of the choice of open space and urban development spatial concepts on landscape-level habitat metrics. The full model included the interaction between these two factors. I used a Tukey's test to assess multiple pairwise comparisons. Distributions were checked for ANOVA normality assumptions and did not require transformation. Significance was assessed at the $p < 0.05$ level for all comparisons. Coefficients of variation among runs ranged from 0.003 to 0.012 (Figure 6).

I also compared the amount of *high-quality habitats* for individual species in each mean alternative future. High-quality habitats are those that have the best conditions to support breeding, foraging, and movement, and have a high ARA score (>7). For the Red-legged frog, high-quality habitats correspond to wetlands (breeding), and riparian and moist upland forests (seasonal migrations); for Western meadowlark, grasslands and oak savannas; and for Douglas squirrel, mature and old growth forests.

RESULTS

The effects of the interaction between open space and development spatial concepts on each scenario's *weighted habitat* means were not significant (interaction $p > 0.10$). Development spatial concepts (compact and dispersed) produced small differences among scenario means, while open space spatial concepts caused larger differences in habitat results. Values ranged from 10,653 (ha x ARA score) in the CD (Compact Development, no open space strategy) scenario to 14,730 in the NDD (Network and Dispersed Development) scenario (Figure 6a).

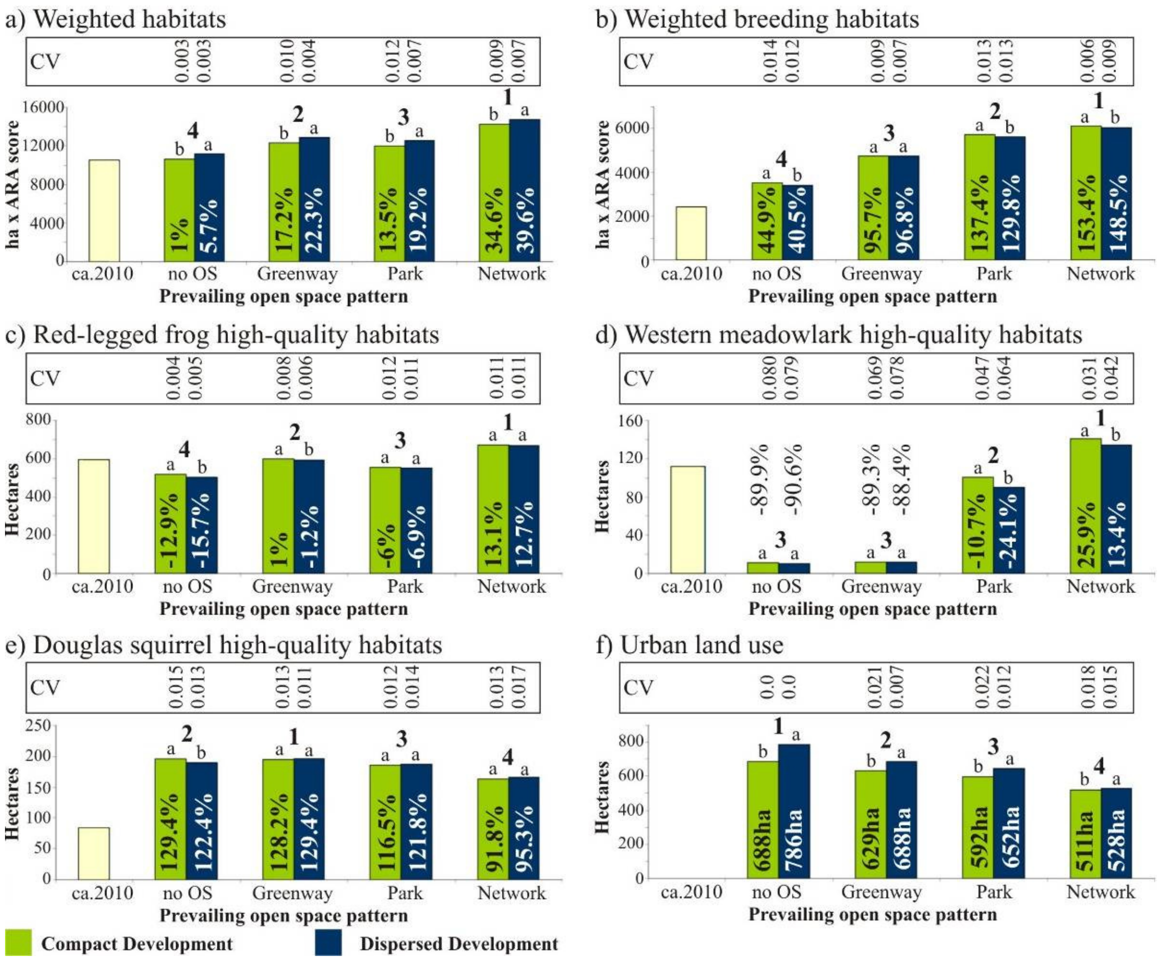


Figure 6. Indicators of landscape change between ca. 2010 urban reserves and 2060 mean alternative futures. CV is the coefficient of variation among scenario runs. Numbers on top of bars indicate significant differences among open space patterns; different letters indicate statistically significant differences between compact and dispersed patterns; percentages indicate increase or decrease. The horizontal axis shows ca. 2010 conditions and 2060 alternative futures in all graphs. Note different scales on the vertical axes. a) Weighted habitats for all three species (hectares x ARA score); b) Weighted breeding habitats for all three species (hectares x ARA score); High-quality habitats for c) Red-legged frog, d) Western meadowlark, and e) Douglas squirrel; f) Area occupied by urban land uses (in hectares).

All dispersed development scenarios presented *weighted habitat* means higher than compact development scenarios (Figure 6a). The larger area occupied by low-density residential development, which can function as habitats for some species, highly influenced this result. Network scenarios presented the highest increase of weighted *habitats* between 2010 and 2060 (Figure 6a).

There was a significant interaction effect between open space and development spatial concepts in determining the amount of *weighted breeding habitats* ($p < 0.05$) (Figure 6b). Alternative future scenarios employing no open space spatial concept presented the lowest increase of breeding habitats, while the network scenarios presented the highest such values. Except for the greenway scenarios, all *compact* development scenarios presented a higher score of *weighted breeding habitats* than dispersed development scenarios did (Figure 6b). Again, network scenarios presented the highest increase in breeding habitats between 2010 and 2060.

The interaction between open space and development spatial concepts highly influenced the amount of *high-quality habitats* for the Red-legged frog ($p < 0.05$) (Figure 6c). The most significant differences were determined by open space spatial concepts ($p < 0.05$). The interaction between compact and dispersed development spatial concepts and open space spatial concepts also influenced *high-quality habitats* for Western meadowlark ($p < 0.05$) (Figure 6d) and for the Douglas squirrel ($p < 0.05$) (Figure 6e).

Relative to 2010, only the network scenarios presented more *high-quality habitat* area for all species (Figure 6c-e). Red-legged frog high-quality habitats increased in the NCD and NDD scenarios. Western meadowlark high-quality habitats increased in the NCD and NDD scenarios. Douglas squirrel high-quality habitats increased in the NCD and NDD scenarios.

High-quality habitats for the Red-legged frog decreased in area in the CD, DD, GDD and both Park System scenarios. The GCD scenario presented a small increase. High-quality habitats for Western meadowlark had a steep reduction in the "no open space" and greenway scenarios. Park system scenarios presented smaller losses of high-quality habitats for the Western meadowlark. High-quality habitats for Douglas squirrel increased in all scenarios. The smallest such gains occurred in the network scenarios, where they nearly doubled. All other scenarios more than doubled high-quality habitat area for the Douglas squirrel.

There was no urban area in the urban reserves in its ca. 2010 conditions. In the year 2060, the highest contrasting land cover areas occupied by urban land uses range from 518 ha in the NCD scenario to 786 ha in the DD scenario, a 51.7% difference (Figure 6f). Comparing scenarios with identical open space spatial concepts, all dispersed development scenarios consumed more area in urban uses than compact development scenarios. The area occupied by urban development was influenced by the interaction of open space and development ($p < 0.05$) (Figure 6f). The network scenarios allow the smallest area for urban development. The largest land consumption for urban development occurred in scenarios that have no open space policy.

DISCUSSION

Wildlife population viability results from a combination of habitat area, quality, and spatial arrangement of habitats; the weight and role of each of these factors on landscape-scale conservation is landscape-specific (Hodgson et al. 2011). Although recognizing the importance of connectivity, this study focused on the amount and quality of habitats for the indicator species. To assess the viability of those species in an urban environment it is necessary to assess processes such as road mortality, mortality during seasonal migration, predation by pets, disturbance, and edge effects, among other.

Compact (CD) and Dispersed Development (DD) scenarios (no landscape ecological spatial concept) presented more developed land (Figure 6f) and less total amount of habitats (Figure 6a,b) than other scenarios. These scenarios had the worst results for all habitat indicators but the Douglas squirrel *high-quality habitats* (Figure 6e). The amount of *high-quality habitats* for the Red-legged frog was smaller but comparable to 2010 quantities. These outcomes result from the assumption that existing riparian zones (ca. 2010) are protected from development under current legislation. This allows vegetation succession in those areas, what created new or improved habitats for these species.

Greenway scenarios showed the second best outcome for total amount of habitats and third for total breeding habitats. These scenarios were somehow neutral for the Red-legged frog. Douglas squirrel presented increases in high-quality habitats (Figure 6c), but the results were devastating for the Western meadowlark (Figure 6d). The focus on corridors left large habitat patches unprotected and allowed development over a larger area, resulting in the second largest developed area among scenarios (Figure 6f).

Park system scenarios had the second best result for weighted breeding habitat (Figure 6b), but both the Red-legged frog and the Western meadowlark had a reduction of high-quality habitats compared to 2010 (Figure 6c,d). Compact development patterns showed a pronounced advantage over the dispersed patterns for the Western meadowlark (Figure 6d).

Network scenarios presented the best habitat results among all scenarios for all indicators (Figure 6a-d) but the Douglas squirrel high-quality habitats (Figure 6e), which had the smallest increase compared to 2010. The two other species had the most high-quality habitats in the network scenarios (Figure 6c,d). Once again, compact development patterns were significantly better for the Western meadowlark (Figure 6d). These results indicate a more balanced distribution of habitats among the three species. All had substantial increase of *high-quality habitats* compared to 2010 amounts. In opposition, the larger habitat area constrained developed land. The network scenarios presented the smallest area occupied by urban land uses.

A closer look at a portion of the urban reserves (Figure 7) shows the variations of open space and development patterns among scenarios. Scenarios that adopt the same open space spatial concept show similar habitat patterns. Urban development patterns of all compact development scenarios (Figure 7b,d,f,h) show more cohesive urban areas than dispersed development scenarios (Figure 7c,e,g,i).

While greenway (Figure 7d,e) and network (Figure 7h,i) scenarios show continuity of open space - what may indicate more connected habitats and may create dispersal corridors for the Red-legged frog and Douglas squirrel - park system scenarios (Figure 7f,g) produced large isolated patches within the urban and agricultural matrices. Agricultural lands also show the effects of different spatial concepts. While the remaining agricultural lands maintained certain contiguity in the compact development scenarios (Figure 7b,d,f,h), urban zones fragmented farmland in all the dispersed scenarios (Figure 7c,e,g,i). Contiguous agricultural lands may provide opportunities for maintaining viable productions and avoid conflicts with residential areas. Larger agricultural areas can be managed for grassland birds.

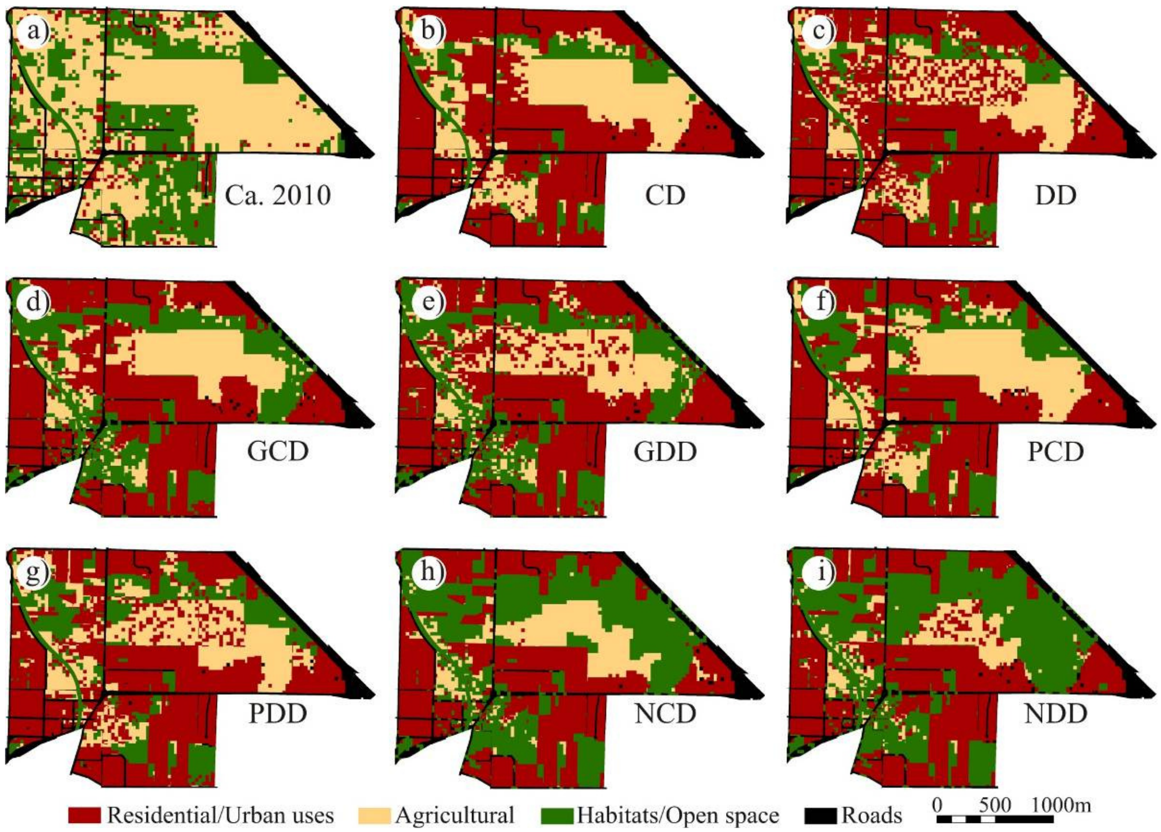


Figure 7. Landscape patterns in a portion of the urban reserves: a) existing conditions (ca. 2010); b) and c) compact vs. dispersed development with no open space spatial concepts; d) and e) greenway scenarios; f) and g) park system scenarios; and h) and i) network scenarios.

The results suggest that if one does not put too much priority on species like the meadowlark, other wildlife may do reasonably well in the greenway scenario, which allows more developable land than park and network scenarios. More stringent open space spatial concepts (as in the network scenarios) provided the best conditions for wildlife populations, but constrained urban development options. A minimum-conservation approach to open space (no landscape ecological spatial concept - CD and DD scenarios) provided more land for urban development but reduced amount of good-quality habitat as would be expected. Park system scenarios created large patches, but failed to establish visible physical connections between habitats. Network scenarios presented the best overall results for the three species, but had the least availability of developable land. Protecting large-area sensitive species like the meadowlark should drive more compact urban development, but some attention to corridors could provide more physically connected habitats for other species.

The landscape ecological spatial concepts tested in this study examined species as the major focus of planning decisions. Decisions about how urban development will unfold should happen concomitantly with ecological decisions, and both should influence each other. Decisions about urban open space and urban form, however, also involve economic, social, and political factors. These include land value as it changes with availability or proximity to open space, street network requirements, costs of infrastructure, degree of difficulty in implementing public transportation, walkability, and sociability, among other. These and other aspects that may vary from community to community must also be considered in planning, but habitat conservation should rank well among these other goals. Somehow legal constraints, real-estate markets, and owner propensities must also affect the urban forms that do get built, but people should decide first what kind of nature they want to experience in cities.

CHAPTER III

A DISPERSAL MODEL APPROACH TO ASSESS THE EFFECTS OF LANDSCAPE ECOLOGICAL SPATIAL CONCEPTS OF OPEN SPACE AND URBAN DEVELOPMENT ON WILDLIFE POPULATION VIABILITY IN AN URBANIZING LANDSCAPE

INTRODUCTION

Urbanization is one of the major causes of habitat loss and fragmentation, which directly affects the ability of wildlife species to disperse and maintain viable populations (Schumaker 1996; Opdam et al. 2006). Predicting animal population response to land-use changes is critical to making well-informed decisions (McRae et al. 2008b). This article demonstrates a modeling approach for evaluating the effects of future urban open space plans on wildlife species persistence in urbanizing landscapes. I evaluated eight scenarios for an area of future metropolitan expansion in Portland, Oregon. Scenarios for the year 2060 were depicted in geographical information system (GIS) maps, and combined four patterns of open space (none, corridors, patches, and networks) with two patterns of urban development (compact and dispersed). Principles of landscape ecology informed the proposition of spatial concepts, which were the basis for producing open space and urban development patterns in the future scenarios (Penteado 2013). Spatial concepts are diagrammatic expressions of principles used by landscape architects and planners to organize ideas and communicate prescriptions for future landscape change. The work reported here focuses on landscape ecological spatial concepts that support biodiversity conservation (Dramstad et al. 1996; Forman and Collinge 1997; Ahern 1999; Botequilha Leitão and Ahern 2002; Opdam et al. 2006).

I used a demographic/dispersal model, *HexSim*, to assess the viability of populations of three wildlife species that are likely to be affected by urbanization in the study area and have contrasting habitat preferences: Red-legged frog (*Rana aurora aurora*), Western meadowlark (*Sturnella neglecta*), and Douglas squirrel (*Tamiasciurus douglasii*).

Recent studies have applied dispersal models to evaluate the effects of habitat arrangement on persistence of wildlife species at different scales and contexts (Calkin et al. 2002; Schumaker et al. 2004; Carroll et al. 2004; McRae et al. 2008b; Marcot et al. 2012; Stronen et al. 2012). McRae et al. (2008) combined a model of climate change with an animal population model [PATCH] to study the response of two bird species; Marcot et al. (2012) used a dispersal model to assess the effects of size and spacing of patches of habitat on Northern spotted owls; Stronen et al. (2012) simulated the effects of human disturbance on wolf populations. Heinrichs et al.used *HexSim* to simulate the population dynamics of the Ord's kangaroo rat (*Dipodomys ordii*) in Alberta, Canada (Heinrichs et al. 2010). However, none of these studies address urban environments, or landscapes undergoing rapid urbanization.

In summary, this study explores the consequences of the choice of open space and development patterns for wildlife populations. The goal is to test an approach able to provide landscape architects and planners with quantitative information to compare among alternatives for the future of a region and to make well-informed land use planning decisions that affect persistence of wildlife species; a quantitative method that can be incorporated into conventional metropolitan planning processes (Marulli et al 2005).

METHODS

This modeling approach combined land-use and land-cover configurations with wildlife population dynamics. First, I chose a region that will be subject to urbanization in the next 50 years (2010-2060). I then chose three species that urbanization in that area is likely to affect. I produced eight scenarios of open space and urban development that present distinct landscape patterns (Penteado 2013) using computer software *Envision* to produce 20 rule-based replicates of each scenario. Scenario land-use maps were converted to habitat suitability maps for each of the three species (Schumaker 2004, Baker 2004, Hulse 2004). I used those suitability maps and species' life history parameters with *HexSim* to develop dispersal models and evaluate the effects of the various landscape arrangements on individual dispersal and resulting populations. The following sections describe these steps.

The goal was to produce simulations that were complex enough to capture the influence of landscape patterns on the ability of animals to move across the landscape to establish territories and breeding habitats, but simple enough to be incorporated in conventional metropolitan planning processes.

STUDY AREA

I applied this framework to two areas designated for future urban expansion (urban reserves) adjacent to Damascus, OR, in the southeastern portion of the Portland metropolitan region. Their areas sum 1,879 ha (Figure 8b). An 800 m buffer surrounding those areas was added to provide connections among them.

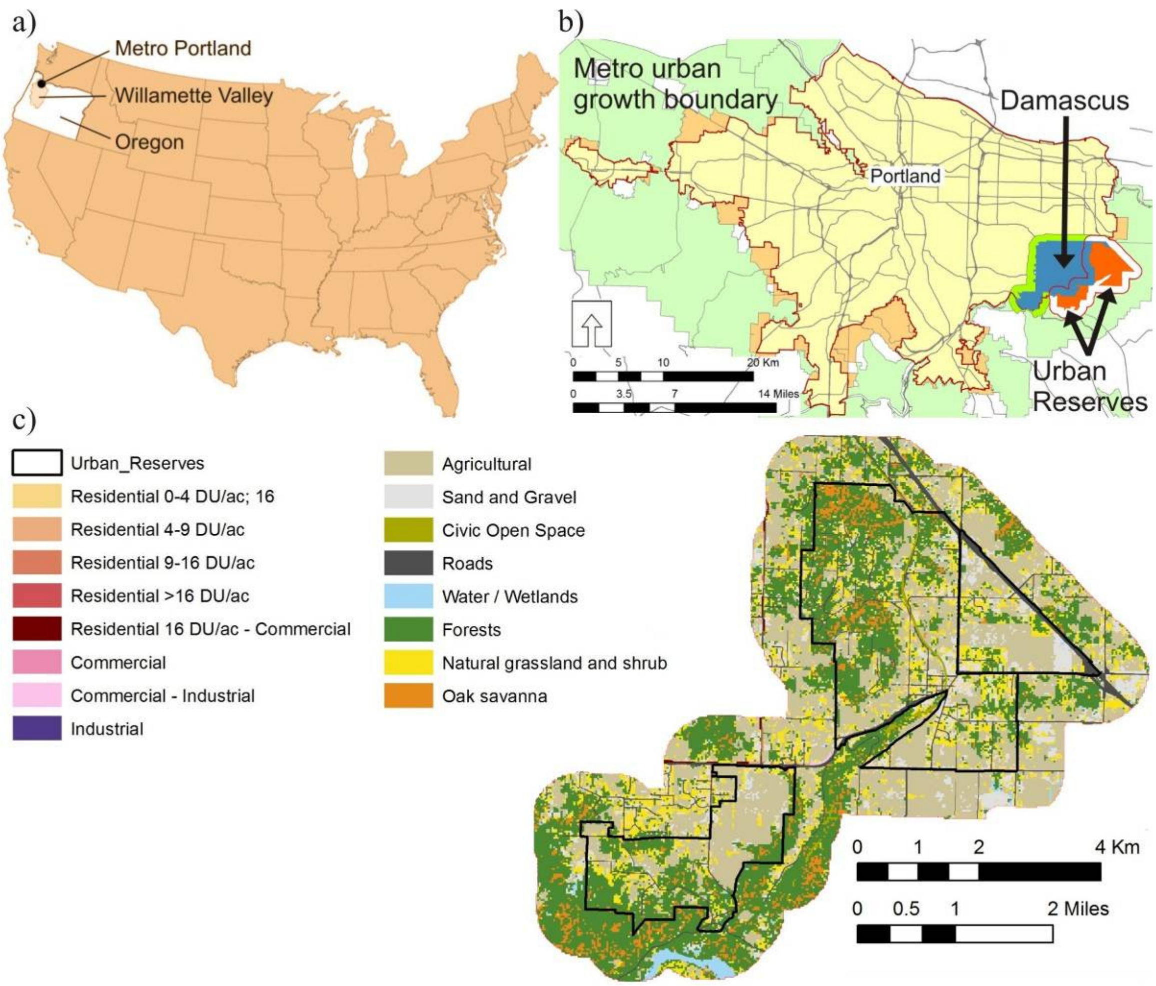


Figure 8. Study area a) within continental United States; b) within the metropolitan region: urban reserves are areas where metropolitan expansion should happen in the next 50 years (red); c) ca. 2010 land use and land cover representation of the area addressed in the dispersal model (see Appendix F for maps of all scenarios) .

The total area used in the simulations sums to 4,592 ha. The study area presents a highly fragmented landscape (ca. 2010), with significant alteration of original habitats where rural land uses prevail (Figure 8c).

Wildlife Species

This study targets three indicator wildlife species. The Northern red-legged frog (*Rana aurora aurora*, henceforth Red-legged frog) is associated with wetlands for breeding and moist forests for seasonal migration; the Western meadowlark (*Sturnella neglecta*) breeds in grasslands and oak savannas; and the Douglas squirrel (*Tamiasciurus douglasii*) is associated with old-growth and mature conifer forests (see Appendix B for further information about these species).

Alternative Future Scenarios

Future scenarios depart from a ca. 2010 representation of the study area's existing conditions. Eight future scenarios for the year 2060 (Table 2) combine four open space (none, corridors, patches, and network) and two urban development patterns (compact and dispersed) (see Appendix F for scenario maps). Planning rules using principles of landscape ecology for corridors, patches and networks, and compact and dispersed urbanization patterns determined the landscape arrangement present in the eight scenarios (Penteado 2013): Compact Development (CD); Dispersed Development (DD); Greenway and Compact Development (GCD); Greenway and Dispersed Development (GDD); Park System and Compact Development (PCD); Park System and Dispersed Development (PDD); Network and Compact Development (NCD); and Network and Dispersed Development (NDD).

Table 2. Scenarios combine open space and urban development patterns.

		Open Space			
		No Open Space	**Corridors**	**Patches**	**Network**
Development	**Compact**	Compact Development	Greenway and Compact Development	Park System and Compact Development	Network and Compact Development
	Dispersed	Dispersed Development	Greenway and Dispersed Development	Park System and Dispersed Development	Networl and Dispersed Development

All scenarios incorporate at least a set of minimum habitat conservation strategies. A 60m-wide buffer around streams, mature and old growth forests, wetlands, grasslands and oak savannas are protected from development. In those areas, modeling simulated vegetation succession. My scenarios contrast and test landscape patterns intended to support species movements via 1) increased corridors to connect habitat patches; 2) increased patch size and distribution both to increase total habitat area and to serve as stepping stones for movement; 3) a combination of increased habitat patch sizes and area with corridor connections; or 4) neither increased patches or corridors.

Greenway scenarios emphasize corridors and strategies for protecting and restoring riparian forest. Streams create a framework for promoting an armature of open space. *Park System* scenarios adopt parks as a means to create larger habitat patches and stepping-stones. These scenarios test the ability of the chosen species to move through a fragmented landscape where there are fewer connecting habitat corridors. *Network* scenarios link habitat patches, stepping-stones and corridors to protect and connect habitats for the chosen species and consequently protect biodiversity (Opdam et al. 2006).

Compact development scenarios depict urbanization strategies for built land uses that concentrate development around existing transportation corridors, in areas of lower ecological impact. Urban development in these scenarios has higher proportions of high-density residential and mixed uses (residential and employment) to minimize loss of open space and maximize ecological function to the year 2060. *Dispersed development* scenarios reproduce existing trends in urban development (large-parcel, single-family), which occur, in the simulations, in developable areas except those where habitat conservation is a priority.

Dispersal Model

I used computer software *HexSim* (version 2.5) to assess wildlife population viability from a dispersal perspective, which assumes organisms are in search of suitable territories to meet their life history needs. My aim was to build simple but scientifically defensible models that evaluate population viability in the endpoint landscapes (2060) of each scenario for the three chosen species.

HexSim is a spatially-explicit, individual-based computer model designed for simulating terrestrial wildlife population dynamics and interactions (Schumaker 2011).

This model combines spatial landscape data with organism response to various land cover types to examine population viability (Stronen et al. 2012). *HexSim* couples species' habitat needs to their survival, reproduction and movement rates. *HexSim* evaluates the effects that spatial patterns may have on wildlife populations by testing the ability of individuals to disperse in the landscape. This software and its predecessor (PATCH) have been applied in several peer-reviewed studies of wildlife responses to landscape change (Carroll et al. 2003b; Stronen et al. 2012) and have been demonstrated in over 30 publications (Hulse et al. 2002; Schumaker et al. 2002; Schumaker et al. 2004; Stronen et al. 2012).

HexSim uses species-habitat associations, area requirements, estimates of demographic parameters and movement characteristics, survival, reproduction, and movement information (Schumaker et al. 2004) (Table 3). Species population viability in *HexSim* is strongly based on the ability of individuals to move through the landscape for both foraging/feeding and for dispersal to breeding locations. *HexSim* produced spatial data (*HexMaps*) and simulation results expressed in census tables (measures of population size through time) that contain population size data by replicate and time step.

Table 3. Species parameters used in the simulations. Reproduction considers individuals that survive the 1st year (Red-legged frog: 5% survive to metamorphosis; Western meadowlark: 50% fledge; and Douglas squirrel: 25% survive first year) to improve processing time. Report logging period starts after populations reach steady state.

	Red-legged frog	**Western meadowlark**	**Douglas squirrel**
Breeding habitats	Wetlands	Savannas and grasslands	Old-growth and mature conifer forests
Suitable habitats (migratory and non-breeding)	Moist forests	Crops, grains, grass seed rotation and pastures	Low-density residential, parks, open and hardwood forests
Initial population	300 individuals	1000 individuals	100 individuals
Time steps/log period	50/20	200/50	100/50
Home range	less than 1 ha	7 ha	less than 0.6 ha
Reproduction	45	5	Average 2
Dispersal	< 1.2 km.	> 1.6km	< 0.15 km
Breeding strategy	Breeding affinity.	Adults return to original or adjacent to original territory. Juveniles acquire new.	Juveniles acquire new area.
Territorial	No	Yes	Yes

Landscape representations of scenarios in a geographic information system contained habitat scores, ranging from zero to ten, that reflect habitat quality for each species (Schumaker et al. 2004; Baker and Landers 2004). I adopted those scores to produce suitability maps for each species (Appendix H). Hence, each scenario generated three suitability maps, one for each species that I then converted into bitmap representations. Appendix H contains suitability maps for ca. 2010 and all scenarios. These maps originated hexagonal representations (*HexMap*) that *HexSim* uses to simulate life-cycle events. Each hexagon is 30m wide. The hexagonal grid facilitates movements to adjacent hexagons in multiple directions. *HexMaps* contained a simplified representation of the landscape; four land cover categories represented the landscape: breeding habitats, suitable non-breeding habitats, urban matrix (which includes all roads), and rural matrix. Urban matrix hexagons received higher mortality rates to impose a higher stress on moving individuals.

Twenty *HexSim* simulation replicates for ca. 2010 and for each of the eight 2060 combinations of open space and urban development patterns were conducted for 50 (Red-legged frog), 100 (Douglas squirrel) and 200 year (Western meadowlark). Simulations started with populations in breeding sites. I used different numbers of individuals for each species. Because there was a small amount of wetlands in the area, I used a starting population of 300 Red-legged frogs to make sure most wetlands were populated. I used the same strategy for the Western meadowlark but with a larger initial population (1,000 individuals). Douglas squirrel habitats were abundant in the ca. 2010 landscape. Its initial population was smaller (100) in order to observe their ability to move across the landscape and colonize habitats in the ca. 2060 future scenario landscapes.

EVALUATION

I measured population viability by looking at populations resulted from the capacity of the landscape to facilitate or impede species dispersal. I then explored wildlife habitat effects of urban open spaces in the 2060 scenarios, by contrasting them with the same qualities in the ca. 2010 landscape. I tracked two categories of population, breeding individuals and floaters (individuals that disperse in the landscape in search of breeding habitats), and used population size mean estimates across the multiple replicate simulations to compare across scenarios (Carroll et al. 2003a; McRae et al. 2008b;

Stronen et al. 2012). Increases and/or decreases of breeding populations indicate the ability of those landscapes to sustain populations of the chosen species as a function of habitat arrangement and can be compared across scenarios. Comparing resulting populations (census) for each species for each scenario shows which spatial concepts were more effective in providing conditions for dispersal. By looking at breeders and floaters, I could also look at the influence of different types of habitats – habitats that are used for breeding and habitats that are used for movements. I used a two-way ANOVA to test the interaction between open space and urban development patterns and a Tukey test to perform multiple comparisons of means with a 95% family-wise confidence level. Both tests used statistical software R version 2.14.1 (The R Foundation for Statistical Computing 2011).

RESULTS

The effects of the combination of open space and development spatial concepts were significant on most scenario's breeding individual’s and floater’s means for all three species (interaction $p < 0.05$). Park and network spatial concepts produced small differences ($p = 0.66$) in Western meadowlarks breeding individuals. Development spatial concepts (compact and dispersed) produced significant differences among most scenario means. Exceptions were *floaters* between the Red-legged frog’s greenway scenarios ($p = 0.95$), Park and Dispersed Development (PDD) and Greenway and Compact Development (GCD) scenarios ($p = 0.35$), and between PDD and Greenway and Dispersed Development (GDD) scenarios ($p = 0.95$) (Figure 9b).

RED-LEGGED FROG

Network and Compact Development (NCD) scenario presented the largest increases, followed by Network and Dispersed Development (NDD) and PDD. PDD had a small increase of breeding individuals compared to 2010, but the number of floaters decreased. Alternative future scenarios employing no open space spatial concept (Compact Development (CD) and Dispersed Development (DD)) and greenway scenarios presented reduced populations of both breeding individuals and floaters but comparable to 2010 quantities. Most compact development scenarios presented larger numbers of breeding individuals and floaters than dispersed development scenarios. Greenway and

Dispersed Development (GDD) scenario had a slightly larger number of breeding individuals than Greenway and Compact Development (GCD); both scenarios had small differences in *floaters* (p = 0.95). There were also small differences between GCD and Park and Dispersed Development (PDD) floaters and GCD and PDD floaters. Relative to 2010, the DD scenario had the largest reductions.

The baseline landscape (ca. 2010) showed a population of 647 breeding individuals and 22,347 floaters. In the future scenarios, breeding individual means ranged from 593 (DD) to 942 (NCD) individuals. Floaters ranged from 19,734 (DD) to 30,427 (NCD) individuals.

WESTERN MEADOWLARK

The simulations of the existing landscape (ca. 2010) indicated that there are patterns that may sustain a small viable population of breeders. CD, DD, GCD, and GDD scenarios were not able to sustain Western meadowlark populations. The baseline landscape (ca. 2010) showed a population of 21 breeding individuals and 62 floaters. The initial population (1,000 individuals) steeply dropped to extinction after a few time steps. Park and network scenarios presented reduced populations of breeding individuals compared to ca. 2010 but larger populations of floaters in dispersed development scenarios. Compact development scenarios presented significantly smaller populations for both indicators than dispersed development scenarios. Park and network patterns showed little influence in determining differences of breeding individuals, but park scenarios presented larger quantities of floaters. In the future scenarios, breeding individuals means ranged from 12 (NCD) to 16 (PDD and NDD) individuals. Floaters ranged from 60 (NCD) to 81 (PDD) individuals. NCD scenario had the largest reductions. NCD scenario presented the large decreases, followed by PCD. PDD and NDD had the smallest decreases of breeding individuals compared to 2010, but the number of floaters increased.

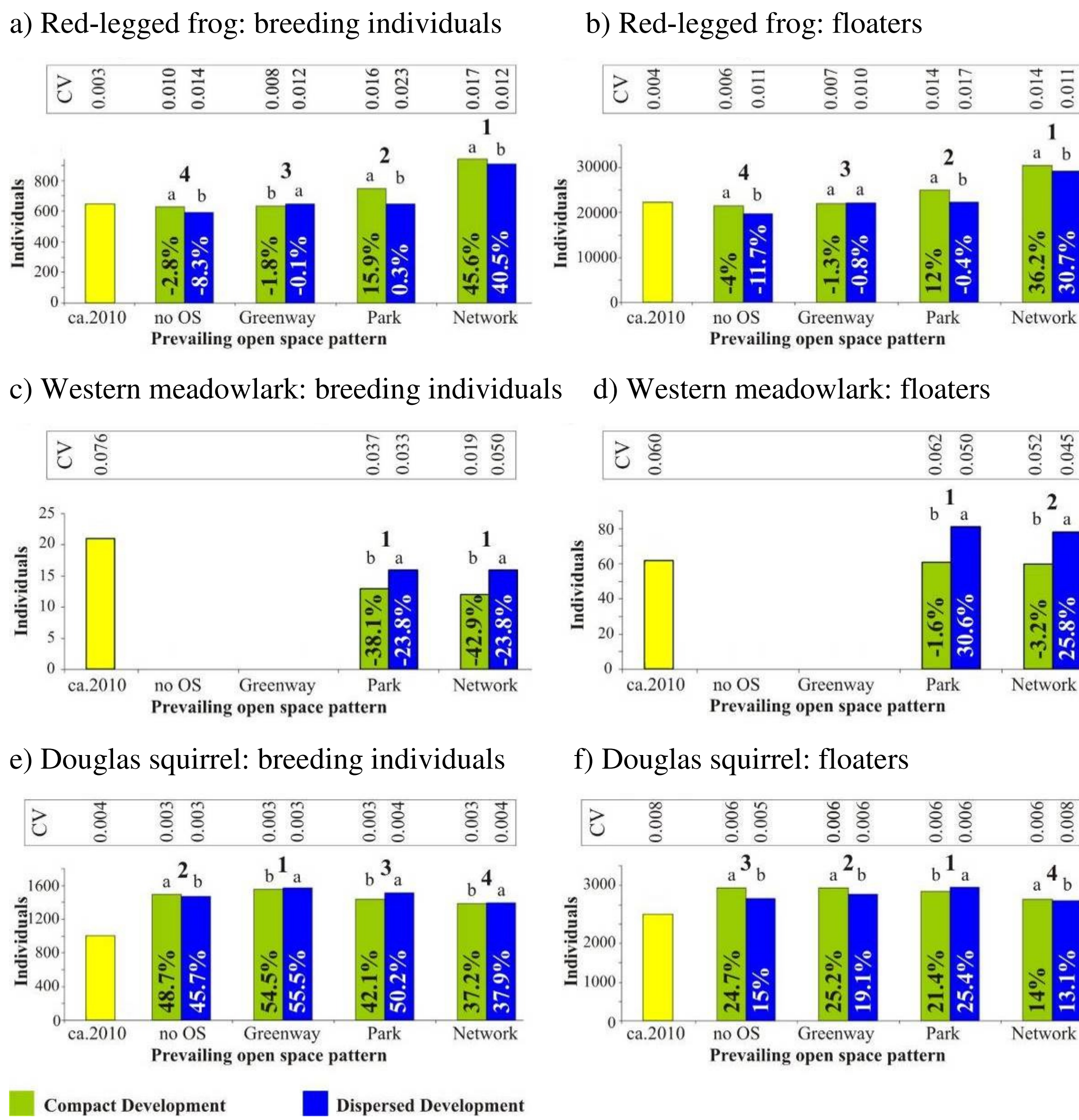


Figure 9. Indicators of population change between ca. 2010 urban reserves and 2060 urbanized landscapes. CV is the coefficient of variation among scenario runs. Numbers on top of bars indicate significant differences among open space patterns; different letters indicate statistically significant differences between compact and dispersed patterns; percentages indicate increase or decrease in population relative to ca. 2010 landscape estimated populations. The horizontal axis shows ca. 2010 conditions and 2060 alternative futures in all charts. Note different scales on the vertical axes. The first column uses mean scenarios to illustrate landscape change; the second column uses population means among the 20 HexSim runs. a) Red-legged frog Breeding individuals and b) Floaters; c) Western meadowlark Breeding individuals and d) Floaters; and e) Douglas squirrel Breeding individuals and f) Floaters. Breeding individuals are individuals that were able to breed; floaters are those dispersing in search for breeding habitats.

Douglas Squirrel

There were increases of Douglas squirrel populations in all 2060 scenarios compared to 2010 (Figure 9e,f). Greenway scenarios had the largest increases of breeding individuals. PDD and GCD scenarios had the largest increases of floaters, while the network scenarios had the smallest increases for both breeding individuals and floaters (Figure 7e,f). Greenway and park scenarios had the largest proportion of breeding individuals in relation to the total population (33 to 34% of the total populations are breeding individuals).

In scenarios that adopted open space policies, all compact development scenarios sustained smaller number of breeding individuals than dispersed development scenarios. Values ranged from 1,384 (NCD) to 1,569 (GDD) breeding individuals. In the no open space scenarios (CD and DD), compact development performed better than dispersed. Floater populations were larger in all compact development scenarios but the PCD scenario. Values ranged from 3,107 (NDD) to 3,439 floaters (GCD).

LIMITATIONS

Any ecological evaluation model is a simplified representation of ecological processes. This dispersal modeling approach was simple in order to provide data and visualizations of the effects of spatial concepts on wildlife dynamics. Because it was simple, some real-world qualities were not directly addressed. I used some modeling tools to simulate the effects of some of those qualities.

The simulation used does not include interaction among different species. Red-legged frogs are susceptible to predation and competition with Bullfrogs. In this model, predation of Red-legged frogs by Bullfrogs is implicit in the first year survival rate. Predation by house pets is also indirectly addressed by mortality rates in urban areas, as well as road kill. Urban development projections did not expand the road network. This is particularly important in dispersed development scenarios where new urban zones appear isolated. This may have an impact on results, especially for Red-legged frogs and Douglas squirrels, and is discussed in the next section. Also, the simulation represents year 2060. However, as land cover evolves to natural conditions in protected or restored wetlands, exotic species (e.g. Bullfrogs) find less suitable conditions to thrive. This change is not taken into account in the model.

Understanding broad-scale ecological processes that depend on connectivity, and making effective conservation planning decisions to conserve them, requires quantifying how connectivity is affected by landscape features (McRae et al. 2008a). No direct indicator of connectivity was adopted, but the measure of population size and visualizations of model runs shed light on the role of connectivity in the eight scenarios.

DISCUSSION

Within the limitations of the model and given the scenario representations, results indicate which scenarios and which combinations of open space and urban development sustain viable populations of the three target species expressed in terms of estimated abundance ca. 2060. Each species is addressed in the next section, and the Conclusion offers an overall summary of the relative effects of each future scenario on each species' population viability.

RED-LEGGED FROG

Red-legged frogs disperse to relatively large areas and require close association with moist forests, stream banks, and wetlands (COSEWIC 2004). They breed in vegetated shallows of wetlands, ponds, ditches, springs, marshes, margins of large lakes, slow-moving portions of rivers, typically, ephemeral ponds, house yards and neighborhood parks where building density is low, as well as small natural or modified catchment areas used for storage of stormwater run-off (O'Neil 2001; Davidson et al. 2001; COSEWIC 2004; Lannoo 2005; Chelgren et al. 2006). Habitat fragmentation is of particular concern in view of the species' seasonal migrations between forested areas and wetland breeding sites (COSEWIC 2004).

All scenarios sustained populations of Red-legged frogs. They all have small portions of remaining or restored wetlands that serve as breeding habitats for Red-legged frogs and larger areas of riparian forests used as migratory habitats. The small wetland area relative to the area covered by forests results in proportionally smaller numbers of individuals that find breeding habitats compared to the amount of individuals that are not able to establish breeding habitat and remain browsing the landscape for suitable breeding habitats.

Network scenarios had a large increase of Red-legged frog populations. The images in Figure 10 contrast two snapshots from ca. 2010 and NCD model runs. Ca. 2010 *HexMaps* (Figure 10a,b) show the movements performed by frogs in areas surrounding the larger wetland. Observing simulation runs it is possible to see individuals moving back and forth without ever reaching other wetlands. In contrast, NCD maps depict similar movements performed in a landscape where more corridors are present. Frogs are able to disperse longer distances and reach and colonize other breeding habitats.

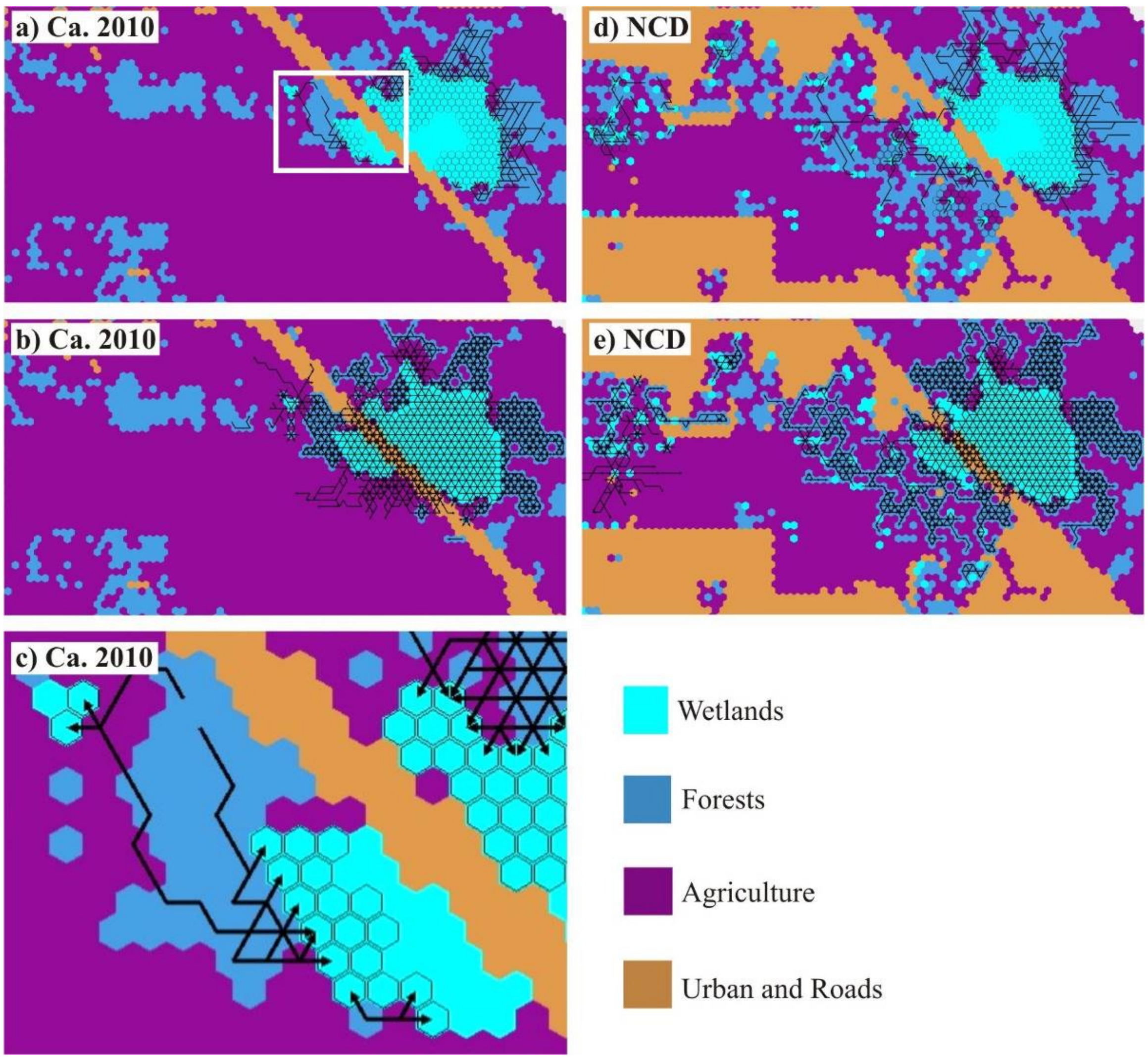


Figure 10. Red-legged frog suitability maps (HexMaps). a) Ca. 2010 and d) Network and Compact Development Scenario (NCD): small black arrows depict migration from moist forests toward wetlands for breeding while hexagons show individuals exploring areas for establishing breeding territories; b) Ca. 2010 and e) NCD: small black arrows depict dispersal of juvenile and adults after breeding; c) enlarged area outlined in a) – each hexagon is 30m wide.

WESTERN MEADOWLARK

Western meadowlarks breed and feed in relatively large expanses of grasslands and prairies, but flocks sometimes feed on corn, wheat, and other grains (Morrison 1993; Oregon Department of Fish and Wildlife 2006). Declines of grassland bird populations result from loss (urbanization), degradation (land management practices, disruption of natural disturbance regimes), and fragmentation (smaller isolated patches) of habitat (Johnson and Igl 2001; Oregon Department of Fish and Wildlife 2006).

Western meadowlarks are scarce in the northern Willamette Valley (where Portland is located) (Myers and Kreager 2010). However, the ca. 2010 simulation showed that the landscape could sustain a mean population of approximately 83 individuals (21 breeding individuals and 62 floaters) after simulation reached steady state. In the ca. 2010 landscape, Western meadowlark habitats are dispersed across the landscape in small patches. In four scenarios (CD, DD, GCD, and GDD), simulations started with a population of 1,000 individuals and rapidly declined leading to extinction. Those scenarios presented small, isolated patches of habitats unable to sustain viable populations of Western meadowlarks. In the development of CD and DD scenarios, no open space spatial concept was applied. GCD and GDD scenarios focused on vegetated corridors, which were represented mostly by riparian corridors. The relatively larger number of floaters indicates that there are suitable habitats for feeding - as the crops mentioned above -, but those birds are not able to find habitat for breeding. The lack of spatial concepts and policies for large patches of grasslands and oak savannas affected the persistence of meadowlarks in those scenarios.

Four 2060 scenarios sustained populations: PCD, PDD, NCD, and NDD. These scenarios provided the best conditions for the meadowlark. In these scenarios, simulation maps showed a pattern of use that differs from the pattern in the ca. 2010 landscape. Here, birds use a group of small close patches (Figure 11) while in the other four future scenarios birds concentrate in large patches (Figure 12). This species tends to have large territories that are not confined to single fields (Frawley 1989). The NCD scenario presented an average 12 breeding individuals after steady state. This scenario presents larger and closer patches that allowed this population to persist. The NCD scenario had a 42.9% decrease of population mean compared to ca. 2010 population.

Parameters for dispersal distance adopted in the simulation were large enough to allow birds to colonize other patches within the study area. During simulations, it was possible to observe that birds were able to explore other patches. However, the size of those patches and isolation from large patches apparently prevented Western meadowlarks to establish viable populations.

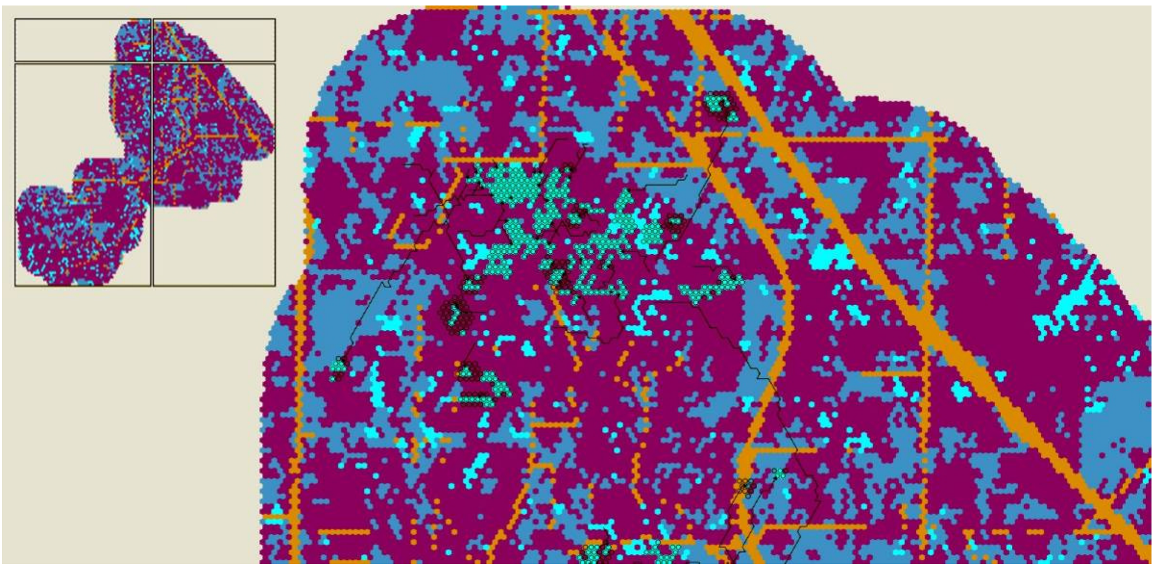


Figure 11. HexSim representation of a portion of ca. 2010 suitability maps for the Western meadowlark. Birds occupy and disperse to smaller patches.

The model used to produce scenarios (*Envision*) considers vegetation succession, i.e. the natural change of vegetated habitats to later successional stages. Management of grasslands and oak savannas could prevent loss of those habitats. Management of remaining agricultural lands could include practices that create suitable conditions for grassland birds. “Fallow fields, lightly-grazed pastures, grass seed fields, vineyards, and Christmas tree farms can provide habitat for grassland birds and some other wildlife" (Oregon Department of Fish and Wildlife 2006). Golf courses could also contribute to conservation of bird communities if appropriate design features are adopted (LeClerc and Cristol 2005).

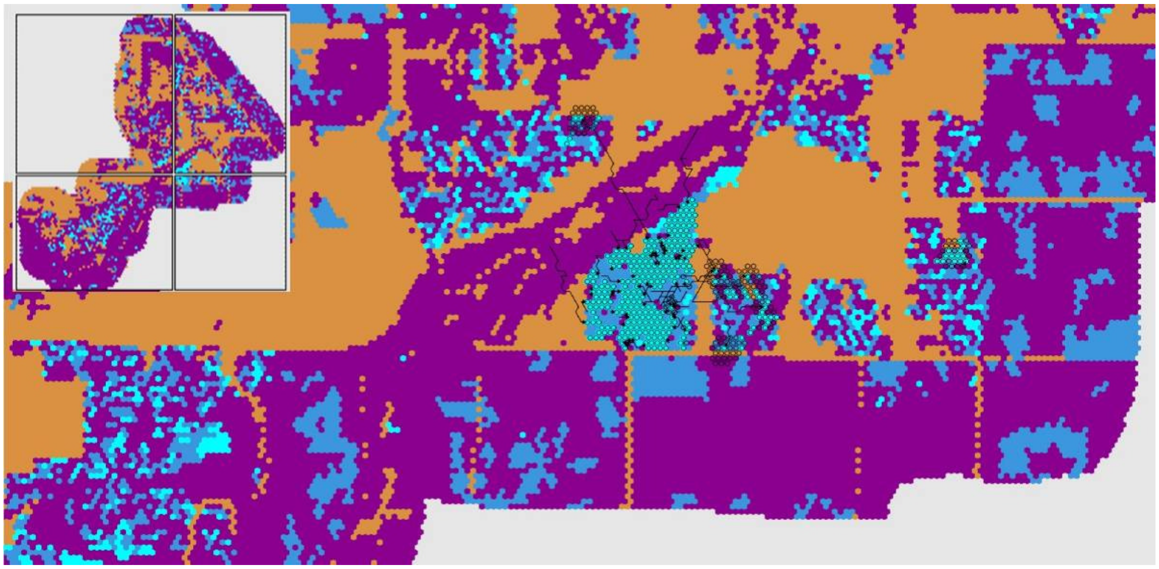


Figure 12. HexSim representation of a portion of the NCD scenario suitability map. Birds occupy one large patch and disperse to small patches.

DOUGLAS SQUIRREL

Simulations started with small populations – 100 individuals. During the 100-year duration of each simulation, squirrels looked for suitable breeding habitats. All scenarios showed an increase in Douglas squirrel populations. This indicates that there was an improvement of landscape structure in every scenario.

In fact, it is possible to observe the evolution of occupancy – squirrels that construct territories – by looking at scenario runs (Figure 13). The *HexMap* representation of Ca. 2010 (Figure 13a) shows no urban areas. The GDD and NDD *HexMaps* show large urban extents. The ca. 2010 map shows a large amount of breeding habitats interspersed with other forests suitable for movement and foraging. There was a significant reduction of habitats and large urban growth, but the GDD map shows a large, continuous tract of breeding habitats with smaller areas of other forests and other smaller corridors surrounded by the urban matrix. The fifty-year simulation emulates vegetation succession that allows forests to mature, hence creating larger areas of suitable habitats for the Douglas squirrel. The use of a small initial population (100 individuals) permitted observing the evolution of squirrels. They mostly dispersed through corridors, but sometimes were able to reach and colonize patches that were in relative isolation from the corridor (Figure 13c).

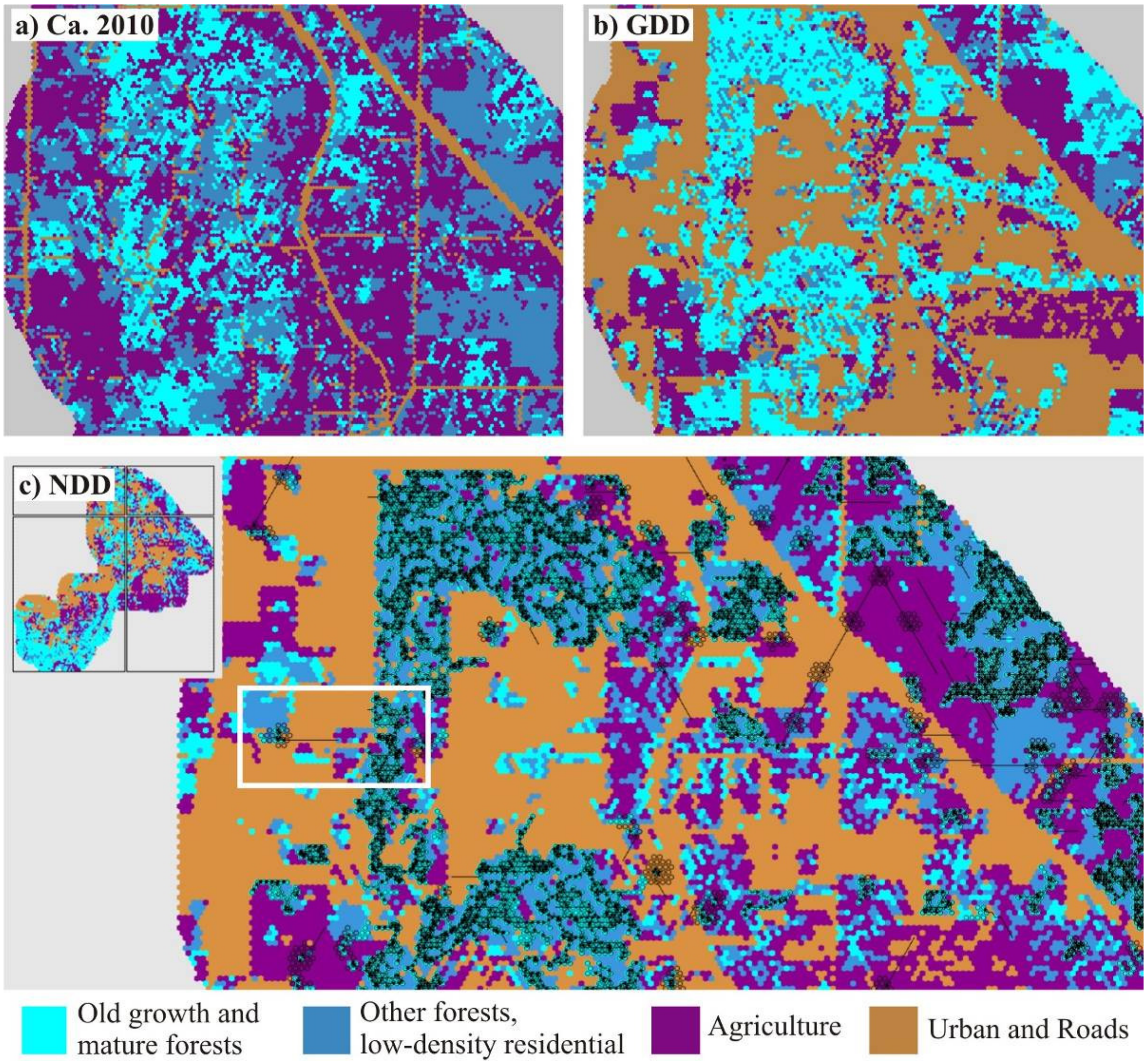


Figure 13. Douglas squirrel suitability maps (HexMaps): a) Ca. 2010 and b) Greenway and Dispersed Development Scenario (GDD) ca. 2060 show the different habitat patterns; c) occupation and dispersal patterns of Douglas squirrel in the NDD scenario. Note occupancy and dispersal to smaller, isolated patches (outlined). Inset shows location of the enlarged area in the study area.

CONCLUSIONS

The eight future scenarios, each having a different combination of open space and urban development patterns, produced different results for each species. Park and network scenarios presented the best results across all three species. While the no open space and greenway scenarios presented good results for both the Red-legged frog and the Douglas squirrel, these scenarios did not sustain viable populations of Western meadowlarks.

The networks produced in the future scenarios present connected habitat patterns. However, they contain various types of habitats. This habitat heterogeneity causes network scenarios to not perform best for some indicators, but also leads them to sustain more species (as noted by Opdam 2006).

Differences among open space showed that, while some scenarios were best for one individual species, the same scenario could be worst for another species. While greenway scenarios performed best in sustaining breeding populations of Douglas squirrel, the same scenarios had the worst results for the Western meadowlark and worst for Red-legged frog among scenarios that had applied open space spatial concepts, illustrating the necessary wildlife species trade-offs that must sometimes be confronted when landscapes are configured primarily to suit human preferences.

While network scenarios showed the worst results for Douglas squirrel, they also presented increases compared to ca. 2010 populations. These results indicate that choices for protecting species individually – by adopting their best scenarios – may dramatically affect other species. Network scenarios present the best results for two species (Red-legged frog and Western meadowlark) and, although not the best for Douglas squirrel, these ca. 2060 scenarios still promote increased populations relative to ca. 2010 conditions. Network scenarios are likely to present the best combinations to sustain diversity of species.

Large amounts of Red-legged frog floaters indicate that this species may benefit from urban structures. If appropriately managed, frogs may use sustainable drainageways (O'Neil 2001; COSEWIC 2004) and house yards and parks (Davidson et al. 2001).

Decisions about wildlife conservation are among many other decisions involved in planning new large expanses of urbanization. A few dispersed development scenarios presented the best results in this assessment, but it is likely that compact development strategies also promote efficient use of infrastructure and sociability, among other benefits (Arendt et al. 1994; Calthorpe and Fulton 2001).

The major outcome from this study is the test of an assessment method that can potentially help decision-making in the planning process. As noted by Opdam et al (2006) “stakeholders said that working with quantitative indicators enhanced their communication and made decision-making more efficient”. This assessment method may be a valuable contribution in the planning process when choices include preferences for alternative spatial concepts and their effects on wildlife species persistence.

CHAPTER IV

CONTRASTING TWO QUANTITATIVE METHODS TO ASSESS THE EFFECTS OF APPLYING LANDSCAPE ECOLOGICAL SPATIAL CONCEPTS ON WILDLIFE POPULATION VIABILITY IN AN URBANIZING LANDSCAPE

INTRODUCTION

Urbanization is an important cause of habitat loss, fragmentation and adverse impacts on biodiversity (Marzluff and Ewing 2001; Alberti 2005; Bryant 2006; Forman 2008b). When natural, more pristine landscapes change to urban patterns, ecological processes, movements, flows of species, and connectivity are affected (Alberti 2005; Forman 2008b; Beardsley et al. 2009). Natural resources decrease and conflicts over land use increase (Beardsley et al. 2009).

There is a strong relationship between patterns of open space and urban development as it affects ecological processes (Forman and Godron 1981; Arendt et al. 1994; Hough 2004; Kaplan and Austin 2004; Alberti 2005). Compact patterns of urbanization prevent excessive consumption of land, reduce infrastructure expense and protect open space. Other urban pattern planning strategies include densification, clustering, changing the mix of housing densities and types, reducing single family development; increasing the percentage of town-homes and small-lot single family homes; and densifying commercial development (Arendt et al. 1994; Alberti 1999; Calthorpe and Fulton 2001; Calthorpe Associates et al. 2002; Bengston et al. 2004; Kaplan et al. 2004; Kaplan and Austin 2004; Forman 2008b; Beardsley et al. 2009; Calthorpe 2010).

Decisions about urban open space are essential in wise urban and land use planning processes (Bengston et al. 2004; Maruani and mit-Cohen 2007). The various forms of open space have the potential to create an armature for urban expansion that protect natural patterns and processes (Girling and Kellett 2005; Forman 2008b).

Landscape ecology provides one framework to address landscape change (Ahern 1999; Forman 2008b) and open space planning. Landscape ecology has increasingly grown as a normative basis for sustainable landscape planning. Designers and planners use spatial concepts to translate principles of landscape ecology into working diagrams to anticipate (and presumably reduce or solve) ecological problems such as habitat fragmentation and loss of biodiversity. This study proceeds on the assertion that landscape ecology, when used as part of the knowledge base for design and planning, can generate evidence-based spatial concepts concerning both natural and cultural variables that can inform the thoughtful planning of urban open space systems (Dramstad et al. 1996; Ahern 1999; Forman 2008b).

The challenge for planners is deciding what spatial concepts should be applied to maintain or create a landscape structure that protects ecological processes and provides space for urban land uses (Rodiek 2008; Marcot et al. 2012) or, as Forman puts it, ‘‘mold the land so nature and people both thrive longterm" (Forman 2008a).

As noted above, several authors support compact patterns of development as better than dispersed ones in protecting open space and habitats. Some support networks as better than other patterns in achieving conservation goals (Opdam et al. 2006), while still others emphasize the importance of patches (Alberti 2005), amount of habitats (Hodgson et al. 2011) or connectivity (Lindenmayer and Fischer 2007). However, little is known about the direct effects of those patterns and alternative open space and urbanization plans on specific wildlife populations or how to research this problem. The literature indicates that we need to know more about the response of individual species of wildlife to landscape change in developing urban areas. In this study, I contrast two quantitative methods to assess how landscape patterns that apply landscape ecological spatial concepts can affect wildlife viability. This is also an attempt to bridge ecological research and public policy (Quay, 2004).

This study employs an alternative futures analysis framework. I developed eight future scenarios of land use/ land cover that simulate urban expansion in the eastern edge of metropolitan Portland, Oregon (Penteado 2013). They combined four patterns of open space – no open space (minimal conservation), corridors, patches, and networks – and two patterns of urban development – compact and dispersed. I used two quantitative methods to assess the effects of landscape ecological spatial concepts on wildlife populations. For the first assessment, I used spatial metrics of indicators of habitat quantity and quality (Penteado 2013). The second used a computerized dispersal model for three different species to obtain future population size estimates following urbanization, again for each of the eight alternative future patterns of land use/ land cover. The purpose of this article is to compare and contrast the results from the two assessment methods. The aim was to investigate how they agree or disagree, and discuss the consequent implications for planning. Such an approach is premised on the notion that the evaluation of scenario outcomes and implications can enhance decision-making activities (Mahmoud et al. 2009). I approach this work as a designer and landscape planner seeking to test and identify more defensible, pragmatic processes for decisions in the urbanization planning process.

METHODS

I first produced the eight scenarios using a spatial computer model. Scenarios used a common ca. 2060 human population projection for the study area (Figure 4). I addressed three species of interest, the Red-legged frog, Western meadowlark, and Douglas squirrel. The Western meadowlark (*Sturnella neglecta*) is nearly extinct in Oregon's northern Willamette Valley (Oregon Department of Fish and Wildlife, 2010), where Portland is located. Development and loss of wetlands threaten the persistence of Red-legged frogs (*Rana aurora aurora*). Douglas squirrels (*Tamsciurus* douglasii) may be pressed by urban development, reduced habitats, increased predation and road kill. I used a GIS map to represent the initial condition of the landscape ca. 2010. The computer program *Envision* (Bolte et al. 2009b) was used to produce the eight scenarios of land use/land cover for through to the year 2060 and to compute habitat quantity and quality metrics. I then used an individual dispersal model, *HexSim* (Schumaker 2011), to evaluate the amount of individuals of each species sustained in each scenario.

ALTERNATIVE FUTURE SCENARIOS

Scenarios combined open space spatial concepts for corridors, patches and networks with urban development spatial concepts (compact and dispersed). Two scenarios, Compact Development (CD) and Dispersed Development (DD) projected urban expansion with minimum conservation policies. Two greenway scenarios – Greenways and Compact Development (GCD) and Greenways and Dispersed Development (GDD) – emphasized open space corridors. Park system scenarios – Park System and Compact Development (PCD) and Park System and Dispersed Development (PDD) – focused on producing larger patches. Network scenarios – Networks and Compact Development (NCD) and Networks and Dispersed Development (NDD) – combined corridors and patches in an open space network.

I used land use modeling software *Envision* to model urban expansion, and to produce 20 spatially explicit representations of each alternative future land use and land cover scenario. *Envision* has been used – as well as its predecessor *Evoland* – in several studies in the Willamette Valley (Hulse et al. 2000; Hulse et al. 2002; Baker et al. 2004; Bolte et al. 2007; Hulse et al. 2009; Bolte 2009a; Bolte 2009b). In *Envision*, human population growth creates a demand for residential and employment land uses; spatial concepts, converted into policies, drive land allocation for open space and urban development by the model in a manner linked to the intentions of each scenario. Multiple runs of a given scenario in *Envision* produce probabilistic variations in final (in my case, ca. 2060) patterns of land use/ land cover, each of which is consistent with the intentions of its guiding scenario. I conducted 20 runs of each of the eight alternative future scenarios and, for comparison, selected mean scenarios for each of the eight scenarios for assessing habitat metrics. Mean scenarios are the alternative futures that most closely represent the means obtained for indicators of habitat quantity and quality among the 20 alternative futures produced. Results from the *Envision* model runs include maps and databases for each mean scenario.

FIRST ASSESSMENT: HABITAT QUANTITY AND QUALITY

The first assessment used *Envision*'s maps and tables to produce metrics of habitat quantity and quality and area occupied by urban development (Table 4). I used six indicators to contrast ca. 2060 future scenarios with each other and against ca. 2010 (existing conditions). "Weighted habitats" is the total area of habitats multiplied by suitability scores (which expresses habitat quality – Schumaker 2004) for the three species as a group; "weighted breeding habitats" accounts for breeding habitats for the three species; and “high-quality habitats” quantifies area of the best habitats for breeding, foraging and dispersal for each species (Penteado 2013).

SECOND ASSESSMENT: DISPERSAL MODEL

The second assessment used the species dispersal model *HexSim* (Schumaker 2011) to evaluate the ability of the future scenarios’ landscape structure to sustain overall populations and individual’s ability to disperse. The measure used in this assessment was average population size over time of each species in each scenario. I used results means from 20 multi-run replicates of each alternative future scenario to compare, ca. 2060, the number of breeding individuals (individuals capable of establishing breeding territories), floaters (individuals that remain searching for territories), and total population (the sum of breeding individuals and floaters).

CONTRASTING METHOD

I compared high-quality habitat area for each species from the first assessment with the total population for each species from the second assessment (Figure 14). I then sought discrepancies and consistencies between the two assessments within and across scenarios.

RESULTS

RESULTS FROM FIRST ASSESSMENT

The first assessment aimed to obtain indicators of quantity and quality of habitats for the three indicator species as a group and individually (Table 4a). The habitat scores included metrics of habitat quality. Network scenarios presented the best overall results for “weighted habitats” and “weighted breeding habitats”, two indicators that combine area and habitat scores to indicate suitability for the three species taken as a set. Network scenarios also performed well for “high-quality habitats” for the three species. “High-quality habitats” include the best habitats for breeding, foraging and movements. For the Douglas squirrel, network scenarios presented the least beneficial results among scenarios but nearly doubled the amount of habitats relative to ca. 2010. Western meadowlark had habitat area reduced in greenway and no open space scenarios relative to ca. 2010. Urban development area decreased as habitat area increased across scenarios:

network scenarios produced the smallest urban development footprint, while the no open space scenarios had the largest urban footprint.

Table 4. Summary results from both assessments. Numbers in the first assessment (a) express values from mean scenarios, which represent the alternative future that is closest to the mean quantities obtained among the 20 Envision runs of each scenario; the second assessment (b) shows mean values from 20 HexSim dispersal model replicates of the first assessment's mean scenarios. "Weihab" (weighted habitats) is the sum of all habitat polygons multiplied by their suitability scores (ARA) for all three species; "breedhab" (weighted breeding habitats) uses the same procedure considering breeding habitats only; "high-quality habitats" is the total area of suitable breeding, foraging, and dispersal habitats for each species. The second assessment is expressed in number of individuals where "BI" represents breeding individuals, "FL" is the number of floaters and "TP" is the total population. Numbers in bold face show increases relative to ca. 2010 quantities; numbers in italics show decreases. Shaded cells show the best means among scenarios. "Urban" indicates the area occupied by development (residential and employment areas) in mean scenarios. RLF = red-legged frog, WML = western meadowlark, DSQ = Douglass squirrel.

a) First assessment: habitat quantity and quality

	weihab	breedhab	High-quality habitats (ha)			Urban	Agricultural
	ha x ARA	ha x ARA	RLF	WML	DSQ	ha	ha
2010	10,542	2,419	597	112	85	0	620
CD	10,653	3,508	*519*	*11*	195	688	*404*
DD	11,139	3,403	*504*	*11*	189	786	*330*
GCD	12,341	4,737	601	*12*	194	629	*312*
GDD	12,894	4,736	*593*	*16*	194	688	*265*
PCD	11,975	5,734	*553*	*101*	186	592	*315*
PDD	12,556	5,622	*552*	*90*	187	652	*296*
NCD	14,205	6,124	673	140	164	511	*126*
NDD	14,730	6,051	675	134	163	528	*130*

b) Second assessment: dispersal model – population sizes

	RLF			WML			DSQ		
	BI	FL	TP	BI	FL	TP	BI	FL	TP
2010	647	22,347	22,994	21	62	84	1,009	2,746	3,755
CD	*629*	*21,455*	*22,084*	*0*	*0*	*0*	1,500	3,423	4,923
DD	*593*	*19,734*	*20,327*	*0*	*0*	*0*	1,470	3,158	4,628
GCD	*635*	*22,064*	*22,699*	*0*	*0*	*0*	1,559	3,439	4,998
GDD	*646*	*22,166*	*22,812*	*0*	*0*	*0*	1,569	3,271	4,840
PCD	750	25,018	25,768	*13*	*61*	*74*	1,434	3,334	4,768
PDD	649	*22,265*	*22,914*	*16*	81	97	1,516	3,443	4,959
NCD	942	30,427	31,369	*12*	*60*	*72*	1,384	3,131	4,515
NDD	909	29,207	30,116	*16*	78	94	1,391	3,107	4,498

RESULTS FROM SECOND ASSESSMENT

The second assessment aimed to project the size of the populations of each species that each scenario could sustain. For each species, I used number of breeding individuals and floaters (individuals that remain browsing the landscape) (Table 4b). Network scenarios performed best for the Red-legged frog, followed by park scenarios. The number of breeding individuals increased in both cases. The number of floaters decreased in the Park and Dispersed Development Scenarios. Populations presented small decreases in no open space and greenway scenarios. Greenway and no open space scenarios were not able to support populations of Western meadowlark. Park and Dispersed Development performed best for the Western meadowlark, but park and network scenarios presented comparable quantities of breeders and floaters. For the Douglas squirrel, Greenway scenarios performed best, but all scenarios presented increased populations. Network scenarios resulted in the smallest ca. 2060 population among all scenarios.

CONTRASTING HIGH-QUALITY HABITATS WITH TOTAL POPULATION

This section contrasts "High-Quality Habitats" area (henceforth "habitats") from the first assessment with "Total Population" (henceforth "population") from the dispersal model. The analysis focuses on contrasting percentage changes in ca. 2060 scenarios relative to the ca. 2010 quantities, using mean scenarios obtained with *Envision* and dispersal model means obtained with *HexSim* for comparison. In both cases, there was a small variability (coefficient of variation – CV – in Figure 14) among the 20 multiple runs of the scenarios (produced with *Envision*) and the 20 dispersal model replicates (produced with *HexSim*).

Dispersed Development, greenway and Park and Dispersed Development scenarios presented percentage increases and/or decreases of Red-legged frog population proportional to habitat area change (Figure 14a and b). The Park and Compact Development scenario presented a decrease of habitat area, but an increased population. Network scenarios presented population percentage increases almost three times (31 - 36%) larger than the increase of habitat area (12 - 13%). All compact development scenarios had more habitat than dispersed development scenarios. Only the Greenway and Dispersed Development scenario had larger ca. 2060 populations than the compact equivalent.

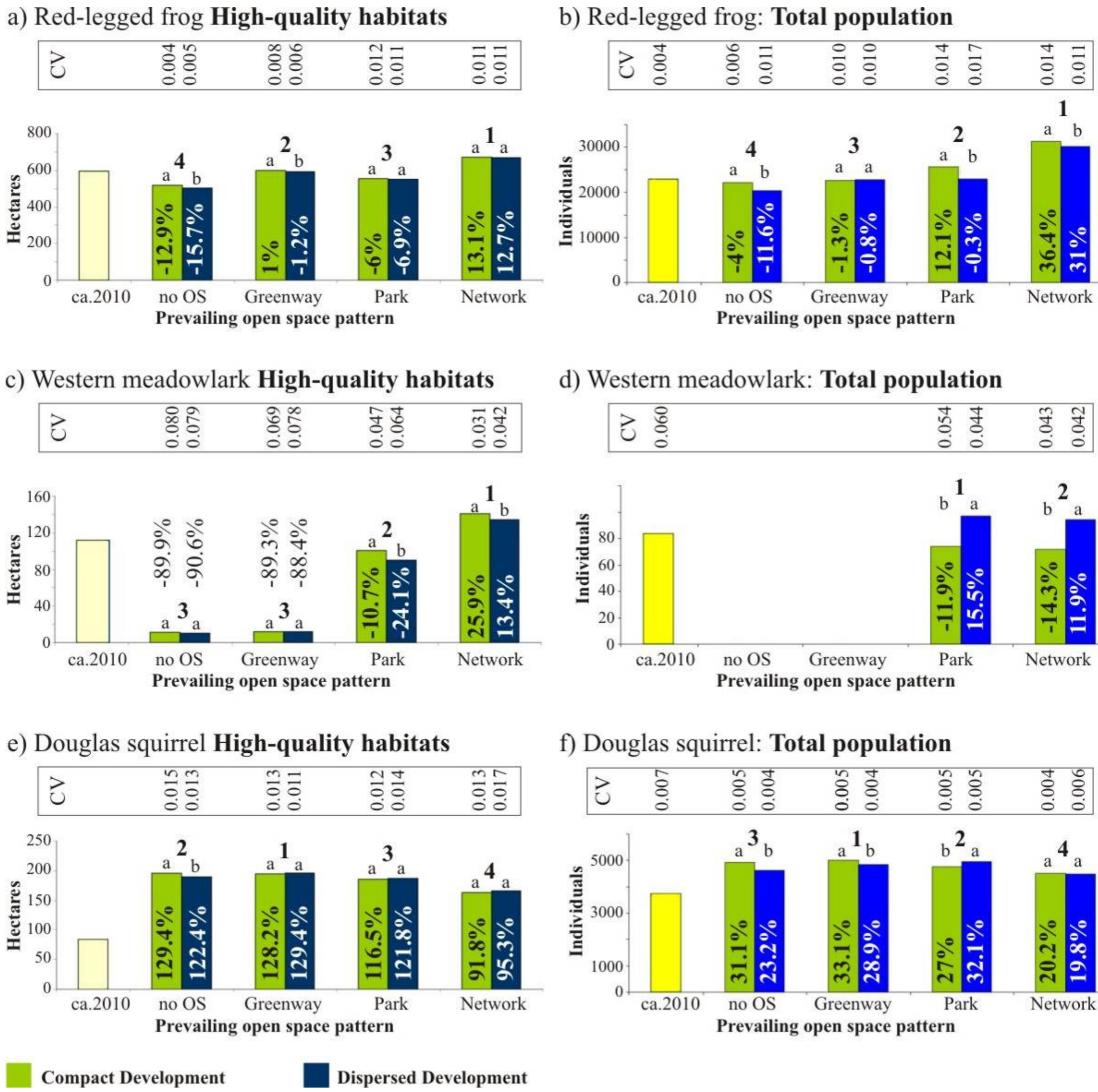


Figure 14. Indicators of landscape change between ca. 2010 and 2060 alternative futures. CV is the coefficient of variation among scenario runs. Numbers on top of bars indicate significant differences among open space patterns; different letters indicate statistically significant differences between compact and dispersed patterns; percentages indicate increase or decrease of ca. 2060 relative to ca. 2010 conditions. The horizontal axis shows ca. 2010 conditions and 2060 alternative futures in all graphs. Note different scales and units on the vertical axes: a), c), and e) High Quality Habitat area (adapted from Penteado, 2013); b), d) and f) Total Population. Percentages for high-quality habitats (a, c, and e) represent change between the mean 2060 scenarios and ca. 2010 quantities. Percentages for total population (b, d, and e) report change of averages across the 20 HexSim runs of mean scenarios.

No open space (CD and DD) and greenway scenarios presented a large reduction of habitat area for the Western meadowlark (Figure 14c and d). The total habitat area indicates the possibility of having a viable population, but the dispersal model showed those scenarios promote the extinction of meadowlarks in the study area. The percentage decrease of populations in the Park and Compact Development scenario was consistent with the decrease of habitat area, as was the increase of population consistent with the increase of habitat area in the Network and Dispersed Development scenario. All compact development scenarios presented more habitat area for the Western meadowlark than dispersed development. Dispersed development in park and network scenarios had larger populations.

The percentage increases of population of Douglas squirrel are consistent with the increases of habitat area (Figure 14e and f) for the Douglas squirrel: all scenario means presented percentage increases of habitat area an average 4.3 times larger than the percentage increase of total population. Compact and dispersed development patterns played a small role in determining differences within open space patterns, but dispersed development produced somewhat larger habitat areas, except for the no open space pattern, and compact development resulted in slightly larger populations, with the exception of the park scenarios.

DISCUSSION

Landscape ecological analysis often employs concepts of patch, corridor and matrix metrics to characterize and understand landscape pattern (Turner 1989; Forman 1995). The focus of this research is to understand how these concepts, when applied as an armature of open space in urbanization plans, affect wildlife with different habitat needs and life histories. Its audience is landscape planners seeking quantitative methods for pragmatically assessing the effects of open space plans based on principles of landscape ecology to protect biodiversity.

It is evident in the literature that urbanization causes significant impact on natural resources (Marzluff and Ewing 2001; Alberti 2005), but its effect on wildlife still need further understanding. The approaches presented here provide two different ways of furthering understanding: first by assessing habitat quantity and quality under ca. 2060 alternative futures, second by focusing on population sizes of target species for these same futures. The following sections discuss implications of applying landscape ecological spatial concepts to protect open space within urbanization plans to the outcomes of both assessment types. The analysis confronted the importance of habitat quantity and quality versus population size that result from the spatial arrangement of those habitats. Results showed that the amount and quality of habitats, urban development patterns, and the processes considered (species dispersal and migration) were influential in determining scenario differences, and that results were, at times, counterintuitive.

The importance of the amount of habitats versus their arrangement in the landscape – which influences habitat connectivity – has been debated (Lindenmayer and Fischer 2007; Hodgson et al. 2011). Both assessments show the importance of having breeding habitat to sustain viable populations of the three species addressed. However, some discrepancies appeared in the results where scenarios with less habitat than ca. 2010 presented larger populations ca. 2060. In such cases, it is likely that pattern, and not habitat quantity alone, is important in determining the number of individuals. In some cases, the second assessment corroborated the first; in other cases, they disagree. Clearly, a species' life history strategy may matter in such instances. I briefly address each of the three modeled species below.

RED-LEGGED FROG

The Red-legged frog breeds in vegetated shallows of wetlands, ponds, ditches, springs, marshes, margins of large lakes, slow-moving portions of rivers where emergent vegetation is abundant, and occasionally in house yards, neighborhood parks, and small stormwater storage areas. They migrate seasonally between forested areas and wetland breeding sites. Network scenarios presented the best combination of protection of breeding and dispersal habitats for the Red-legged frog. Modest increases of habitat area produced large increases of population. Park scenarios showed comparable habitat area, but presented small losses of habitat area. Population increased in the Park and Compact Development scenario despite its decrease of habitat area, which indicates that urban pattern (compact development) may have played an important role in determining the increased population while its dispersed development counterpart presented a small decrease of population relative to ca. 2010. The Network and Compact Development scenario also presented some advantage over Network and Dispersed Development, also indicating the influence of compact over dispersed development. Scenarios with no open space spatial concepts (CD and DD), compact and dispersed development presented comparable habitat loss, but population had a smaller decrease in the compact development scenario. Comparing across open space patterns, compact development performed better than dispersed development except for the greenway scenarios' total population (the difference was not statistically relevant).

WESTERN MEADOWLARK

The Western meadowlark forages and nests in large areas of grasslands and prairies >6 ha in size that may be comprised of several patches. It uses scattered shrubs, trees or posts for singing perches and is more abundant in grassland interiors. Both sets of No open space and greenway scenarios presented small habitat area, which could indicate the ability of those landscapes to sustain small populations of Western meadowlark. However, the dispersal model showed that the habitat area was insufficient in those scenarios. Despite the increase of habitat area in the Network and Compact Development scenario, the dispersal model showed a decrease of population. Conversely, habitat area decreased in the Park and Dispersed Development but the population increased. Both compact development scenarios (park and network) had decreased populations of Western meadowlark, while dispersed development scenarios presented increased populations. The consistent difference between development patterns raises questions, for this particular species, regarding the assertion that compact development patterns result in useful habitat (Arendt et al. 1994; Calthorpe and Fulton 2001; Kaplan et al. 2004). The ca. 2010 landscape and the scenarios that supported viable populations presented different habitat patterns. The ca. 2010 landscape presented scattered but relatively large habitat patches. No open space and greenway scenarios for ca. 2060 presented a larger number of smaller habitat patches. Park and network scenarios presented at least one large patch. For Western meadowlark as modeled in this study, it was the ***combination*** of open space and development patterns that proved fundamental in determining future population viability.

DOUGLAS SQUIRREL

Douglas squirrels are associated with old-growth conifer stands, but may be abundant in second-growth or mature stands. Their home range is less than 0.6 ha. They compete for the same habitats as other tree squirrels (northern flying squirrel and Townsend chipmunk). All scenarios presented more habitats for Douglas squirrel than ca. 2010 in the first assessment. Population projections proportionally followed habitat gain, but at much smaller rates. Greenway scenarios – which addressed mainly riparian corridors – had the best results in both assessments. CD and DD scenarios also performed well, mainly because minimal conservation assumptions allowed vegetation succession in riparian corridors. Network scenarios showed the smallest amount of habitats and individuals, probably because those scenarios have a more balanced distribution of habitats among species. This species demonstrated less sensitivity to differences between compact and dispersed development patterns.

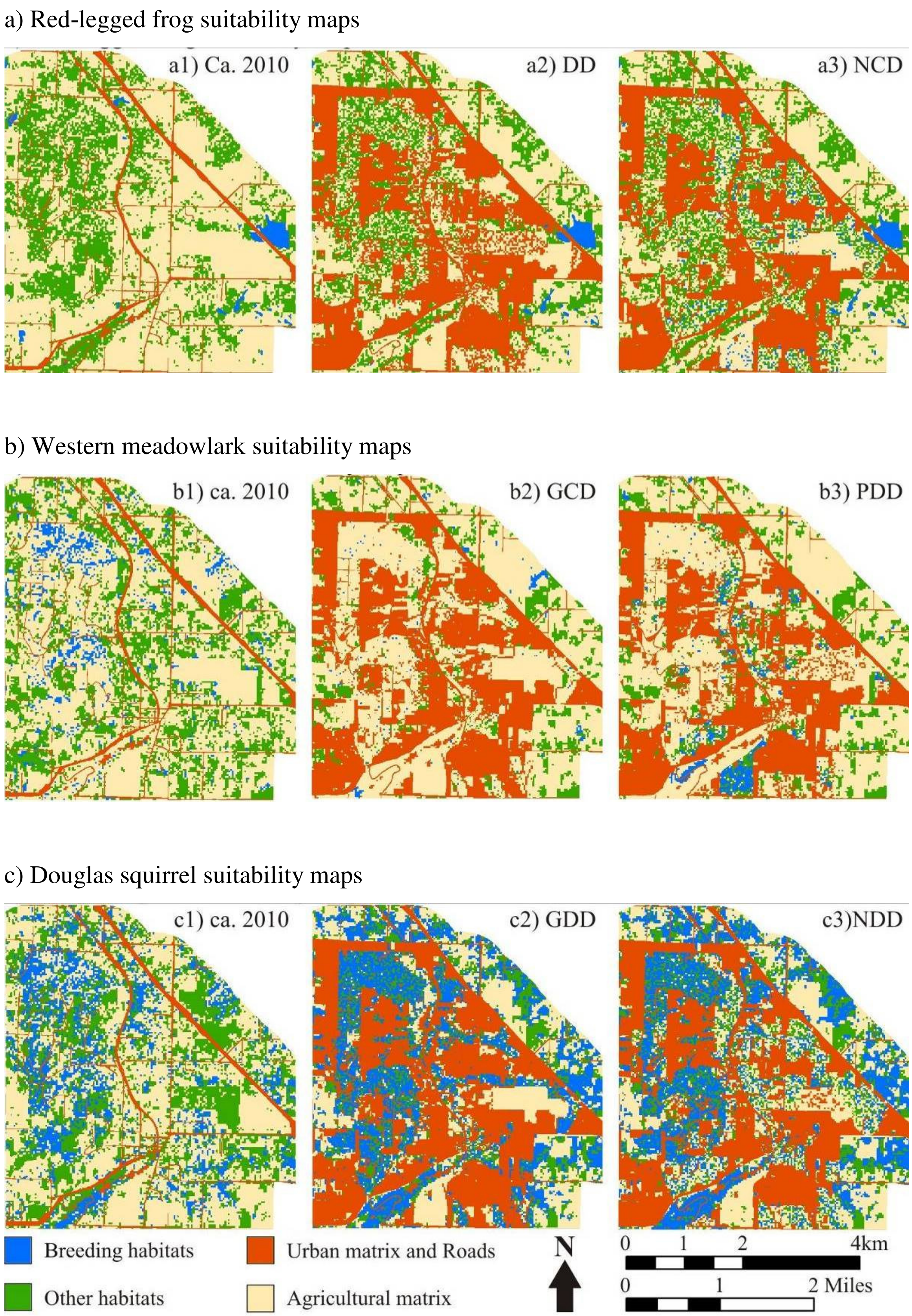
EFFECTS OF OPEN SPACE PATTERNS

The literature on population viability shows a disagreement about the relative importance of habitat quantity and quality versus habitat arrangement in the landscape. My study indicates that the relative influence of these indicators on a species' viability may depend on species life history and, thus, these indicators should not be considered in isolation. Hodgson et al. (2011) emphasize habitat quantity in opposition to the importance of the general arrangement of habitats in the landscape. Some of my results indicate that this should be weighted differently for different species. For the Western meadowlark, patch size was important but arrangement of smaller patches in the ca. 2010 landscape was influential in maintaining a population. During simulation runs, birds could be observed moving among small close patches. For Red-legged frogs, proximity – therefore arrangement – may be more important because they depend on moist environments to support their movements over longer migration distances. For the Douglas squirrel, quantity of high-quality habitats seemed enough to maintain viable populations, perhaps partly because this species disperses over comparatively short distances.

In this study, I used greenways as a planning pattern to implement corridors. It has been argued that greenways are critical for addressing biodiversity conservation in urban areas (Bryant 2006). Several authors defend the value of greenways for addressing biodiversity, especially in urban areas (Ndubisi et al. 1995; Ahern 2002; Bryant 2006). The greenway and network scenarios promoted an expansion of protected corridors along streams paralleling recreation corridors. In the modeled ca. 2060 landscapes, the 60m-wide vegetated corridors provided pathways for Red-legged frog migrations and dispersal of Douglas squirrels (Figure 15a3, c2, and c3). Although greenway scenarios were not successful for the Western meadowlark, an increase in forested areas may benefit forest birds (Marzluff and Ewing 2001) yet not benefit species, e.g. the meadowlark, that are more dependent on grasslands. Increased riparian vegetation that supports Red-legged frogs and Douglas squirrels may also benefit birds and mammals that use riparian corridors. In the Metro Portland region, 93% of bird species use riparian areas (Hennings and Soll 2010).

For the Red-legged frog, scenarios with more connected patterns (greenway and network) did better than scenarios that did not address corridors (park system and no open space) for high-quality habitats, but park scenarios had larger total populations than greenways. This indicates that providing corridors is not the only condition to be considered. For Western meadowlark, greenway scenarios ranked low in both assessments. The dispersal model confirmed that those scenarios do not support viable populations. For the Douglas squirrel, network scenarios ranked low in both assessments, but still supported an increased population compared to ca. 2010.

Figure 15 (next page). Suitability maps (previous page). a1) One large wetland and several wetlands (blue) appear near some migratory habitats (green); a2) in the Dispersed Development scenario, some wetlands were developed and less migratory habitats are available; a3) a network of migratory habitats appear near the original large wetland and new wetlands; b1) Some patches appear in the northwestern corner; b2) in the Greenway and compact Development scenario, only a few, small, isolated patches are present; b3) a large patch appears in the central, southern portion; c1) breeding and dispersal habitats appear throughout the area; c2 and c3) all habitats increase in area and are more connected. Note dispersed urbanization in a2, b3 and c3)


a) Red-legged frog suitability maps
a1) Ca. 2010
a2) DD
a3) NCD
b) Western meadowlark suitability maps
b1) ca. 2010
b2) GCD
b3) PDD
c) Douglas squirrel suitability maps
c1) ca. 2010
c2) GDD
c3)NDD
Breeding habitats
Urban matrix and Roads
Other habitats
Agricultural matrix
N
0 1 2 4km
0 1 2 Miles

EFFECTS OF URBAN PATTERN

Several authors debate the problems caused by dispersed patterns of urbanization. In this study, under Oregon's land use planning system, urbanization is contained within an area reserved for urbanization. However, patterns typical of this type of development can be observed in the scattered distribution of low-density residential areas that spread through agricultural lands. All dispersed development scenarios showed those patterns, especially in scenarios where open space spatial concepts were not applied (CD and DD). In compact development scenarios, urbanization occurred closer to existing transportation corridors and open space policies limited the expansion of development over open space. In all compact development scenarios, developed uses occupied smaller and contiguous areas when compared to dispersed development scenarios with the same open space pattern.

Different open space and urban patterns may also result in different degrees of disturbance. Although disturbance is understood as a "relatively discrete event in space and time that disrupts ecosystem, community, or population structure (…) human disturbance will occur through temporary recreational use or through more permanent habitation use" (Briffett 2001). In the dispersal model, disturbance is indirectly assessed through model parameters. Mortality rates attributed to an urban landscape matrix and its roads emulate the effects of disturbance, such as pet predation and road kill. Because park and network scenarios have larger habitat areas and patches, disturbance may be smaller than in no open space and greenway scenarios. In greenway scenarios, the relatively narrow corridors and proximity to recreational activities and residences may make habitats more susceptible to disturbance (Briffett 2001). Although it is necessary "to maximize the wildlife and habitat value of corridors" in landscape plans (Briffett 2001), it is important to recognize that urban areas have limited availability of land, and, because of proximity to urban activities, open space corridors will often be affected by urban uses. Nearby residential and recreational uses may cause wildlife disturbance.

The expansion of road networks, which is not typically the same in different patterns of urbanization, increases disturbance for some species. Compact development tends to optimize the transportation network and may include transit-oriented development (Calthorpe 2010). Dispersed development, on the other hand, requires an extended network of roads to connect discontinuous development zones and is less prone to accommodate a viable transit system. Some of the results obtained from the wildlife dispersal model indicated that dispersed development caused smaller effects on populations or a larger increase of populations than compact development. Two aspects may have influenced these results. First, the software used for simulating scenarios – *Envision* – did not represent new roads connecting new development zones. Second, dispersed development may actually be more permeable to some species and even support viable habitats for foraging and dispersal for some life history strategies. Although compact development produces a smaller urban footprint, it creates denser urban zones that may act as barriers to wildlife dispersal and increased pressures and disturbance in habitats adjacent to urban development.

Urban development and expansion of habitats caused farmland area to decrease in all scenarios (Table 4). Farmland maintained contiguous patterns in compact development scenarios because there are lesser gaps in urbanization (Figure 15 and Appendices F and H). On the other hand, dispersed development fragmented farmland. This latter pattern may reduce habitat for and increase disturbance to Western meadowlark, which uses crops for foraging and can breed in crops managed for that bird's life cycle (Oregon Department of Fish and Wildlife 2006). Some agricultural types, like pasture, may be suitable for amphibians as well as for grassland birds.

CONCLUSION

This study looked at wildlife population viability to inform decisions that anticipate regional urban development and affect biodiversity. Traditionally, designers and planners often look at habitat quantities, total natural areas, or employ spatial concepts qualitatively (Calthorpe and Fulton 2001; Forman 2008b). Here, I offer a quantitative analysis, distinguishing effects by species and habitat type, to better understand the implications of using different landscape ecological spatial concepts in landscape pattern decisions concerned with sensitive species. Distinguishing evaluations by species provides more information that can contribute to planning decisions.

The approaches tested in this study proved to be useful even for tools designed for other disciplines and adapted for landscape architects and planners. The alternative future scenarios method helped to visualize a large number of possible outcomes; the assessments helped understand the tradeoffs among various open space patterns and compact vs. dispersed development relative to the target species. These tools also helped confront accepted theories and assumptions with quantitative data. For example, the conventional wisdom is that compact versus dispersed development makes a lot of difference on wildlife, but results showed this varied among the set of species studied. More research is needed regarding the relation between habitat conservation and patterns of urbanization, but several lessons derive from study results:

- If one considers only the total area of habitats or natural areas in contrasting wildlife effects of alternative future scenarios, the large areas of "green" on a map (i.e. areas off limits to development) may hide habitat insufficiencies for some species.

For planners of future metropolitan pattern, decisions should consider more than habitat area. This work indicates that, in such settings, it is important to look beyond the big numbers. Table 4 offers a metric of total amount of habitats (weighted habitats). If one looks at total habitat only, any scenario may look favorable for biodiversity conservation (i.e. all scenarios have increased amounts of weighted habitat). Developers may choose those with more availability of developable land (in all scenarios, urban footprint is inversely proportional to habitat area). For example, if considering only total weighted habitat, greenway scenarios may look good for wildlife, but considering only total habitats obscures, for example, the devastating effects of greenway scenarios on Western meadowlark viability, a species whose life history strategy requires large areas of upland grasslands.

- The effectiveness of applying spatial concepts is not equal for species with different life histories, habitat requirements, territory size, and movement characteristics.

Different species benefit from the different patterns that result from different landscape ecological spatial concepts. Only by careful consideration of these results can one understand the tradeoffs for alternative future landscape plans. The use of spatially-explicit wildlife dispersal models, like *HexSim*, enable detailed explorations for chosen species of how starting condition patterns of source/sink habitats evolve over time with landscape changes propelled by alternative future scenarios. With maps of individual movements, the prospect arises for local infrastructure designs that better anticipate movement patterns of sensitive species. This work indicates that, because of differences in life history strategies, such better informed planning may prove critical for certain sensitive species' long term viability.

- For some species, populations increase when habitats increase, independent of pattern; populations do not always increase proportionally with habitat gain.

For the Douglas squirrel, a dramatic increase in habitats resulted in a relatively modest increase in population. In the network scenario models, the Red-legged frog behaved in the reverse: a modest increase of habitat area in particular configurations resulted in a relatively large population increase. Even reduced habitat areas in the park scenario models resulted in larger populations for some species. This seemingly counterintuitive result largely relates to the home range size of each species' territory. Species that demand larger breeding territories demand larger increases of habitat to support growing populations. Species that demand highly specialized habitat – such as wetlands – but need only small home range territories may thrive even with reduced habitats if the remaining habitats have the qualities needed.

- Some species depend on a more complex landscape pattern – a combination of open space/habitats mixed within development patterns.

Western meadowlarks showed they demand large patches of grassland to breed and forage. The dispersal model showed that urban pattern also plays an important role in determining the size of the resulting population.

- There were bigger quantitative differences in wildlife population impacts across open space patterns than within them (compact vs. dispersed development).

Except for the Western meadowlark, which advantages from dispersed development over compact development, the other two species were significantly influenced by open space pattern but not as much by urban development patterns. For the Red-legged frog and Douglas squirrel, development patterns did not appear as important as the differences among open space patterns, which indicates that the choice of open space spatial concept may disproportionately affect resulting population viability for species with certain life history strategies.

I addressed three species in this study. However, they also represent beyond just this specific group of species. The meadowlark represents grassland bird species that require large contiguous habitats in order to breed successfully but are very mobile. The

Red-legged frog represents frogs and other amphibians that require a combination of spatial proximity of wetlands and moist forests and have a particular way of moving. Douglas squirrels and other tree squirrels and small mammals require mature forests, but that can also occur in residential areas where there is enough tree canopy and trees are allowed to mature and are less sensitive to human presence.

This work illustrates the potential importance of applying landscape ecological spatial concepts. Quantitative assessments to assess wildlife impacts of urban development improve planning decisions. It shows the value of integrating open space into thinking about the future form and pattern of urbanizing regions by showing how a carefully conceived open space armature can structure planning priorities and enrich both the urban and open space environment by maintaining viable populations of species of concern.

CHAPTER V

CONCLUSION

In this dissertation I presented an approach to urban open space planning with a focus on biodiversity. I first developed alternative future scenarios of open space and urban development. Because the focus of this open space planning experiment was on wildlife population viability as a measure of biodiversity, I used two methods to assess the components of population viability, habitat area and quality on one hand, and configuration on the other (Termorshuizen et al. 2007). Chapters II to IV were organized to demonstrate this approach and reflect my research design. As a set, they answer my overarching question:

What are the effects of different landscape ecological spatial concepts, when applied to the design of urban open spaces, on wildlife population viability, expressed by habitat quality, quantity and spatial configuration, of representative amphibian, bird and mammal species as they experience urbanization?

To answer this question I proposed two sub-questions. The first (*What landscape ecological spatial concepts applied to urban open space plans provide the most and the best habitats for the target species?*) was answered in Chapter II, where I presented the alternative future scenarios study and the evaluation of habitat quantity and quality. Results showed that scenarios that adopted the open space network spatial concept presented the best overall quantities for indicators that combined habitats for the three species, followed by scenarios based on greenway and parks spatial concepts. When looking at individual species, network scenarios of open space presented the most habitats for the Red-legged frog and the Western meadowlark, but presented the least habitat increase for the Douglas squirrel. The worst results were obtained for the Western meadowlark in the greenway and no open space scenarios, which had steep reductions of habitat area for this species.

Chapter III presented the answers to my second sub-question (What landscape ecological spatial concepts are best in sustaining viable populations for the indicator species from a movement perspective?). I presented the dispersal model approach to evaluate the effect of habitat configuration on each species' populations. Network scenarios presented the best results for the Red-legged frog, with park and greenway scenarios second and third, respectively. For the Western meadowlark, park scenarios did modestly better than network scenarios, but no other scenarios sustained viable populations. For the Douglas squirrel, greenway scenarios performed best, park scenarios second, and followed by no open space and network scenarios. Chapter IV contrasted the two methods of evaluating each alternative's wildlife effects and summarized the lessons obtained from the dual approach. In some cases, the second assessment corroborated the first, but population size for the three species varied in different proportions when compared to habitat area change.

Spatial concepts developed from principles of landscape ecology proved useful for creating an armature of open space. The results show that urban open space planning processes can benefit from a deeper understanding of the effects of landscape ecological spatial concepts on wildlife viability. Although not the core of my dissertation, the following sections discuss the implications for metropolitan planning, and open space planning as a subset of it, followed by the study's limitations and implications for future research.

METROPOLITAN PLANNING PROCESSES

Metropolitan planning is a complex endeavor where open space is one of many subsystems of concern. Others include transportation, economic development, housing needs, public health and water supply. (Forman 2008b). Planning of new urban zones customarily involves deep understanding of cultural and socioeconomic systems, but open spaces are not always among the top priorities. While open space has gained importance in metropolitan planning in recent decades, urban open spaces have generally emphasized human, not wildlife, use. Commonly, biodiversity is not one of the main dimensions of physical planning (Forman 2008b). When biodiversity is addressed, planners usually indicate natural areas, areas of high habitat value to protect or restore, areas that are sensitive or are at risk, and areas to be acquired in the future (Metro 1992), generally depicted as green areas on a map, as can be seen in several examples of open space planning in American and other cities (Metro 1992; Calthorpe and Fulton 2001; Rottle and Maryman 2006).

As discussed previously, landscape ecology offers a knowledge base for spatial planning – (Ndubisi 2002; Termorshuizen et al. 2007). Landscape ecology has been increasingly adopted as the scientific basis for planning open space systems, greenways, etc. Landscape ecological principles and spatial concepts have been adopted in physical planning proposals in several cities and metropolitan regions. A recent example is Forman's approach to metropolitan planning in the Barcelona Region, where he addresses multiple subsystems (Forman 2004; Forman 2008b). His proposal for open space includes a plan of nature in the Barcelona Region (Figure 16) clearly based on the land mosaics theory (Forman 1995).

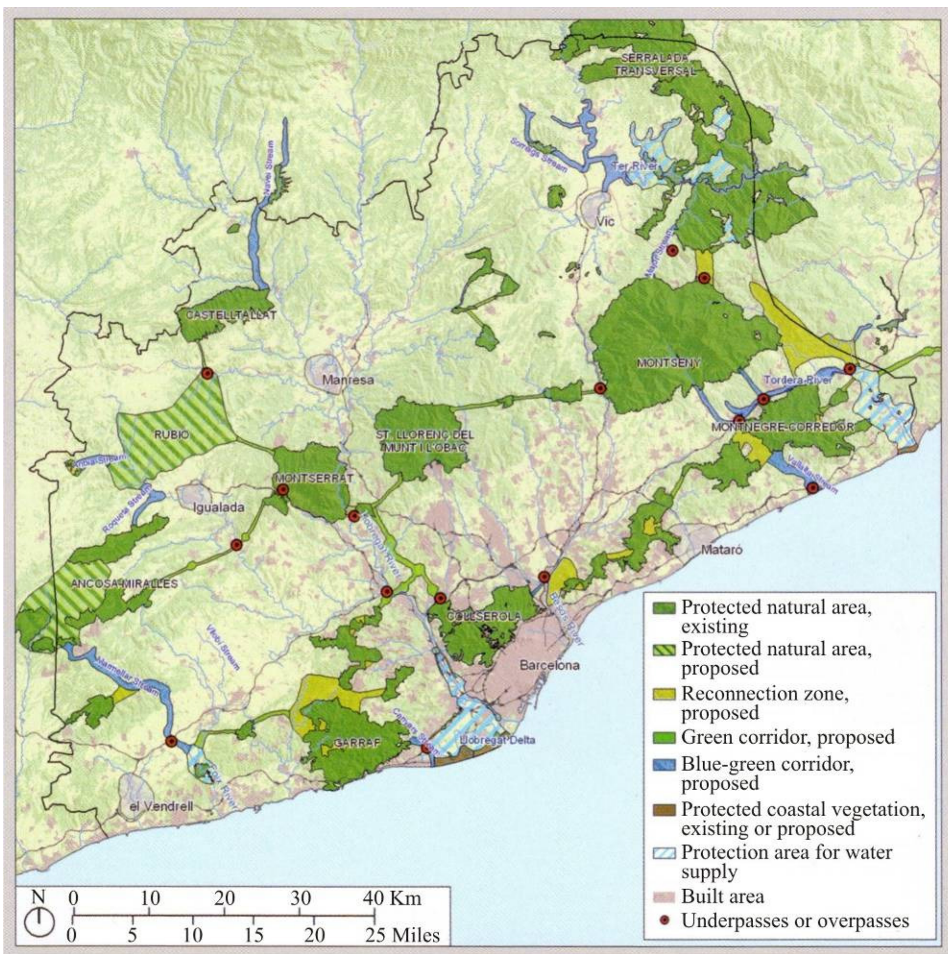


Figure 16. Forman's plan for nature in the Barcelona Region (adapted from Forman 2008). Note the large existing and proposed natural areas (patches), reconnection zones, and corridors.

Steinitz indicates that there are gaps between landscape ecology and landscape planning (Steinitz 2001), while Botequilha and Ahern defend that there is a need for methods that strengthen the potential contributions between landscape ecology and landscape architecture (Botequilha Leitão and Ahern 2002). The next section offers conclusions from my study on deepening the links between landscape ecology and landscape architecture, and particularly its joint contribution to theory and practice by addressing the *process* of metropolitan open space planning**.**

CONTRIBUTIONS TO THE PROCESS

Forman, describing his plan for Barcelona, advises that "the objective of the planning project is to outline promising spatial arrangements and solutions that enhance natural systems and associated human land uses for the long-term future" (Forman 2008b). What is too often lacking in such efforts, and what I proposed here, is a way of assessing how promising proposed spatial arrangements are determined through defensible procedures that could pragmatically fit in a metropolitan planning process. I evaluate the potential of resulting plans by providing defensible evidence of some of the mechanisms that lead to the statistical differences in the relationships between proposed patterns of urbanization and their biodiversity effects. The results demonstrated that a modeling approach could provide quantitative answers that may meaningfully inform the dialogue among planning stakeholders and, consequently, the quality of decisions. The results also illustrated the degree to which, if designers are relying on simpler, more habitat-based metrics alone, they may be getting a different answer than would be produced by a population viability model. The analysis herein shows where, how, and how much development produces what effects, and, in turn, what to protect through strategies such as land acquisition, protection of agricultural areas and infrastructure design. Therefore, my research approach deals with the fundamental components of landscape structure, composition and configuration.

The model used for producing the alternative futures, *Envision*, is a powerful tool for experimenting with a large number set of options for open space and urban form. If introduced early in the metropolitan planning process, such alternative future simulation tools may enhance communication with stakeholders and their appreciation of tradeoffs for wildlife species and urban development. The policy structure that drives simulations allows planners to explore diverse outcomes and to use the model to test the sensitivity of evaluative results to plan changes by turning policies on and off or adjusting their application frequency. New policies can be added to address incoming issues.

For the dispersal model representations of the species in the modeled alternative future landscapes, I adopted a landscape classification composed of four elements: breeding habitats, movements and foraging habitats, agricultural matrix, and urban matrix. The representation attempted to echo both species life histories and land mosaics components – patch, corridor, and matrix – in a form sufficiently simplified to enhance its applicability within the time and resource constraints of a typical metropolitan open space planning process.

This framework has potential for application in other regions if sufficient data are available. For creating the landscape representation of the initial landscape it is necessary to have a good land use and land cover representation in a geographic information system. Taxlot data, streams and other important geographic features contribute to add realism to the simulations. The land use and land cover is also important to implement the dispersal model, especially for addressing suitability for indicator species. Availability of information about the species life histories is also key for developing meaningful dispersal models (Table 3). It is also important to select species that are sensitive to development, represent other species, have different dispersal strategies, and demand a variety of habitat types.

CONTRIBUTIONS FOR THEORY

> *"We should understand that landscape planning is not a science, although it depends on science, including ecology"* (Steinitz 2001).

This research brings together an open space and urban development planning perspective with a simulation modeling approach to obtain a deeper understanding and more defensible explanation of an ecological issue – the persistence of wildlife populations in areas stressed by urbanization. It combines two ways of dealing with this problem. While planners deal with spatial relationships that involve natural and socioeconomic components through maps and plans, modelers translate landscape change and biological and ecological parameters into computational algorithms and digital representations of results. The ultimate product of this combination is sets of quantitative data that, with interpretation and assessment, have the potential to improve decisions in planning processes.

The use of a wildlife dispersal model (*HexSim*) to assess the effects of different configurations of land use and land cover and, by extension, the wildlife habitats they represent, deepens the understanding of the traditionally qualitative use of landscape ecological spatial concepts. I argue that the resulting ecological assessment strengthens the linkages between landscape ecology theory and planning practice.

This approach also contributes to the long running debate between having ‘enough’ habitat versus having viable populations within some pattern of habitats, especially the understanding of how decisions about open space and urban form differently affect species with different requirements (Termorshuizen et al. 2007; Hodgson et al. 2011). It proved valuable to choose species from three different taxonomic groups with distinct life histories in addition to considering total amount of habitats or natural areas.

LIMITATIONS

As in any modeling approach, the methods I adopted are less than perfect. Landscape planning is a broad and comprehensive activity that involves many instances, issues, and stakeholders. This dissertation focuses on two elements of planning in a simplified form: wildlife requirements and urban development. I focus below on key limitations of the methods used in this study:

Generalization: The simplifications of the representation of the three target species used in the dispersal model allow this approach to be generalized from this to other landscapes. However, which information is required about chosen species’ life history parameters will depend on how the chosen species use the study area landscape in question.

Simplification of societal needs: As discussed above, metropolitan planning is a complex process. For the purposes of this study, I used a limited set of planning variables: human population growth projections and the associated area required to accommodate residential zones at multiple densities and affiliated employment areas. Also, by adopting Damascus’s definition of high-density I am in conflict with some of the literature that defends higher densities for compact development patterns of urbanization (Calthorpe 2010).

***Envision* and the use of agents:** A more complex simulation environment can be explored in *Envision* than what I employed. Stakeholders' preferences can be represented as separate classes of agents, each of which can actively influence model outcomes. However, the process for gathering data and incorporating them into modeling requires time and resources (human and material) that were beyond my capacity to include within the dissertation timeframe and resources, and that, given my driving questions, were not required.

Dispersal model: I chose to use one biodiversity indicator, population size, to assess one ecological process, individual movement for each chosen species. *HexSim*, however, contains multiple possible indicators and simulation capabilities that could improve modeling. These are discussed in the Future Research section. In addition, "sustainability analysis must consider the interplay and dynamic evolution of social, economic and natural systems" (Swart et al. 2004). Again, largely due to time and resource constraints, and with the guidance of my dissertation committee, I chose to constrain the analysis to a particular representation of the interplay and dynamic evolution of social, economic and natural systems over a 50 year period, again in response to my driving questions, and to represent the resulting landscapes for the year 2060.

RECOMMENDATIONS FOR FUTURE RESEARCH

- Experiment with the approach in other regions and with other species: the method is straightforward and replicable, but requires data about land use and land cover and species that are inherent to a given location. This research was built upon data that have been developed for many years (Hulse et al. 2000; Hulse et al. 2002; Schumaker et al. 2002; Hulse et al. 2004; Baker et al. 2004; Schumaker et al. 2004). Availability of data is key to operate in a GIS platform, as well as research about species life histories.
- Experiment at other scales, with finer grain representations of open space and development patterns: this research was developed at a landscape scale, well suited to metropolitan planning efforts. Although sometimes design and planning are so closely linked that they may become indistinguishable (Lyle 1985), focusing at the tax lot parcel extent more commonly encountered with design projects may reveal nuances that are not captured at the landscape extent. For example, it may reveal gradients of habitat quality –

which can be captured in a more recent version of *HexSim* – and include differences between edge and interior habitats and the influence of adjacency of diverse land uses, at the smaller extent where neighborhood or individual property owner actions could make detectable differences in biodiversity effects. An improved representation of the landscape at these more local extents may allow including, for example, building footprints, parking lots and roads with more detail. A closer look at a smaller territory may also allow investigating the species in the field, and as a result, produce a more accurate, field-tested understanding of species behavior in the face of urbanization.

- Improve population viability models: there are other capabilities that can be obtained from the dispersal model. For example, interactions among species like predation and competition, sink and source habitats, and productivity, among others.
- I used Damascus comprehensive plan in which The maximum residential density for compact development used in this study was based on Damascus's Comprehensive Plan. What I call compact is relatively low-density when compared to the literature. There is a need to test this framework for denser development.

CONCLUDING REMARKS

> *"… landscape architects, unlike a lot of other disciplines, study things because they are interested in it, but then we want to do something about it, want to build more supportive environments for people and other species with them… there is a unique quality to research in landscape architecture that distinguishes it from many other disciplines… what it means do research in the discipline… research to advance the discipline of landscape architecture and the practice by creating deeper linkages, where research helps us to become better designers, and thoughtful designers become better scholars and researchers"*(Johnson 2010).

An important finding from this work is that, of the set tested, there is no single future scenario that will satisfy all societal motivations and be best for every species – not one of them is best for all species. I have conducted a deep investigation into the particular habitat needs of these three focal species with eight different scenarios, employing twenty representations of each, over a 50-year timeframe, taking into account future human population projections. It is significant that no spatial concept or scenario is best for all three species. In addition, it is significant that one cannot have the most habitat area, highest habitat quality and the best arrangement of habitats for the three species *and* the most developable land at the same time in a single scenario. Tradeoffs must be confronted, and to do so well requires the best advance information and understanding available of the consequences of each.

This work demonstrates that an approach like this can be meaningful in a metropolitan planning process. As a landscape architect, and with a target audience of metropolitan planners seeking an ecologically defensible approach, I brought to bear the lessons of landscape ecology on future urban patterns with the aim of improving metropolitan planning in a practical way, and by so doing to better inform urban open space planning decisions to improve biodiversity effects.

APPENDIX A
SCENARIO ASSUMPTIONS

Conservation of most important habitats: breeding habitats for all three species and habitats used for migration are protected from development. Those include all areas that present high-quality habitats for the target species: wetlands for the Red-legged frog, grasslands and oak savannas for the Western meadowlark, and mature and old growth forests for the Douglas squirrel. The stream network provides an armature of connected corridors (Girling and Kellett 2005).

Protection of important habitats: buffers surrounding breeding habitats create protection from development, which can be achieved through public acquisition of land to protect open space (Bengston et al. 2004). A 60m-wide setback protects streams and creates conditions for restoration of riparian forests. A 30m-wide setback (between 60 and 90m from stream) was prioritized for recreational uses (bike and biking trails).

Restoration of important habitats: areas adjacent to conservation zones may contribute to the protection of and buffering of conservation areas. Areas where historic vegetation corresponded to potential restored habitats have higher priority. In some scenarios, these areas may accommodate other land uses such as recreation, low-density housing, and community gardens. For the Red-legged frog, these are areas that could buffer wetlands from development; areas that reconnect portions of wetlands and streams under roads; for the Western meadowlark, areas adjacent to existing grasslands with first priority to historic prairie and savanna; and for the Douglas-squirrel, areas adjacent to mature and old-growth conifer forests.

Restoration of corridors: all scenarios assume the protection of a 60m-wide buffer from streams to provide an armature for dispersal (Cook 1991). Development is not allowed in those areas. Wetlands, streams, and patches bisected by roads are reconnected by underpasses to allow movements of Red-legged frog and Douglas squirrel (Hilty et al. 2006).

Urban development assumptions regulate the allocation of human population and employment areas in the urban reserves. Compact development scenarios seek more favorable conditions for reducing the urban footprint and maintaining existing open space. This pattern reduces the need to expand road networks, consequently reducing habitat fragmentation. Development is preferred in areas of low ecological value and easier access to transportation corridors (Forman 2008b). In the compact development scenarios, development policies initially create denser, mixed-use urban centers containing housing and employment areas. Density decreases as distances to centers increase. In the dispersed development scenarios, development occurs in any developable, non-conservation areas, with a higher proportion of single-family development. Low-density development may sustain biodiversity (Steinitz et al. 1996). In all scenarios, employment areas have easy access to *major* arterials in areas of lower ecological value (Forman 2004).

Two minimum conservation scenarios explore the effects of having no open space spatial concept applied. The *Compact Development Scenario (CD)* depicts urbanization strategies that concentrate development around existing transportation corridors, in areas of lower ecological impact. Buffers around streams are protected from development. The *Dispersed Development Scenario (DD)* reproduces existing trends in urban development, which occurs in any developable area except those where conservation is priority. Here, the 60m-wide stream buffers are also protected.

The *Greenway and Compact Development Scenario (GCD)* emphasizes corridors as a means to provide corridors and higher residential densities to protect open space. An existing greenway running through the area anchors the network of corridors. Streams create a framework for dispersal and for protecting and restoring riparian forest. Riparian areas also connect to larger tracts of upland forest. Urban land uses aggregate around transportation infrastructure and existing development to prevent loss of open space.

The *Greenway and Dispersed Development Scenario (GDD)* represents the currently most common trends of development. Urban sprawl is contained by the urban growth boundary (UGB), but the desire for large-parcel, single-family development drives a dispersed urban pattern on the landscape. Open space is anchored on the existing greenway. The network of streams expands corridors to other areas for both residents and wildlife.

The *Park System and Compact Development Scenario (PCD)* adopts parks as a means to create habitats and allow movements using stepping-stones. The various types of parks in the area are the framework for protecting and restoring habitats. This scenario explores the ability of the chosen species to move through a fragmented landscape where corridors are less present. Urban areas present higher proportions of high density development. The *Park System and Dispersed Development Scenario (PDD)* also adopts parks to protect and restore habitats. Urban development in this scenario is based on lower densities.

The *Network and Compact Development Scenario (NCD)* adopts networks as means to produce the highest conservation value and corridors for the chosen species, integrating habitat patches, stepping-stones and corridors. Urban development is based on higher proportions of high-density residential and mixed uses to achieve minimal loss of open space and maximize ecological function to the year 2060. The *Network and Dispersed Development Scenario (NDD)* also adopts networks, but urban settlement presents higher proportions of low-density development.

APPENDIX B
TARGET WILDLIFE SPECIES

This study targets three focal wildlife species: one amphibian (Northern red-legged frog - *Rana aurora aurora*, henceforth Red-legged frog), one bird (Western meadowlark - *Sturnella neglecta*), and one mammal (Douglas squirrel - *Tamiasciurus douglasii*). The study area presents suitable habitats for all three species. These species demand small territories and are likely to be present after urbanization, but are susceptible to habitat fragmentation that results from urbanization. In the species selection process, species that demand large territories were avoided (e.g. cougar, coyote, red fox, or northern spotted-owl). The selected species are associated with a variety of habitats: the Douglas squirrel is associated with various types of forest, while the Western meadowlark is present in grasslands and oak savannas, and the Red-legged frog in wetlands and moist forests. By selecting a suite of target species, planning guidelines to support them also apply to other species with similar requirements (Rubino and Hess 2003). For example, the Red-legged frog may share habitats with northwestern salamanders, long-toed salamanders, Pacific chorus frog, and rough-skinned newts (Lannoo 2005). The Western meadowlark may coexist with other grassland birds such as western bluebird, Oregon vesper sparrow, horned lark, grasshopper sparrow, and common nighthawk (Oregon Department of Fish and Wildlife 2006).

Northern red-legged frog (*Rana aurora aurora*)

The red-legged frog occurs from the northern Californian coast to British Columbia, extending east towards the lower elevations of the Cascade range, with the most reduced and fragmented portion of the range occurring in the Willamette Valley (Lannoo 2005). It is federally considered a threatened species (Davidson et al. 2001) and a critical/vulnerable species in the state of Oregon (Hennings and Soll 2010).

The Oregon Department of Fish and Wildlife (2006) classifies the Red-legged frog as a Strategy Species, a species that "have small or declining populations or are otherwise at risk". For The Committee on the Status of Endangered Wildlife in Canada (COSEWIC), “because of its relatively large spatial requirements and close association with moist forests, stream banks, and wetlands, the Red-legged Frog is emblematic of wilderness values, forest ecosystem health and the need to consider landscape-wide habitat connections" (COSEWIC 2004).

Red-legged frogs feed in water on decomposing benthic substrate and adults can consume terrestrial invertebrates (O'Neil 2001) and juvenile conspecifics and salamanders (Lannoo 2005).

Agricultural and urban land uses cause habitat fragmentation, draining of wetlands, loss and modification of forest habitats, removal of riparian vegetation, pollution of breeding habitats with pesticides, herbicides, and fertilizers that impact red-legged frog populations (Kiesecker et al. 2001; COSEWIC 2004; Lannoo 2005). Habitat fragmentation is of particular concern in view of the species' seasonal migrations between forested areas and wetland breeding sites (COSEWIC 2004), along with the introduction of non-native sport fish and exotic bullfrogs to aquatic habitats, which benefit from less complex humanized environments (Kiesecker et al. 2001; Doubledee et al. 2003).

Red-legged frogs breed in vegetated shallows of wetlands between sea level and 1200m in elevation (Lannoo 2005), in ponds, ditches, springs, marshes, margins of large lakes, and slow-moving portions of rivers, typically where emergent vegetation is abundant (COSEWIC 2004), or ephemeral ponds (Chelgren et al. 2006). House yards and neighborhood parks may play a small role in keeping breeding grounds for the red-legged frog (Davidson et al. 2001), where building density is low (10-30% impervious surface development) (O'Neil 2001), or small natural or modified catchment areas used for storage of stormwater run-off (Ostegaard et al. 2003 in (COSEWIC 2004) where rainwater is temporary (O'Neil 2001). Egg-masses are most numerous in ponds with over 30% forest cover within 200 m from the shore (COSEWIC 2004) and can be deposited as deep as 5m (Lannoo 2005).

Metamorphosed individuals (juvenile) are largely terrestrial and inhabit a variety of forest types, but are most abundant in older, moist stands. (COSEWIC 2004). They travel long-distances through terrestrial habitats (Chelgren et al. 2006), distances larger than 0.5km from nearest breeding site using moist, densely vegetated riparian microhabitats (summer) (Lannoo 2005).

Adults are observed more than 300m from breeding pools in mesic forests and riparian areas (Lannoo 2005). When conditions are suitable, these frogs can be encountered on the forest floor far from water bodies; distances of 200-300 m away from water have been noted on rainy nights. Adult frogs migrate between aquatic breeding sites and terrestrial foraging habitats, sometimes over many kilometers. (COSEWIC 2004). Observation on Vancouver Island and the Gulf Islands suggest that the species is commonly found in second growth forests, and occasionally occurs in suburban gardens and seasonal ponds in pasture- and agricultural lands adjacent to forested areas (COSEWIC 2004). After breeding, adult red-legged frogs are highly terrestrial and can be found far from aquatic habitats" (Kiesecker and Blaustein 1998).

Buffers are needed around habitats to ensure that outside activities do not degrade habitat components" (Fellers and Kleeman 2009). McLeod and Moy found that "residual tree patches can be important short-term refuges for migrating or dispersing amphibians, but their value is size-dependent" (Chan Mcleod and Moy 2009). Their results indicate that "residual trees should be retained in groups and not as individual, scattered trees. Residual tree patches should be between 0.8 ha and 1.5 ha … [and] be located in areas with wet streams or at least where the neighboring stream density is high (Chan Mcleod and Moy 2009).

Western Meadowlark (*Sturnella neclecta*)

> *"In 1927, Oregon's school children voted the western meadowlark as the State Bird. Meadowlark's bright, cheerful colors, beautiful songs, and common appearance in farm and ranch lands endear them to many Oregonians. Due to habitat loss, they are no longer common in some parts of Oregon and have become particularly rare in the Willamette Valley* (Oregon Department of Fish and Wildlife 2006).

Western meadowlark occurs in grasslands and prairies from central Kentucky to the Pacific coast (Morrison 1993). The Oregon Department of Fish and Wildlife (2006) also classifies the Western Meadowlark as a Strategy Species (Oregon Department of Fish and Wildlife 2006).

Declines of grassland bird populations result from habitat loss (urbanization), degradation (land management practices, disruption of natural disturbance regimes), and fragmentation (smaller isolated patches) of habitat (Johnson and Igl 2001; Oregon Department of Fish and Wildlife 2006).

Western meadowlarks feed mostly on grasshoppers, beetles, and other insects (Morrison 1993; Oregon Department of Fish and Wildlife 2006). Flocks sometimes feed on corn, wheat, and other grains (Morrison 1993).

Western Meadowlarks are less abundant in open-space grasslands at urban edges than they are in grassland interiors (Jones and Bock 2002). They require "large expanses of grasslands for foraging and nesting due to relatively large home range requirements; scattered shrubs, trees or posts for singing perches" (Oregon Department of Fish and Wildlife 2006).

Western Meadowlark reaches moderate levels of abundance in plots with moderate limitation imposed by urban encroachment (Haire et al. 2000). In fact, "most of the grassland birds can live alongside people if certain habitat features are provided, such as increased herbaceous plant diversity… Fallow fields, lightly-grazed pastures, grass seed fields, vineyards, and Christmas tree farms can provide habitat for grassland birds and some other wildlife" (Oregon Department of Fish and Wildlife 2006). Golf courses could contribute to conservation of bird communities if appropriate design features are adopted (LeClerc and Cristol 2005). Although the Western Meadowlark requires large territories of grasslands, (Davis and Brittingham 2004) notes that these territories may comprise several patches. Davis (2004) noticed that Western Meadowlark abundances occurred more often in smaller pastures (larger than 8 ha) with low density of shrubs and greater density of tall dead vegetation.

Relative to other passerines in grasslands, this species tends to have large territories that are not confined to single fields (e.g. Frawley 1989). Western Meadowlarks tend to avoid areas with extensive woody vegetation (Johnson and Igl 2001).

Douglas Squirrel (*Tamiasciurus douglasii*)

Douglas squirrels are associated with conifer forests ranging from west of the Cascade Mountains to the coast, from southern British Columbia, Washington, Oregon, to northern California. In general, old-growth stands are preferred over young and mature stands, although studies have shown larger abundance in second-growth or mature stands (Ransome and Sullivan 2004). They feed on seeds, fungi, and occasionally bird eggs and nestlings; food supply determines population fluctuations (Sullivan and Sullivan 1982; Gonzales et al. 2008).

Douglas squirrel produces in average 4 to 6 offspring per year, which can range from 2 to 8, being one litter the norm in Oregon. The first breed occurs between 10 and 12 months of age. Maximum life span is approximately 7 years in the wild. Douglas squirrel is highly territorial and solitary, except during mating. Home range is less than 0.6 ha. Migration may occur if food supply diminishes (O'Neil 2001).

APPENDIX C
DATA DICTIONARY FOR IDU ATTRIBUTES

Attribute: AreaFt

Description: area of IDU in square feet.

Attribute: Acres

Description: area of IDU in acres.

Attribute: LULC2k / STARTLULC

Description: LULC (land use and land cover) is the representation of initial conditions for the whole study area. It originates from PNW-ERCs LULC circa 2000.

Source: PNW-ERC Alternative Futures Project.

Values:

1 Residential 0-4 Dwelling Units/acre
2 Residential 4-9 Dwelling Units/acre
3 Residential 9-16 Dwelling Units/acre
4 Residential >16 Dwelling Units/acre
5 Vacant
6 Commercial
7 Commercial / Industrial
8 Industrial
9 Institutional
10 residential/commercial
11 Urban sand & gravel
12 Urban Civic Open Space
16 Rural residential
18 Railroad
19 Primary roads
20 Secondary roads
21 Light duty roads
22 Other roads
24 Rural sand & gravel
29 Main channel non-vegetated
30 Stream orders 1-4
31 Stream orders 5-7
32 Other water
33 Lakes reservoirs perm wetlands
49 Hardwood, semiclosed upland
51 Forest open
52 Forest semi-closed mixed
53 Forest closed hardwood
54 Forest closed mixed
56 Conifer 0-20 years
57 Forest closed conifer 21-40 years
58 Forest closed conifer 41-60 years
59 Forest closed conifer 61-80 years
60 Forest closed conifer 81-200 years

61 Forest closed conifer 200+ years	85 Pasture
66 Hybrid Poplar	86 Natural grassland
67 Grass seed rotation	87 Natural shrub
68 Irrigated annual rotation	88 Bare / fallow
71 Grain	89 Flooded / marsh
72 Nursery	90 Irrigated perennial
73 Berries and Vineyards	91 Turfgrass
74 Double cropping	92 Orchard
75 Hops	93 Christmas Tree
76 Mint	95 Conifer woodlot
78 Sugar beet seed	98 Oak savanna
83 Hayfield	101 Wet shrub

Attribute: OS

Description: OS is an open space classification based on Metro's park classification and expanded to accommodate new open space types. This attribute is populated as scenarios run and open spaces are created.

Values: 1201 - 1270

1201	Developed park site with amenities
1202	Urban farm
1203	Greenway (recreational)
1204	Greenway (ecological / buffer)
1210	Community center
1211	Trail or path
1212	Community Garden
1220	Open space or natural area without amenities
1221	Open space or natural area: forest
1222	Open space or natural area: oak savanna
1223	Open space or natural area: grassland
1224	Open space or natural area: wetland
1225	Riparian corridor

1226	Wetland buffers with passive recreation
1227	Grasslands buffers with passive recreation
1228	Oak savanna buffers with passive recreation
1229	Thinned forest with passive recreation
1230	Common area of subdivision or condo complex: grass
1231	Common area forest
1232	Common area wetland
1233	Underpass for Red-legged frog
1234	Underpass for Douglas squirrel
1240	Cemetery
1250	Golf course
1260	School grounds or school park
1270	Parking lot

Attribute: ARA

Description: Adamus Resource Assessment habitat classes

Values: Habitat classes: 1 - 34

1 Conifer 0-20 yrs	18 Vineyards, berries
2 Conifer closed 21-40	19 Leafy vegetables
3 Conifer closed 41-60	20 Grass short
4 Conifer closed 61-80	21 Grass natural
5 Conifer closed 81-200	22 Grass tall
6 Conifer closed 200+	23 Bare, burnt, fallow
7 Mixed forest closed	26 Seasonal wetlands
8 Hardwood closed	27 Lakes, reservoirs, permanent wetlands
11 Hardwood semi-closed upland	29 Streams large
12 Tree open upland	30 Channel gravel
14 Shrub dry, tree open, semi-closed, valley	31 Built high density
15 Shrub wet valley	32 Built mid density
16 Christmas trees	33 Built low density
17 Orchards, hybrid poplar	34 Roads, railroads

Attribute: LULC_A

Description: Aggregated LULC classes

Source: PNW-ERC

Values: 0 - 10

1 Urban
2 Rural
3 Agriculture
4 Forest
5 Wetlands
6 Other Vegetation
7 Water
8 Roads

Attribute: Amp

Description: Habitat score for *Rana aurora*

Source: PNW-ERC

Values: 0 - 10

3 Existing wetland (wtlnd = 5), as determined by the National Wetland Inventory, and LULC2K = 66, 67, 68, 72, 73, 74, 75, 78, 83, 85, 86, 87, 88, 90, 91, 92, 93, and 98; for being wetlands, may function as source areas in the ecological evaluation;

6 Existing wetland (wtlnd = 5), as determined by the NWI, and LULC2K = 1, 2, and 16, assuming sustainable stormwater management in low-density residential areas;

8 Forests (LULC_A = 4) except LULC2K = 49 (Hardwood, semi-closed upland)

9 Existing wetland (wtlnd = 5), as determined by the NWI, and Forests except LULC2K = 49

10 Existing wetland (wtlnd = 5), as determined by the NWI, and LULC2K = 89 (flooded/marsh) or 101 or 33 (lakes, reservoirs, permanent wetlands)

Attribute: Brd

Description: Habitat score for *Sturnella neclecta*

Source: Schumaker 2004

Values: 0 - 10

2 LULC2k = 87 (Natural shrub), 89 (Flooded / marsh), 93 (Christmas Tree)

3 LULC2k = 67 (Grass seed rotation), 71 (Grain), 82 (Field crop), 83 (Hayfield), 84 (Late field crop), 85 (Pasture)

9 LULC2k = 98 Oak savanna

10 LULC2k = 86 Natural grasslands

Attribute: Mam

Description: Habitat score for *Tamiasciurus douglasii*

Source: Schumaker 2004

Values: 0 - 10

1 LULC2k = 49 (Hardwood, semi-closed upland), 53 (Forest closed hardwood), 66 (Hybrid Poplar), 92 (Orchard), 93 (Christmas Tree)

2 LULC2k = 12 (Urban Civic Open Space), 16 (Rural residential), 56 (Conifer 0-20 years)

3 LULC2k = 1 (Residential 0-4 Dwelling Units/acre), 11 (Urban sand & gravel)

5 LULC2k = 51 (Forest open)

6 LULC2k = 52 (Forest semi-closed mixed)

7 LULC2k = 54 (Forest closed mixed), 57 (Forest closed conifer 21-40 years), 95 (Conifer woodlot)

8 LULC2k = 58 (Forest closed conifer 41-60 years), 59 (Forest closed conifer 61-80 years)

9 LULC2k = 60 (Forest closed conifer 81-200 years)

10 LULC2k = 61 (Forest closed conifer 200+ years)

Attribute: Park

Description: classification of existing parks used by Metro

Values:

1 Developed Park site with amenities

2 Open space or natural area without amenities

3 Common area of a subdivision or condominium complex

4 Cemetery

5 Golf course

6 School grounds or school park

11 Trail or path

12 Community Garden

Attribute: dem

Description: digital elevation model

Values:Elevation: 0 - 342 ft

Attribute: hydric

Description: Presence or absence of hydric soils

Values: 1 (present) / 0 (absent)

Attribute: popdens

Description: Population density in people per acre

Values: number of people

Attribute: RdBuf

Description: distance from roads

Values:	0 - road	3 - 90 m buffer
	1 - 30 m buffer	4 - 120 m buffer
	2 - 60 m buffer	5 - > 120 m buffer

Attribute: slope

Description: slopes

Values:
0 - slopes smaller than 10%
10 - slopes higher than 10 and smaller than 25%
25 - slopes higher than 25%

Attribute: StBuf

Description: distance from stream

Values:	5 - IDU intersect stream	2 - 90 m buffer
	4 - 30 m buffer	1 - 120 m buffer
	3 - 60 m buffer	0 - > 120 m

Attribute: UR_IN

Description: determines if IDU is within focal area (inside urban reserves)

Values: 1 inside the urban reserves

2 in Damascus Comprehensive Plan

0 outside either - 1/2 mile buffer

Attribute: veg1851

Description: historic vegetation

Values: 1 Closed forest; Riparian & Wetland

2 Closed forest; Upland

3 Emergent wetlands

4 Prairie

5 Savanna

6 Unvegetated

7 Water

8 Woodland

Attribute: wtlnd

Description: IDU rating according to distance to wetland

Values: 5 - wetland

4 - 30 m buffer

3 - 60 m buffer

2 - 90 m buffer

1 - 120 m buffer

0 - > 120 m

Attribute: ZONE

Description: zones are used to allocate new population. Areas that coincide with Damascus's Comprehensive Plan adopt its land use scheme as zones, while the urban reserves have two zones.

Values: 0 Study area, no development

	12 Public Facilities/Open Space	
	20 Roads	

Damascus

Initial	After populated (same values in the urban reserves after populated)	
31	1 Conservation Residential,	1 Dwelling Units/acre
32	2 Low Density Residential,	4 Dwelling Units/acre
33	3 Medium Density Residential,	9 Dwelling Units/acre
34	4 High Density Residential,	20 Dwelling Units/acre
35	non-developable land in Damascus, within 60m from streams, not roads, not existing open space, within Metro's conservation zone, or identified as wetland with other land use.	
7	7 General Employment	
40	10 City Center	16 Dwelling Units/acre
40	10 Neighborhood Center	16 Dwelling Units/acre
40	10 Village Center	16 Dwelling Units/acre

Urban reserves

5	General Employment
11	Developable, residential and mixed-use, residential and employment, 16 Dwelling Unit/acre
13	Conservation, non-developable (high quality/breeding habitats)
14	Potential open space, priority for restoration, non-developable (conservation interest, within 60m from streams + grasslands + savannas or within 60m from streams, within Metro's vegetation = forest, within Damascus), or identified as wetland with other land use.
15	Potential open space, priority for restoration, developable (within Metro's vegetation area and outside 60m from streams or within 60m from streams, within Metro's vegetation, within Damascus)
16	Potential corridors, developable, outside Metro's conservation areas and within 60m from streams and not in zones 13 - 15; other corridors, developable.

Attribute: vegMet

Description: vegetation used to tag conservation and restoration areas, and developable areas close to existing resources. This attribute originates in Metro's vegetation layer (2008).

Values: 1 Forest

2 Grass or Open Field (low structure)

3 Woody or Shrub (includes orchards and tree farms)

Crosswalk LULC / LULCX / ARA / wildlife scores

A = amphibian: Red-legged frog

B = bird: Western meadowlark

M = Mammal: Douglas squirrel

LULC: Land use land cover - PNW-ERC

LULCX: Expanded LULC for new open space classes

ARA: Adamus Resource Assessment

Table 5. LULC/LULC_X/ARA classes crosswalk. LULCX classes that correspond to LULC = 12 are the urban open space types that are produced in the scenarios. Numbers in front of LULCX descriptions correspond to Metro's open space classes and were used as a basis for creating new open space classes. Adamus Resource Assessment (ARA) does not provide a classification for open spaces. I used approximate structural similarity to assign classes and scores to existing and proposed open space types.

lulc_X	lulc_A	ARA	A	B	M	LULCX description	ARA description	r	g	b
1	1	32	0	0	3	Conservation residential, 1 DU/acre	Built mid density	247	215	134
2	1	31	0	0	0	Low-dens. Residential, 4 DU/acre	Built high density	236	172	125
3	1	31	0	0	0	Mid-dens. Residential, 9 DU/acre	Built high density	219	124	94
4	1	31	0	0	0	High -dens. Residential, 20 DU/acre	Built high density	208	82	86
5	3	20	0	0	0	Vacant	Grass short	255	240	240
6	1	31	0	0	0	Commercial	Built high density	236	139	175
7	1	31	0	0	0	Commercial / Industrial	Built high density	191	89	153
8	1	31	0	0	0	Industrial	Built high density	81	57	138
9	1	31	0	0	0	Institutional	Built high density	255	255	255
10	1	31	0	0	0	Residential/commercial, 16 DU/acre	Built high density	220	74	80
11	1	32	0	0	3	Urban sand & gravel	Built mid density	255	240	240
12	1	33	0	0	2	Urban Civic Open Space	Built low density	190	190	190
16	1	33	0	0	2	Rural residential	Built low density	190	190	190

lulc_X	lulc_A	ARA	A	B	M	LULCX description	ARA description	r	g	b
18	2	34	0	0	0	Railroad	Roads, railroads	99	99	99
19	2	34	0	0	0	Primary roads	Roads, railroads	2	2	2
20	2	34	0	0	0	Secondary roads	Roads, railroads	41	41	41
21	2	34	0	0	0	Light duty roads	Roads, railroads	79	79	79
22	2	34	0	0	0	Other roads	Roads, railroads	79	79	79
24	3	23	0	0	0	Rural sand & gravel	Bare, burnt, fallow	250	234	214
29	6	30	0	0	0	Main channel non-vegetated	Channel gravel	239	165	7
30	7	28	0	0	0	Stream orders 1 - 4	Streams small	0	126	194
31	7	29	0	0	0	Streams orders 5 - 7	Streams large	0	126	194
32	7	29	0	0	0	Other water	Streams large	0	126	194
33	7	27	10	0	0	Lakes reservoirs perm wetlands	Lakes, reservoirs, permanent wetlands	37	90	166
42	6	35	0	0	0	Barren				
49	4	11	0	0	1	Hardwood, semi-closed upland	Hardwood semi-closed upland	97	137	36
51	4	12	8	0	5	Forest open	Tree open upland	206	188	193
52	4	10	8	0	6	Forest semi-closed mixed	Mixed forest semi-closed upland	195	84	79
53	4	8	8	0	1	Forest closed hardwood	Hardwood closed	149	191	196
54	4	7	8	0	7	Forest closed mixed	Mixed forest closed	121	164	152
55	4	10	8	0	6	Forest semi-closed conifer				
56	4	1	8	0	2	Conifer 0-20 years	Conifer 0-20 yrs	204	226	124
57	4	2	8	0	7	Forest closed conifer 21-40 years	Conifer closed 21-40	189	219	64
58	4	3	8	0	8	Forest closed conifer 41-60 years	Conifer closed 41-60	151	202	71
59	4	4	8	0	8	Forest closed conifer 61-80 years	Conifer closed 61-80	75	138	48
60	4	5	8	0	9	Forest closed conifer 81-200 years	Conifer closed 81-200	54	101	34
61	4	6	8	0	10	Forest closed conifer 200+ years	Conifer closed 200+	0	77	65
62	4	11	0	0	1	Forest Semi-closed hardwood				
66	3	17	0	0	1	Hybrid Poplar	Orchards, hybrid poplar	170	184	91
67	3	22	0	3	0	Grass seed rotation	Grass tall	245	249	235
68	3	22	0	3	0	Irrigated annual rotation	Grass tall	177	215	166
71	3	22	0	3	0	Grain	Grass tall	204	195	152
72	3	19	0	0	0	Nursery	Leafy vegetables	114	13	112
73	3	18	0	0	0	Berries and Vineyards	Vineyards, berries	101	109	174
74	3	19	0	0	0	Double cropping	Leafy vegetables	213	220	117
75	3	18	0	0	0	Hops	Vineyards, berries	204	227	171
76	3	19	0	0	0	Mint	Leafy vegetables	119	196	158
78	3	19	0	0	0	Sugar beet seed	Leafy vegetables	224	218	210
79	3	19	0	0	0	Row crop	Leafy vegetables	184	118	165
80	3	20	0	0	0	Grass	Grass short	254	244	162
82	3	22	0	3	0	Field crop	Grass tall	158	157	133
83	3	22	0	3	0	Hayfield	Grass tall	164	158	106
84	3	22	0	3	0	Late field crop	Grass tall	252	222	169
85	3	22	0	3	0	Pasture	Grass tall	201	215	189
86	6	21	0	10	0	Natural grassland	Grass natural	248	228	22

lulc_X	lulc_A	ARA	A	B	M	LULCX description	ARA description	r	g	b
87	6	14	0	2	0	Natural shrub	Shrub dry, tree open, semiclosed, valley	131	116	25
88	3	23	0	0	0	Bare / fallow	Bare, burnt, fallow	181	176	172
89	5	26	10	2	0	Flooded / marsh	Seasonal wetlands	163	215	246
90	3	19	0	0	0	Irrigated perennial	Leafy vegetables	0	174	90
91	3	20	0	0	0	Turfgrass	Grass short	143	204	33
92	3	17	0	0	1	Orchard	Orchards, hybrid poplar	255	239	218
93	3	16	0	2	1	Christmas Tree	Christmas trees	229	67	130
95	4	7	0	0	7	Conifer woodlot	Mixed forest closed	34	90	104
98	4	13	0	9	0	Oak savanna	Oak savanna	230	115	26
99	6	15	10	0	0	Non-tree wetlands				
101	6	15	10	0	0	Wet shrub	Shrub wet valley	174	199	229

Table 6. Open space classes.

OS					
1201	Developed park site with amenities	Built low density	190	190	190
1202	Urban farm	Grass tall	204	195	152
1203	Greenway (recreational)	Built low density	190	190	190
1204	Greenway (ecological / buffer)	Most likely a riparian forest	195	84	79
1210	Community center	Built high density	255	255	255
1211	Trail or path	Built low density	190	190	190
1212	Community Garden	Leafy vegetables	101	109	174
--	Open space or natural area without amenities	--------------------	-	-	-
1221	Open space or natural area: forest	Mixed forest semi-closed upland	195	84	79
1222	Open space or natural area: oak savanna	Oak savanna	230	115	26
1223	Open space or natural area: grassland	Grass natural	248	228	22
1224	Open space or natural area: wetland	Seasonal wetlands	163	215	246
1225	Riparian corridor				
1226	Wetland buffers with passive recreation				
1227	Grasslands buffers with passive recreation				
1228	Oak savanna buffers with passive recreation				
1229	Thinned forest with passive recreation				
1230	Common area of subdivision or condo complex: grass	Grass short	255	255	255
1231	Common area: forest	Forest open	206	188	193
1232	Common area: wetland	Lakes reservoirs perm wetlands	37	90	166
1240	4 Cemetery	Grass short	255	255	255
1250	5 Golf course	Grass short	255	255	255
1260	6 School grounds or school park	Grass short	255	255	255

Crosswalk LULC2K / Damascus Comp Plan

Table 7. Crosswalk between land use classes as represented in Damascus's Comprehensive Plan and PNW-ERC's LULC2K

Damascus zones	LULC2K	LULC_X
Conservation Residential	1. Res. 0-4 Dwelling Units/acre	1. Conservation res. - 1 DU/acre

Low Density Residential	2. Res. 4-9 Dwelling Units/acre	2. Low density res. - 4 DU/acre
Medium Density Res.	3. Res. 9-16 Dwelling Units/acre	3. Medium density res. - 9 DU/acre
High Density Residential	4. Res. >16 Dwelling Units/acre	4. High density res. - 20 DU/acre
Commercial	6. Commercial	6. Commercial
General Employment	7. Commercial / Industrial	7. Commercial/industrial
City Center		
Neighborhood Center	10. Residential/commercial	10. Urban center - 16 DU/acre
Village Center		
Public Facilities / Open Space	Urban Civic Open Space	1201 - 1270. Open space
Roads	19. Primary roads 20. Secondary roads 21. Light duty roads	19 - 21 Roads

Crosswalk Veg1851 / LULC2K / LULC_X

Veg1851	**LULC2K**	**LULC_X**
1 Closed forest; Riparian & Wetland	56 Conifer 0-20 years 57 Forest closed conifer 21-40 years 58 Forest closed conifer 41-60 years 59 Forest closed conifer 61-80 years 60 Forest closed conifer 81-200 years 61 Forest closed conifer 200+ years	1221 Open space or natural area: forest
2 Closed forest; Upland	49 Hardwood, semi-closed upland	1221 Open space or natural area: forest
3 Emergent wetlands	33 Lakes reservoirs perm wetlands 89 Flooded / marsh 101 wet shrub	1224 Open space or natural area: wetland
4 Prairie	86 Natural grassland	1223 Open space or natural area: grassland
5 Savanna	98 Oak savanna	1222 Open space or natural area: oak savanna
6 Unvegetated	29 Main channel non-vegetated 88 Bare / fallow	
7 Water	30 Stream orders 1 - 4 31 Streams orders 5 - 7 32 Other water	
8 Woodland	51 Forest open 52 Forest semi-closed mixed 53 Forest closed hardwood 54 Forest closed mixed	

APPENDIX D

POLICIES

Open space: Conservation

Policy 10	**CONS1 Conservation of breeding habitats for Red-legged frog**
Policy goal(s)	Protect wetlands. Determines that a local government agency is willing to acquire lands within the urban reserves that have wetlands for conservation of breeding habitats for the Red-legged frog, or landowners and/or developers have incentives to dedicate part of a parcel for conservation. Includes IDUs identified as wetlands (NWI) and delimited as “potential resource features for Metro's Fish and Wildlife Protection program”.
Site attributes	UrIn = 1 and LULC_X = 89 {Flooded Marsh} and wtlnd = 5 and OS = 0
Outcomes	Zone = 13 {Conservation} and OS=1224{Open space or natural area: wetland}:100
Policy 11	**CONS2 Conservation of migration corridors for Red-legged frog**
Policy goal(s)	Protect riparian forests within 60m from streams from development. Land becomes a conservation zone. Determines that a local government agency is willing to acquire lands within the urban reserves that have riparian forests for conservation of migration corridors for the Red-legged frog, or landowners and/or developers have incentives to dedicate part of a parcel for conservation.
Site attributes	UrIn = 1 and LULC_A = 4 {Forest} and LULC_X != 49 {Hardwood Semi-closed Upland} and wtlnd != 5 {wetland} and StBuf > 2 {90m} and OS = 0
Outcomes	ZONE=13 {Conservation} and OS=1221{Open space or natural area: forest}:100
Policy 12	**CONS3 Conservation of high-quality habitats for Western meadowlark (grasslands)**
Policy goal(s)	Protect existing grasslands from development. Land becomes a conservation zone. Determines that a local government agency is willing to acquire lands within the urban reserves that have natural grasslands for conservation of high-quality habitats for the Western meadowlark, or landowners and/or developers have incentives to dedicate part of a parcel for conservation.
Site attributes	UrIn = 1 and LULC_X = 86 {Natural Grassland} and OS = 0
Outcomes	ZONE=13{Conservation} and OS=1223{Open space or natural area: grassland}:100
Policy 13	**CONS4 Conservation of high-quality habitats for Western meadowlark (oak savanna)**
Policy	Protect existing oak savannas from development. Land becomes a

goal(s)	conservation zone. Determines that a local government agency is willing to acquire lands within the urban reserves that have oak savanna for conservation of high-quality habitats for the Western meadowlark, or landowners and/or developers have incentives to dedicate part of a parcel for conservation.
Site attributes	UrIn = 1 and LULC_X = 98 {oak savanna} and OS = 0
Outcomes	ZONE=13{Conservation} and OS=1222{Open space or natural area: oak savanna}:100
Policy 14	**CONS5 Conservation of high-quality habitats for Douglas squirrel**
Policy goal(s)	Protect existing mature conifer forests and old growth from development. Land becomes a conservation zone. Determines that a local government agency is willing to acquire lands within the urban reserves that have forests for conservation of high-quality habitats for the Douglas squirrel, or landowners and/or developers have incentives to dedicate part of a parcel for conservation. It includes: Forest closed conifer 41-60 years, Forest closed conifer 61-80 years, Forest closed conifer 81-200 years, Forest closed conifer 200+ years
Site attributes	UrIn = 1 and Mam > 7 {conifer older than 40 years} and OS = 0
Outcomes	ZONE=13{Conservation} and OS=1221{Open space or natural area: forest}:100

Open space: Creation of corridors

Policy 20	**COR1 Creation of habitat corridor**
Policy goal(s)	Expand existing and new conservation areas to create corridors. Applies to areas zoned as a potential corridor, is not residential, commercial, industrial, or road, and creates conservation areas at an early successional stage.
Site attributes	UrIn = 1 {Inside Urban Reserve} and ZONE = 14 and LULC_A != 1 {Urban} and Park != 11 (Miller and Hobbs 2000) and LULC_A != 4 {Forest} and OS = 0
Outcomes	Expand(UrIn = 1 and ZONE = 14 and LULC_A != 1 and Park != 11 and LULC_A != 4 and OS = 0, 1100000, ZONE=13{Conservation} and LULC_X=86 {Natural Grassland} and OS=1223 {Open space or natural area: grassland}):50; Expand(UrIn = 1 and ZONE = 14 and LULC_A != 1 and Park != 11 and LULC_A != 4 and OS = 0, 1100000, ZONE=13{Conservation} and LULC_X=87 {Natural shrub} and OS=1223 {Open space or natural area: grassland}):50
Policy 21	**COR2 Creation of underpasses for Red-legged frog in wetlands**
Policy goal(s)	Reconnect wetlands intersected by roads. Part of the road that is adjacent to a wetland converts to an underpass.
Site	UrIn = 1 {Inside Urban Reserve} and wtlnd = 5 {wetland} and ZONE =

attributes	20 {Roads} and OS = 0
Outcomes	Expand(UrIn = 1 and wtlnd = 5 and ZONE = 20 and OS = 0, 110000, ARA=26 {Seasonal wetlands} and OS=1233{Underpass for Red-legged frog}):50
Policy 22	**COR3 Creation of underpasses for Red-legged frog in streams**
Policy goal(s)	Reconnect river banks. If a road intersects a stream or stream bank, part of that road becomes an underpass.
Site attributes	UrIn = 1 {Inside Urban Reserve} and ZONE = 20 {Roads} and StBuf = 5
Outcomes	ARA=28{Streams small} and Amp=7{check} and OS=1233 {Underpass for Red-legged frog}:100
Policy 23	**COR4 Creation of underpasses for Douglas squirrel**
Policy goal(s)	Allow protected passage under roads (Donaldson 2005) or canopy connection (Forman, 2003). Part of the road that is adjacent to a high-quality habitat, an underpass reconnects the habitats
Site attributes	UrIn = 1 {Inside Urban Reserve} and ZONE = 20 {Roads} and (NextTo(LULC_A = 4 {Forest}) or NextTo(OS = 1221 {Open space or natural area: forest}) or NextTo(OS = 1234 {Underpass for Douglas squirrel}))
Outcomes	Mam=5 and OS=1234{Underpass for Douglas squirrel}:25

Open space: Protection of habitats

Policy 30	**BUF1 Protection of breeding habitats for red-legged frog**
Policy goal(s)	Create wetland buffers to protect habitat and improve water quality.
Site attributes	UrIn = 1 {Inside Urban Reserve} and (wtlnd = 4 { < 30m from wetland} or wtlnd = 3 { < 60m from wetland}) and LULC_A != 1 {Urban} and LULC_A != 8 {Roads} and OS = 0 and Park != 11 (Miller and Hobbs 2000) and LULC_A != 4
Outcomes	Expand(UrIn = 1 and (wtlnd = 4 or wtlnd = 3) and LULC_A != 1 and LULC_A != 8 and OS = 0 and Park != 11 and LULC_A != 4, 600000, ZONE=14{Restoration - non-developable} and LULC_X = 87):50
Policy 31	**BUF2 Protection of grasslands for western meadowlark**
Policy goal(s)	Protect grasslands and provide areas for passive recreation. It applies to protection of conservation areas created by policy CONS3 that creates protected grasslands.
Site attributes	UrIn = 1 {Inside Urban Reserve} and NextTo(OS = 1223 {Open space or natural area: grassland}) and OS =0 and LULC_X != 86 {Natural Grassland} and ZONE != 20 {Roads} and LULC_A != 1 {Urban}
Outcomes	Expand(UrIn = 1 and NextTo(OS = 1223) and OS =0 and LULC_X != 86 and ZONE != 20 and LULC_A != 1, 600000, ZONE=14 {Restoration - non-developable} and LULC_X = 86):100
Policy 32	**BUF3 Protection of oak savannas for western meadowlark**

Policy goal(s)	Protect oak savannas and provide areas for passive recreation. It applies to protection of conservation areas created by policy CONS4 that creates protected oak savannas.
Site attributes	UrIn = 1 {Inside Urban Reserve} and NextTo(OS = 1222 {Open space or natural area: oak savanna}) and OS = 0 and LULC_X != 98 {Oak savanna} and ZONE != 20 {Roads} and ZONE != 13 {Conservation} and LULC_A != 1 {Urban}
Outcomes	Expand(UrIn = 1 and NextTo(OS = 1222) and OS = 0 and LULC_X != 98 and ZONE != 20 and ZONE != 13 and LULC_A != 1, 600000, ZONE=14{Restoration - non-developable} and LULC_X = 86 {Natural grassland}and OS=1228 {Oak savanna buffers with passive recreation}):50; Expand(UrIn = 1 and NextTo(OS = 1222) and OS = 0 and LULC_X != 98 and ZONE != 20 and ZONE != 13 and LULC_A != 1, 600000, ZONE=14{Restoration - non-developable} and LULC_X = 87 {Natural srub} and OS=1228 {Oak savanna buffers with passive recreation}):50
Policy 33	**BUF4 Protection of habitats for Douglas squirrel**
Policy goal(s)	Protect forests and provide areas for passive recreation. It applies to protection of conservation areas created by policy CONS5 that creates protected forests.
Site attributes	UrIn = 1 and NextTo(Mam > 8) and LULC_X >= 51 {Forest open} and LULC_X <= 57 {FCC 21-40 yrs} and ZONE != 13 {Conservation} and LULC_A != 1 {Urban} and LULC_A != 8 {Roads} and OS = 0
Outcomes	Expand(UrIn = 1 and NextTo(Mam > 8) and LULC_X >= 51 and LULC_X <= 57 and ZONE != 13 and LULC_A != 1 and LULC_A != 8 and OS = 0, 600000, OS=1221{Open space or natural area: forest}):40; Expand(UrIn = 1 and NextTo(Mam > 8) and LULC_X >= 51 and LULC_X <= 57 and ZONE != 13 and LULC_A != 1 and LULC_A != 8 and OS = 0, 600000, OS=1229{Thinned forest with passive recreation}):40; Expand(UrIn = 1 and NextTo(Mam > 8) and LULC_X >= 51 and LULC_X <= 57 and ZONE != 13 and LULC_A != 1 and LULC_A != 8 and OS = 0, 600000, LULC_X = 12 and OS=1201{Developed park site with amenities}):20

Open space: Restoration of habitats

Policy 40	**RST1 Restoration of breeding habitats for red-legged frog**
Policy goal(s)	Restore wetlands on sites identified as wetlands (NWI) that present other land cover or land use. Determines that a local government agency is willing to acquire lands within the urban reserves that have wetlands for restoration of breeding habitats for the Red-legged frog,

	or landowners and/or developers have incentives to dedicate part of a parcel for restoration. Includes IDUs identified as wetlands (NWI) and delimited as "potential resource features for Metro's Fish and Wildlife Protection program".
Site attributes	UrIn = 1 {Inside Urban Reserve} and Zone = 14 and wtlnd = 5 and OS != 1224 {Open space or natural area: wetland}
Outcomes	LULC_X=89 {Flooded Marsh} and OS=1224 {Open space or natural area: wetland}:100
Policy 41	**RST2 Restoration of riparian corridors**
Policy goal(s)	Expand corridors within the riparian zone (within 60m from a stream) and areas zoned as potential corridors. Lands that have land cover other than forest have priority for riparian forest restoration. All lands within 60m from a stream are protected from development.
Site attributes	UrIn = 1 {Inside Urban Reserve} and LULC_A != 4 {Forest} and (ZONE = 14 {Restoration - non-developable} or ZONE = 16 (Hargrove et al. 2005)) and LULC_A != 1 {Urban} and OS != 1224 {Open space or natural area: wetland} and LULC_X != 86 {Natural Grassland} and LULC_X != 98 {Oak savanna}
Outcomes	LULC_X=101{Wet Shrub} and OS=1225 {Riparian corridor}:100
Policy 42	**RST3 Restoration of habitats for Western meadowlark (grasslands)**
Policy goal(s)	Expand grasslands to provide larger breeding habitat. Existing agricultural lands adjacent to grasslands are converted to grasslands to provide breeding habitat for Western meadowlark.
Site attributes	UrIn = 1 {Inside Urban Reserve} and ARA = 22 {Grass tall} and NextTo(LULC_X = 86 {Natural Grassland})
Outcomes	Expand(UrIn = 1 and ARA = 22 and NextTo(LULC_X = 86), 1100000, LULC_X=86 and OS=1223 {Open space or natural area: grassland}):100
Policy 43	**RST4 Restoration of habitats for Western meadowlark (oak savanna)**
Policy goal(s)	Expand oak savannas to provide larger habitat. Priority is given to agricultural areas where savanna historically occurred. These areas become parks where restored savannas function as habitat.
Site attributes	UrIn = 1 {Inside Urban Reserve} and ARA = 22 {Grass tall} and veg1851 = 5 {Savanna} and NextTo(ARA=13) and LULC_X != 86
Outcomes	Expand(UrIn = 1 and ARA = 22 and veg1851 = 5 and NextTo(ARA=13) and LULC_X != 86, 1100000, OS=1222 {Open space or natural area: oak savanna}):100
Policy 44	**RST5 Management of golf course for Western meadowlark (grasslands)**
Policy goal(s)	Manage golf courses as habitats.
Site attributes	UrIn = 1 {Inside Urban Reserve} and Park = 5 {golf course}
Outcomes	Expand(UrIn = 1 and Park = 5, 1100000, LULC_X=86 and OS=1250 {Golf course}):100

Policy 50	**GWY1 Creation of greenways as habitats**
Policy goal(s)	Transform the Springwater trail into an urban greenway. Zone changes to create conditions for establishing a 300m-wide greenway. By changing zoning, those lands can be restored and become a conservation area in the future, enhancing the ecological value of the greenway and improving corridors for the Red-legged frog and the Douglas squirrel.
Site attributes	UrIn = 1 {Inside Urban Reserve} and ZONE != 20 {Roads} and ZONE != 13 {Conservation} and Within(Park = 11 (Miller and Hobbs 2000), 150) and Park != 11 (Miller and Hobbs 2000) and OS != 1211 {Trail or path} and LULC_A != 4 {Forest} and LULC_A !=1 {urban}
Outcomes	ZONE=14 {Restoration - non-developable} and OS=1204 {Greenway (ecological / buffer)}:100

Open space: active recreation

Policy 60	**PRK1 Creation of parks near residential areas**
Policy goal(s)	Create recreational areas. Conifer forests can be thinned for protection from fire and transformed to parkland when within a certain distance from residential areas.
Site attributes	UrIn = 1 {Inside Urban Reserve} and LULC_A = 4 {Forest} and Within(LULC_A = 1 {Urban}, 400) and ZONE != 13 {Conservation} and Amp = 0 {0} and Mam < 7
Outcomes	Expand(UrIn = 1 and LULC_A = 4 and Within(LULC_A = 1, 400) and ZONE != 13 and Amp = 0 and Mam < 7, 110000, LULC_X=12 {Civic Open Space} and OS=1201 {Developed park site with amenities}):25; Expand(UrIn = 1 and LULC_A = 4 and Within(LULC_A = 1, 400) and ZONE != 13 and Amp = 0 and Mam < 7, 1100000, LULC_X=51 {Forest open} and OS=1229 {Thinned forest with passive recreation}):75
Policy 61	**PRK2 Creates community gardens**
Policy goal(s)	Some rural residential lands or farmland convert to community gardens as a way to expand the range of open space types.
Site attributes	UrIn = 1 {Inside Urban Reserve} and LULC_A = 3 {Agriculture} and Within(LULC_A = 1 {Urban}, 600) and ZONE != 13 {Conservation} and slope = 0 { < 10%}
Outcomes	Expand(UrIn = 1 and LULC_A = 3 and Within(LULC_A = 1, 600) and ZONE != 13 and slope = 0, 110000, ARA=19 {Leafy vegetables} and OS=1212 {Community Garden}):5
Policy 62	**PRK3 Creates urban farms**
Policy goal(s)	Create urban farms. There is a contemporary desire to keep agriculture within the city as urban farms, to maintain food production close to consumption. Some of the existing farms could

	remain as organic urban farms, what could also provide some habitat for western meadowlark if correct management practices are adopted.
Site attributes	UrIn = 1 {Inside Urban Reserve} and LULC_A = 3 {Agriculture} and Within(ZONE = 5 {General Employment}, 800) and ZONE != 13 {Conservation}
Outcomes	Expand(UrIn = 1 and LULC_A = 3 and Within(ZONE = 5, 800) and ZONE != 13, 110000, OS=1202(Mason 2006) and Brd=5):25
Policy 51	**GWY2 Greenways for recreation and active transportation**
Policy goal(s)	Create trails along riparian vegetation (between 60 to 90 m from stream). Because there are several small streams in the urban reserves, this policy has the potential to create a network of trails that expand the existing Springwater trail and improve non-motorized transportation and recreation network.
Site attributes	UrIn = 1 and (Park = 11 (Miller and Hobbs 2000) or StBuf = 2 {90m}) and ZONE != 13 {Conservation} and wtlnd!=5 and brd = 0
Outcomes	Expand(UrIn = 1 and (Park = 11 or StBuf = 2) and ZONE != 13 and wtlnd!=5 and brd = 0, 1100000, LULC_X=12 {Civic/Open Space} and OS=1203 (Miller and Hobbs 2000)):50

Urban Development: Zoning in the Urban Reserves

Policy 70	**Z01 Creation of centers**
Policy goal(s)	Change zoning in developable land in urban reserves into mixed-use commercial/residential areas with densities up to 16 DU/acre. Sites near arterials are preferred. Conservation and riparian zones areas area excluded.
Site attributes	UrIn=1 and RdBuf < 5 { > 120m} and StBuf = 0 { > 120m} and slope = 0 and OS = 0 and (ZONE = 11 {Developable} or ZONE = 1 {Conservation Residential} or ZONE = 2 {UR: Low Density Residential}) and (NextTo(LULC_X = 19 {Primary roads}) or NextTo(LULC_X = 20 {Secondary roads}) or NextTo(ZONE = 10 {UR: Center}))
Outcomes	Expand(UrIn=1 and StBuf = 0 { > 120m} and slope = 0 and OS = 0 and (ZONE = 11 {Developable} or ZONE = 1 {Conservation Residential} or ZONE = 2 {UR: Low Density Residential}) and (NextTo(LULC_X = 19 {Primary roads}) or NextTo(LULC_X = 20 {Secondary roads}) or NextTo(ZONE = 10 {UR: Center})), 600000, ZONE=10(Center for Biological Diversity et al. 2007)):25
	Expand(UrIn=1 and RdBuf < 5 { > 120m} and StBuf = 0 { > 120m} and slope = 0 and OS = 0 and (ZONE = 11 {Developable} or ZONE = 1 {Conservation Residential} or ZONE = 2 {UR: Low Density Residential}) and (NextTo(LULC_X = 19 {Primary roads}) or NextTo(LULC_X = 20 {Secondary roads}) or NextTo(ZONE = 10 {UR: Center})), 600000, ZONE=10(Center for Biological Diversity et al. 2007)):25

Policy 71	**Z02 Creation of high-density residential zones**
Policy goal(s)	Change zoning in developable land in urban reserves into multifamily residential areas with densities up to 20 DU/acre. Sites near centers are preferred. Conservation and low-density residential zones also qualify if close to centers.
Site attributes	UrIn=1 and StBuf < 3 { > 60m} and slope = 0 { < 10%} and OS = 0 and (ZONE = 11 {Developable} or ZONE=1{Conservation Residential} or ZONE=2{Low Density Residential}) and Within(ZONE = 10 (Center for Biological Diversity et al. 2007), 200)
Outcomes	ZONE=4{High Density Residential}:25
Policy 72	**Z03 Creation of mid-density residential zones**
Policy goal(s)	Change zoning in developable land in urban reserves into mid-density residential areas - town-homes and small lot single-family with densities between 5 and 9 DU/acre. Sites are within walking distance (400m) from centers.
Site attributes	ZONE = 11 {Developable} and Within(ZONE = 10 (Center for Biological Diversity et al. 2007), 400) and slope < 25 and OS = 0
Outcomes	ZONE=3{Medium Density Residential}:20
Policy 73	**Z04 Creation of low-density residential zones**
Policy goal(s)	Change zoning in developable land in urban reserves into low density residential zones with densities between 1 and 4 DU/acre. Sites are at less than 10 min walk (800m) from retail and centers.
Site attributes	ZONE = 11 {Developable} and Within(ZONE = 10 (Center for Biological Diversity et al. 2007), 600) and OS = 0
Outcomes	ZONE=2{Low Density Residential}:20
Policy 74	**Z05 Creation of conservation residential zones**
Policy goal(s)	Change zoning in developable land in urban reserves into general employment zones for industrial and commercial uses.
Site attributes	(ZONE = 11 {Developable} or ZONE = 15 {Restoration - developable} or ZONE = 16 (Hargrove et al. 2005)) and Within(ZONE = 10 (Center for Biological Diversity et al. 2007), 800) and OS = 0
Outcomes	ZONE=1{Conservation Residential}:10
Policy 75	**Z06 Creation of general employment areas in the urban reserves**
Policy goal(s)	Change zoning in developable land in urban reserves into general employment zones for industrial and commercial uses.
Site attributes	ZONE = 5 {General Employment} and OS = 0
Outcomes	Expand(zone=5 and nextto(zone=20) or nextto(lulc_x=6), 1000000, lulc_x=6):35; Expand(zone=5 and nextto(zone=20) or nextto(lulc_x=7), 1000000, lulc_x=7):20; Expand(zone=5 and nextto(zone=20) or nextto(lulc_x=8), 1000000, lulc_x=8):35
Policy 76	**Z07 Creation of parking spaces in industrial and commercial areas**
Policy goal(s)	Create parking areas adjacent to industrial and commercial/industrial

	uses.
Site attributes	ZONE = 5 {General Employment} and (NextTo(LULC_X = 7 {Commercial/Industrial}) or NextTo(LULC_X = 8 {Industrial}) or NextTo(LULC_X = 6 {Commercial})) and OS = 0
Outcomes	LULC_X=20 {Secondary roads} and OS = 1270:25
Policy 77	**Z08 Change zones for DISPERSED DEVELOPMENT**
Policy goal(s)	Distribute developable zones into 5 LULC residential classes.
Site attributes	ZONE = 11 {Developable} or ZONE = 15 {Restoration - developable} or ZONE = 16 (Hargrove et al. 2005) and OS = 0
Outcomes	ZONE=1{Conservation Residential}:19; ZONE=2{Low Density Residential}:29; ZONE=3{Medium Density Residential}:19; ZONE=4{High Density Residential}:15; ZONE=10 (Center for Biological Diversity et al. 2007):15

Urban Development: Zoning in Damascus

Policy 80	**ZDam1 Allow distribution of population in residential/commercial zones**
Policy goal(s)	Create "available capacity" in Damascus's City Center, Neighborhood Center, and Village Center zones. Change allows occupation at a density of 16 dwelling units per acre.
Site attributes	ZONE = 40 (Center for Biological Diversity et al. 2007)
Outcomes	ZONE=50(Center for Biological Diversity et al. 2007):24; ZONE=44{High density}:4
Policy 81	**ZDam2 Allow distribution of population in high density residential zones**
Policy goal(s)	Create "available capacity" in Damascus's High Density Residential zones. Change allows occupation at a density of 16 dwelling units per acre.
Site attributes	ZONE = 34
Outcomes	ZONE=44{High Density Residential}:100
Policy 82	**ZDam3 Allow distribution of population in mid-density residential zones**
Policy goal(s)	Create "available capacity" in Damascus's Medium Density Residential zones. Change allows occupation at a density of 9 dwelling units per acre.
Site attributes	ZONE = 33
Outcomes	ZONE=43{Medium Density Residential}:8; ZONE= 41:25
Policy 83	**ZDam4 Allow distribution of population in low-density residential zones**

Policy goal(s)	Create "available capacity" in Damascus's Conservation Low Density Residential zones. Change allows occupation at a density of 4 dwelling units per acre.
Site attributes	ZONE = 32
Outcomes	ZONE=42{Low Density Residential}:37; ZONE= 41:33
Policy 84	**ZDam5 Allow distribution of population in Conservation residential zones**
Policy goal(s)	Create "available capacity" in Damascus Conservation Residential zones. Change allows occupation at a density of 1 dwelling unit per acre.
Site attributes	ZONE = 31 { Conservation Residential} or zone = 35
Outcomes	ZONE=41{Conservation Residential}:100
Policy 85	**ZDam6 Allocate commercial and industrial uses in Damascus**
Policy goal(s)	Allocate commercial and industrial uses in general employment zones.
Site attributes	ZONE = 7 {General Employment}
Outcomes	LULC_X=6 {Commercial}:40; LULC_X=7 {Commercial/Industrial}:20; LULC_X=8 {Industrial}:40

APPENDIX E

SCENARIO POLICIES ASSIGNMENT

Scenarios:

CD: Compact Development

DD: Dispersed Development

GCD: Greenway and Compact Development

GDD: Greenway and Dispersed Development

PCD: Park and Compact Development

PDD: Park and Dispersed Development

NCD: Network and Compact Development

NDD: Network and Dispersed Development

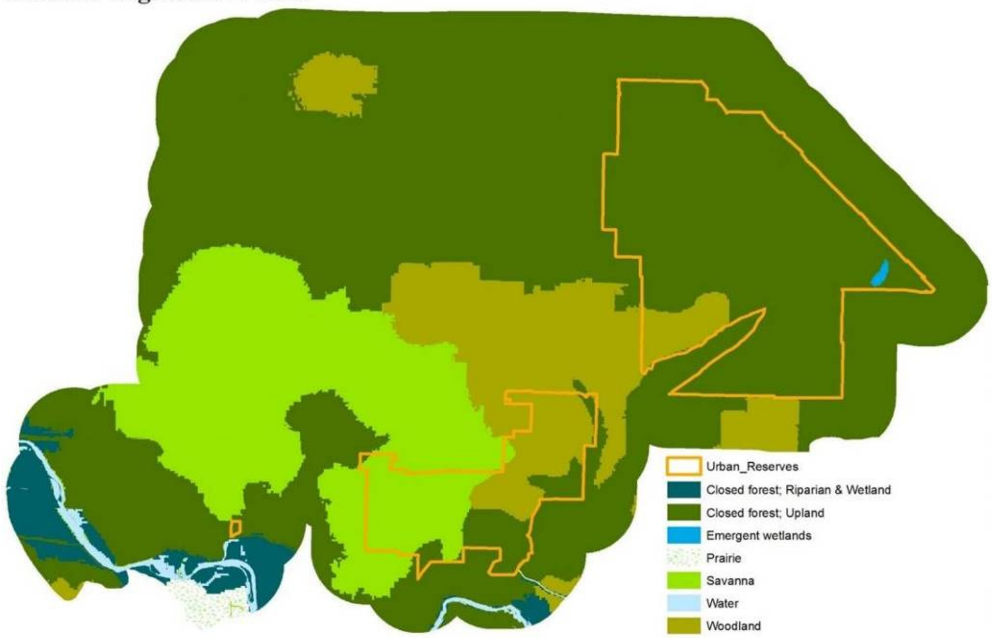
Policy	CD	DD	GCD	GDD	PCD	PDD	NCD	NDD
10 CONS1 Conservation o f breeding habitats for Red-legged frog			X	X	X	X	X	X
11 CONS2 Conservation of migration corridors for Red-legged frog			X	X			X	X
12 CONS3 Conservation of high-quality habitats for Western meadowlark (grasslands)			X	X	X	X	X	X
13 CONS4 Conservation of high-quality habitats for Western meadowlark (oak savanna)			X	X	X	X	X	X
14 CONS5 Conservation of high-quality habitats for Douglas squirrel			X	X	X	X	X	X
20 COR1 Creation of habitat corridor			X	X			X	X
21 COR2 Creation of underpasses for Red-legged frog in wetlands			X	X			X	X
22 COR3 Creation of underpasses for Red-legged frog in streams			X	X			X	X
23 COR4 Creation of underpasses for Douglas squirrel			X	X			X	X
30 BUF1 Protection of breeding habitats for red-legged frog					X	X	X	X
31 BUF2 Protection of grasslands for western meadowlark					X	X	X	X
32 BUF3 Protection of oak savannas for western meadowlark					X	X	X	X
33 BUF4 Protection of habitats for Douglas squirrel					X	X	X	X
40 RST1 Restoration of breeding habitats for					X	X	X	X

Policy	CD	DD	GCD	GDD	PCD	PDD	NCD	NDD
red-legged frog								
41 RST2 Restoration of riparian corridors			X	X			X	X
42 RST3 Restoration of habitats for Western meadowlark (grasslands)					X	X	X	X
43 RST4 Restoration of habitats for Western meadowlark (oak savanna)					X	X	X	X
44 RST5 Management of golf course for Western meadowlark					X	X	X	X
45 RST6 Management of grasslands for Western meadowlark					X	X	X	X
50 GWY1 Creation of greenways as habitats			X	X			X	X
51 GWY2 Greenways for recreation and active transportation			X	X	X	X	X	X
60 PRK1 Creation of parks near residential areas			X	X	X	X	X	X
61 PRK2 Creates community gardens			X	X	X	X	X	X
62 PRK3 Creates urban farms			X	X	X	X	X	X
70 Z01 Creation of centers	X		X		X		X	
71 Z02 Creation of high-density residential zones	X		X		X		X	
72 Z03 Creation of mid-density residential zones	X		X		X		X	
73 Z04 Creation of low-density residential zones	X		X		X		X	
74 Z05 Creation of conservation residential zones	X		X		X		X	
75 Z06 Creation of general employment areas in the urban reserves	X	X	X	X	X	X	X	X
76 Z07 Creation of parking spaces in industrial and commercial areas	X	X	X	X	X	X	X	X
77 Z08 Change zones for DISPERSED DEVELOPMENT (all densities)		X		X		X		X
80 ZDam1 Allow distribution of population in residential/commercial zones	X	X	X	X	X	X	X	X
81 ZDam2 Allow distribution of population in high density residential zones	X	X	X	X	X	X	X	X
82 ZDam3 Allow distribution of population in mid-density residential zones	X	X	X	X	X	X	X	X
83 ZDam4 Allow distribution of population in low-density residential zones	X	X	X	X	X	X	X	X
84 ZDam5 Allow distribution of population in Conservation residential zones	X	X	X	X	X	X	X	X
85 ZDam6 Allocate commercial and industrial uses in Damascus	X	X	X	X	X	X	X	X

APPENDIX F

SCENARIOS

Historic Vegetation : 1851



Ca. 2010

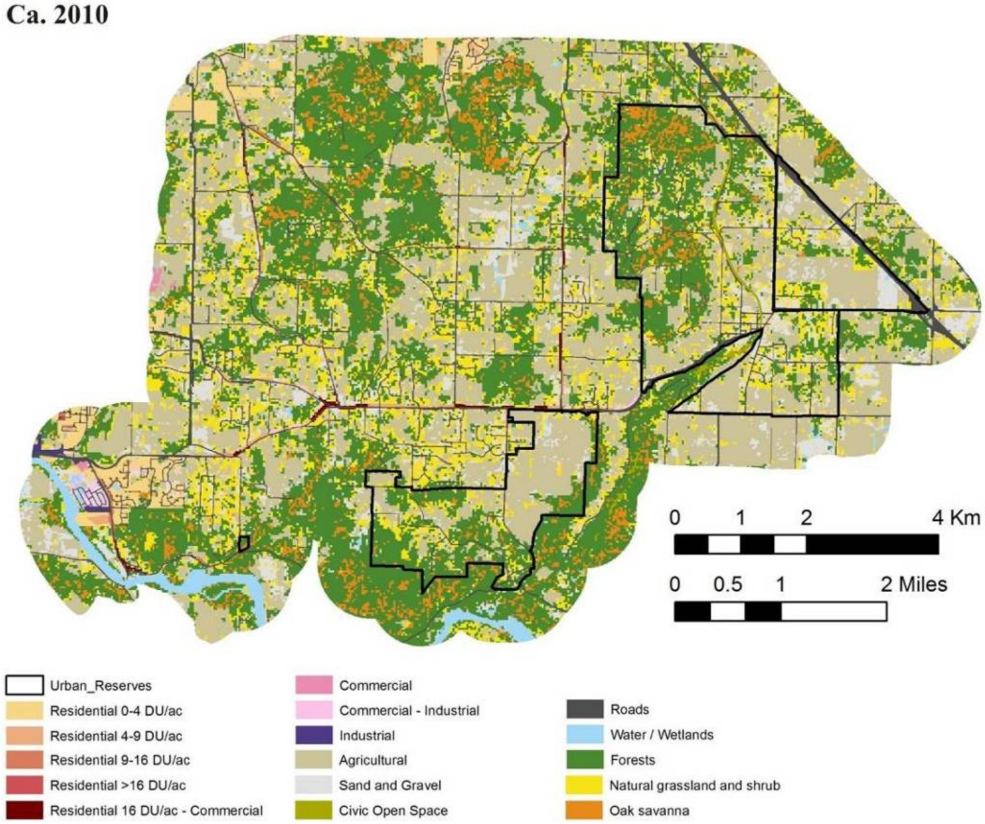


Figure 17. Historic Vegetation and Ca. 2010 land use and land cover.

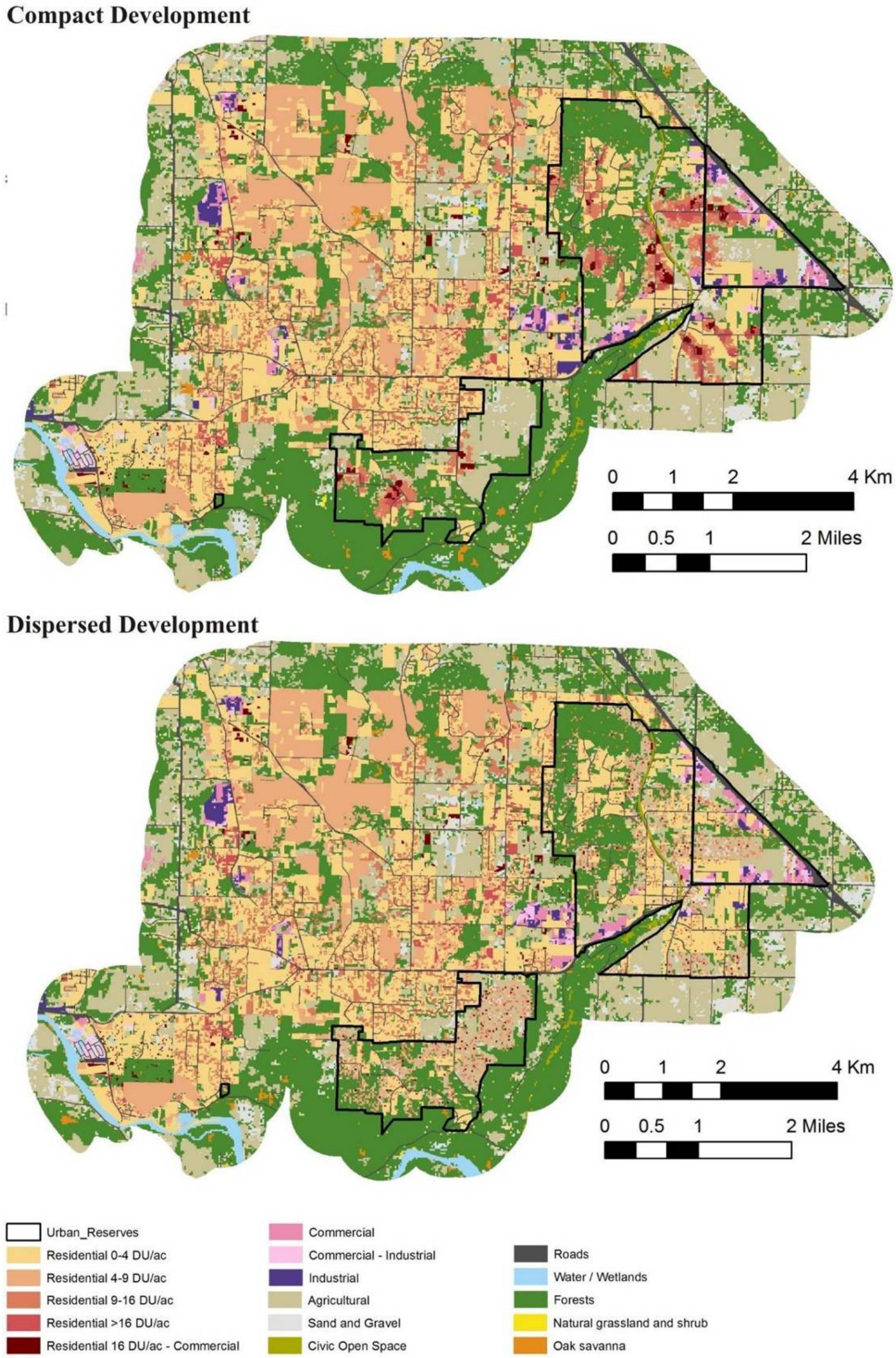


Figure 18. No open space scenarios (CD and DD): land use and land cover.

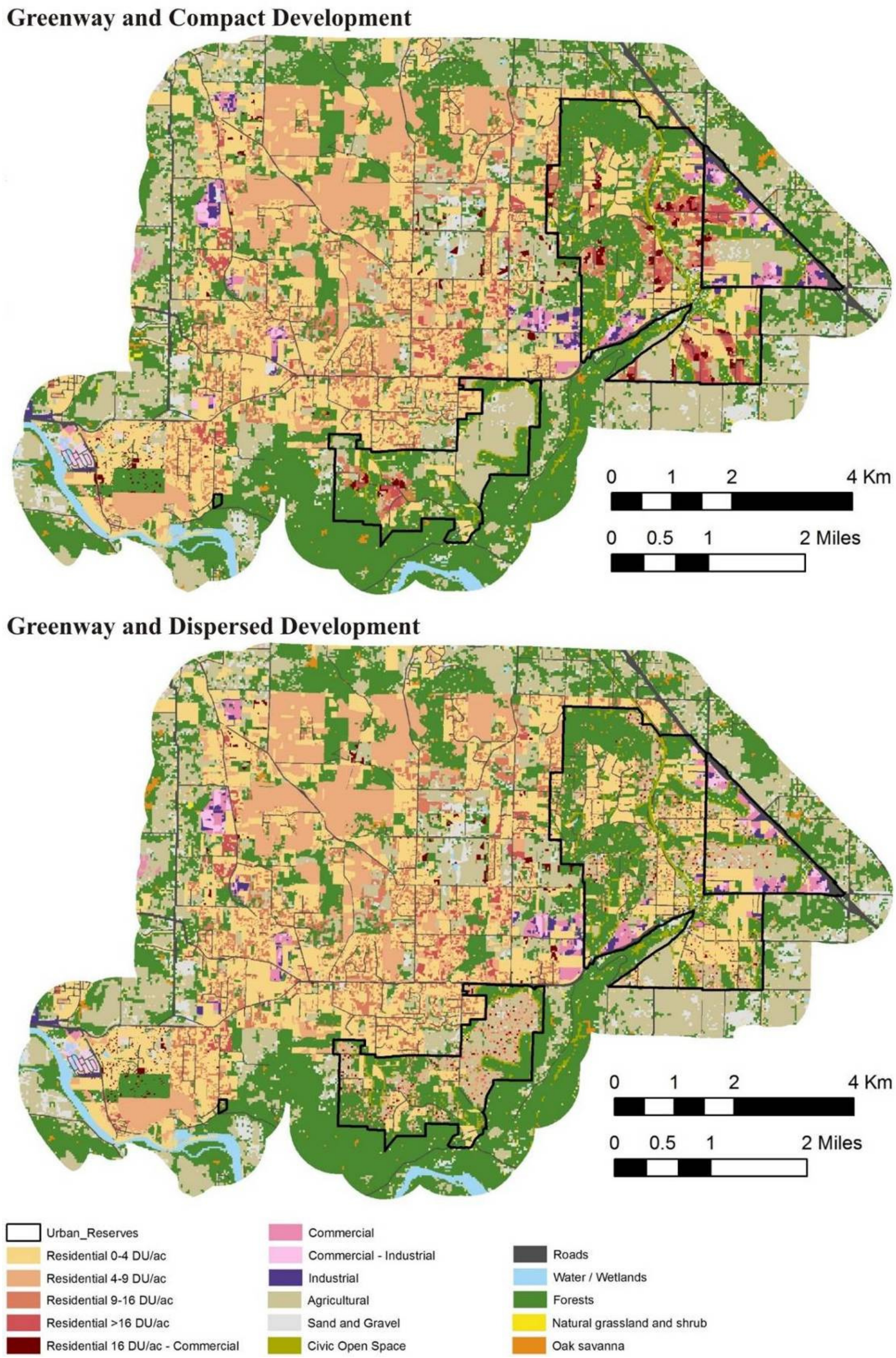
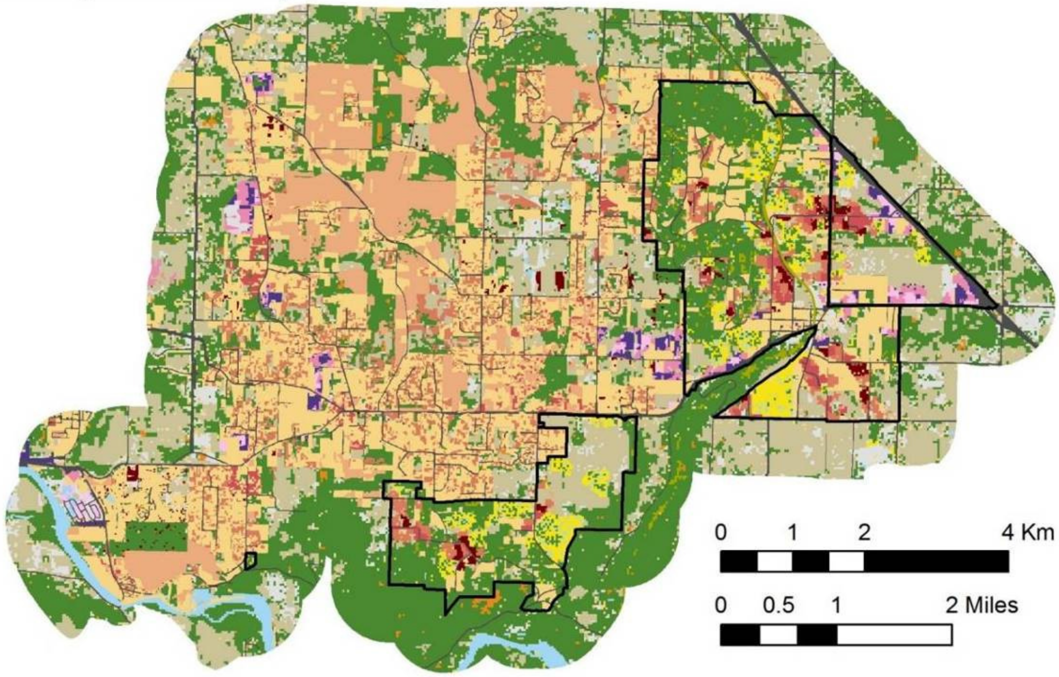


Figure 19. Greenway scenarios: land use and land cover.

Park System and Compact Development



Park System and Dispersed Development

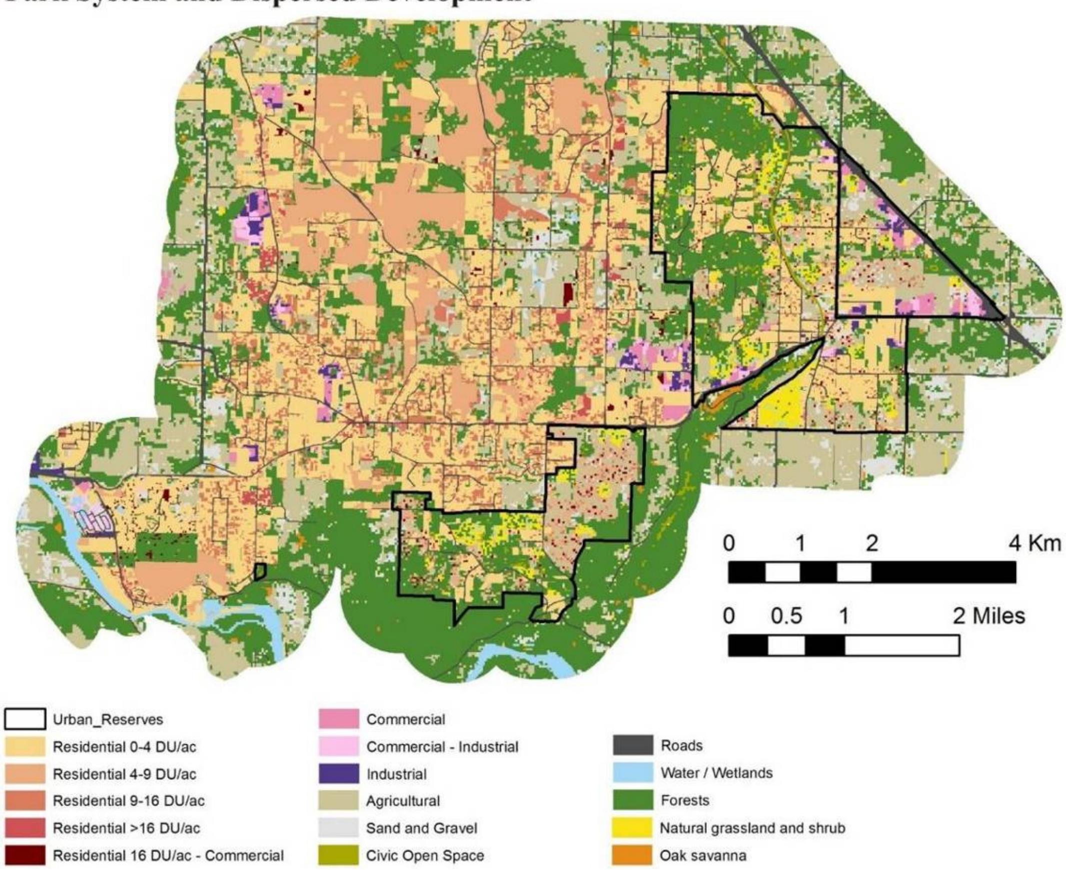


Figure 20. Park System scenarios: land use and land cover.

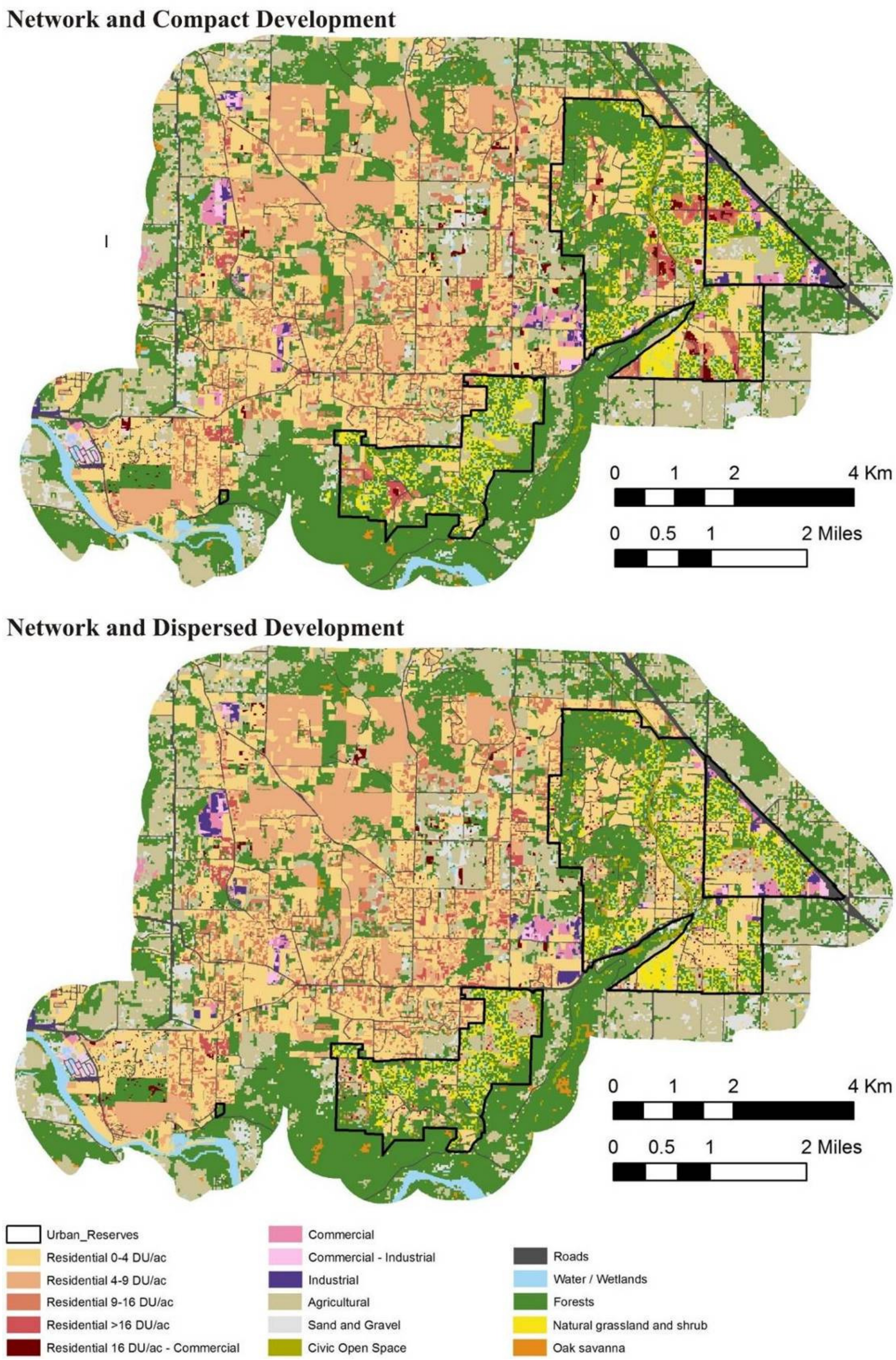


Figure 21. Network scenarios: land use and land cover.

APPENDIX G

STATISTIC TESTS OF HABITAT - CODE AND RESULTS

```
# Reads 00Results.csv
results <- read.csv(file.choose())
attach(results)


# Determines ANOVA of WEIGHTED HABITATS
aovweihab <- aov(habweigh ~
openspace*development)
# Calculates ANOVA of weighted habitats
aov(habweigh ~ openspace*development)
# Summarize statistics ANOVA of weighted habitats
with open space
summary(aovweihab)
boxplot(habweigh ~ openspace*development)


# Determines ANOVA of WEIGHTED BREEDING
HABITATS
aovbreedhab <- aov(breedweig ~
openspace*development)
# Calculates ANOVA of weighted breeding habitats
aov(breedweig ~ openspace*development)
# Summarize ANOVA of weighted breeding habitats
summary(aovbreedhab)
boxplot(breedweig ~ openspace*development)


# Determines ANOVA of HABITATS for RED-
LEGGED FROG
aovamp <- aov(amp ~ openspace*development)
# Calculate ANOVA of amphibian habitats with
development
aov(amp ~ openspace*development)
# Summarize statistics ANOVA of amphibian habitats
with development
summary(aovamp)
boxplot(amp ~ openspace*development)


# Determines ANOVA of HABITATS for WESTERN
MEADOWLARK
aovbrd <- aov(brd ~ openspace*development)
# Calculate ANOVA of bird habitats with development
aov(brd ~ openspace*development)
# Summarize statistics ANOVA of bird habitats with
development
summary(aovbrd)
boxplot(brd ~ openspace*development)


# Determines ANOVA of HABITATS for DOUGLAS
SQUIRREL
aovmam <- aov(mam ~ openspace*development)
# Calculate ANOVA of mammal habitats with
development
aov(mam ~ openspace*development)
# Summarize statistics ANOVA of mammal habitats
with development
summary(aovmam)
boxplot(mam ~ openspace*development)


# Determines ANOVA of POPULATION
aovpop <- aov(pop ~ openspace*development)
# Calculates ANOVA of population
aov(pop ~ openspace*development)
# Summarize statistics ANOVA of population
summary (aovpop)
boxplot(pop ~ openspace*development)


# Determines ANOVA of URBAN LAND USES
aovurban <- aov(urban ~ openspace*development)
# Calculates ANOVA of urban land uses for all
scenarios
aov(urban ~ openspace*development)
# Summarize statistics ANOVA of urban land uses
summary(aovurban)
boxplot(urban ~ openspace*development)


# Determines ANOVA of OPEN SPACE
aovos <- aov(os ~ openspace*development)
# Calculate ANOVA of open space with development
aov(os ~ openspace*development)
# Summarize statistics ANOVA of open space with
development
summary(aovos)
boxplot(os ~ openspace*development)


# Tukey tests

TukeyHSD(aovweihab)

TukeyHSD(aovbreedhab)

TukeyHSD(aovamp)

TukeyHSD(aovbrd)

TukeyHSD(aovmam)

TukeyHSD(aovpop)

TukeyHSD(aovurban)

TukeyHSD(aovos)
```

ANOVA of WEIGHTED HABITATS

Terms:

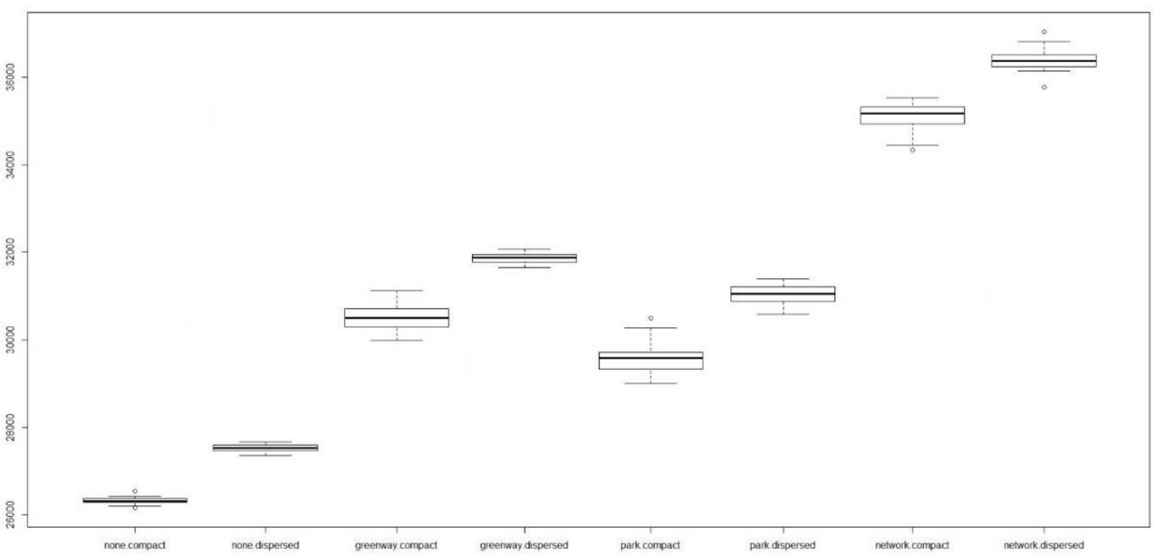
	openspace	development	openspace:development	Residuals
Sum of Squares	1587156977	70278010	295526	9123501
Deg. of Freedom	3	1	3	152

Residual standard error: 244.996

Summary

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	1.587e+09	529052326	8814.155	<2e-16 ***
development	1	7.028e+07	70278010	1170.851	<2e-16 ***
openspace:development	3	2.955e+05	98509	1.641	0.182
Residuals	152	9.124e+06	60023		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1



TukeyHSD(aovweihab) - Weighted Habitats

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = habweigh ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	4571.950	4429.642	4714.2581	0
none-greenway	-4254.075	-4396.383	-4111.7669	0
park-greenway	-868.875	-1011.183	-726.5669	0
none-network	-8826.025	-8968.333	-8683.7169	0
park-network	-5440.825	-5583.133	-5298.5169	0
park-none	3385.200	3242.892	3527.5081	0

$development

	diff	lwr	upr	p adj
dispersed-compact	1325.5	1248.967	1402.033	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	4606.45	4368.3228	4844.5772	0
none:compact-greenway:compact	-4172.70	-4410.8272	-3934.5728	0
park:compact-greenway:compact	-903.75	-1141.8772	-665.6228	0
greenway:dispersed-greenway:compact	1366.00	1127.8728	1604.1272	0
network:dispersed-greenway:compact	5903.45	5665.3228	6141.5772	0
none:dispersed-greenway:compact	-2969.45	-3207.5772	-2731.3228	0
park:dispersed-greenway:compact	532.00	293.8728	770.1272	0
none:compact-network:compact	-8779.15	-9017.2772	-8541.0228	0
park:compact-network:compact	-5510.20	-5748.3272	-5272.0728	0
greenway:dispersed-network:compact	-3240.45	-3478.5772	-3002.3228	0
network:dispersed-network:compact	1297.00	1058.8728	1535.1272	0
none:dispersed-network:compact	-7575.90	-7814.0272	-7337.7728	0
park:dispersed-network:compact	-4074.45	-4312.5772	-3836.3228	0
park:compact-none:compact	3268.95	3030.8228	3507.0772	0
greenway:dispersed-none:compact	5538.70	5300.5728	5776.8272	0
network:dispersed-none:compact	10076.15	9838.0228	10314.2772	0
none:dispersed-none:compact	1203.25	965.1228	1441.3772	0
park:dispersed-none:compact	4704.70	4466.5728	4942.8272	0
greenway:dispersed-park:compact	2269.75	2031.6228	2507.8772	0
network:dispersed-park:compact	6807.20	6569.0728	7045.3272	0
none:dispersed-park:compact	-2065.70	-2303.8272	-1827.5728	0
park:dispersed-park:compact	1435.75	1197.6228	1673.8772	0
network:dispersed-greenway:dispersed	4537.45	4299.3228	4775.5772	0
none:dispersed-greenway:dispersed	-4335.45	-4573.5772	-4097.3228	0
park:dispersed-greenway:dispersed	-834.00	-1072.1272	-595.8728	0
none:dispersed-network:dispersed	-8872.90	-9111.0272	-8634.7728	0
park:dispersed-network:dispersed	-5371.45	-5609.5772	-5133.3228	0
park:dispersed-none:dispersed	3501.45	3263.3228	3739.5772	0

ANOVA of WEIGHTED BREEDING HABITATS

Terms:

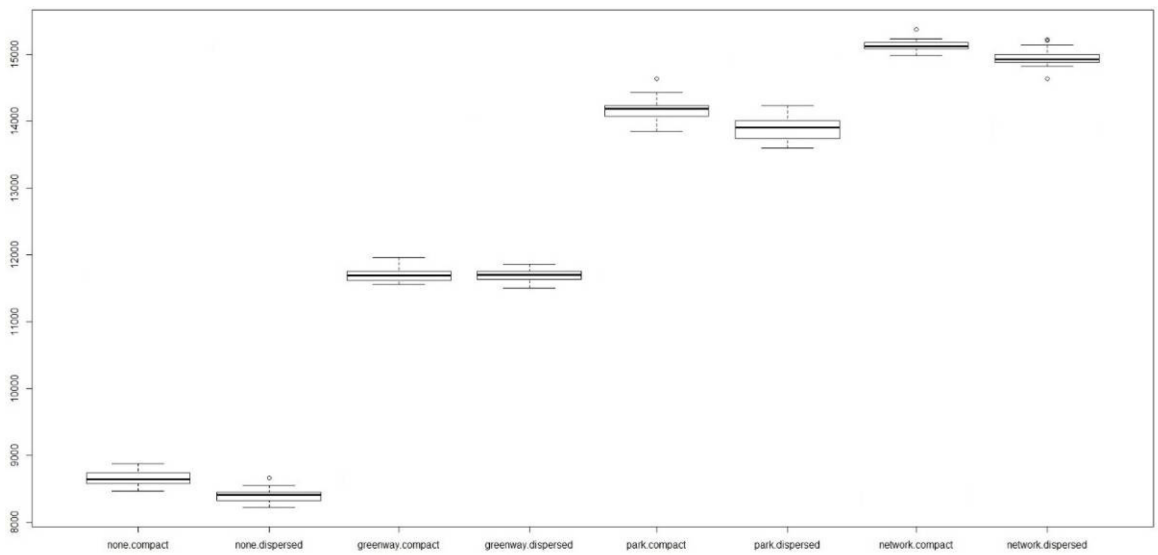
	openspace	development	openspace:development	Residuals
Sum of Squares	1000364215	1288631	466134	2581741
Deg. of Freedom	3	1	3	152

Residual standard error: 130.327

Summary

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	1.000e+09	333454738	19632.148	< 2e-16 ***
development	1	1.289e+06	1288631	75.868	4.78e-15 ***
openspace:development	3	4.661e+05	155378	9.148	1.33e-05 ***
Residuals	152	2.582e+06	16985		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1



TukeyHSD(aovbreedhab) - Breeding habitats

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = breedweig ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	3337.625	3261.923	3413.3266	0
none-greenway	-3164.900	-3240.602	-3089.1984	0
park-greenway	2327.000	2251.298	2402.7016	0
none-network	-6502.525	-6578.227	-6426.8234	0
park-network	-1010.625	-1086.327	-934.9234	0
park-none	5491.900	5416.198	5567.6016	0

$development

	diff	lwr	upr	p adj
dispersed-compact	-179.4875	-220.1997	-138.7753	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	3425.75	3299.0769	3552.42313	0.0000000
none:compact-greenway:compact	-3036.30	-3162.9731	-2909.62687	0.0000000
park:compact-greenway:compact	2462.55	2335.8769	2589.22313	0.0000000
greenway:dispersed-greenway:compact	-3.35	-130.0231	123.32313	**1.0000000**
network:dispersed-greenway:compact	3246.15	3119.4769	3372.82313	0.0000000
none:dispersed-greenway:compact	-3296.85	-3423.5231	-3170.17687	0.0000000
park:dispersed-greenway:compact	2188.10	2061.4269	2314.77313	0.0000000
none:compact-network:compact	-6462.05	-6588.7231	-6335.37687	0.0000000
park:compact-network:compact	-963.20	-1089.8731	-836.52687	0.0000000
greenway:dispersed-network:compact	-3429.10	-3555.7731	-3302.42687	0.0000000
network:dispersed-network:compact	-179.60	-306.2731	-52.92687	0.0006237
none:dispersed-network:compact	-6722.60	-6849.2731	-6595.92687	0.0000000
park:dispersed-network:compact	-1237.65	-1364.3231	-1110.97687	0.0000000
park:compact-none:compact	5498.85	5372.1769	5625.52313	0.0000000
greenway:dispersed-none:compact	3032.95	2906.2769	3159.62313	0.0000000
network:dispersed-none:compact	6282.45	6155.7769	6409.12313	0.0000000
none:dispersed-none:compact	-260.55	-387.2231	-133.87687	0.0000001
park:dispersed-none:compact	5224.40	5097.7269	5351.07313	0.0000000
greenway:dispersed-park:compact	-2465.90	-2592.5731	-2339.22687	0.0000000
network:dispersed-park:compact	783.60	656.9269	910.27313	0.0000000
none:dispersed-park:compact	-5759.40	-5886.0731	-5632.72687	0.0000000
park:dispersed-park:compact	-274.45	-401.1231	-147.77687	0.0000000
network:dispersed-greenway:dispersed	3249.50	3122.8269	3376.17313	0.0000000
none:dispersed-greenway:dispersed	-3293.50	-3420.1731	-3166.82687	0.0000000
park:dispersed-greenway:dispersed	2191.45	2064.7769	2318.12313	0.0000000
none:dispersed-network:dispersed	-6543.00	-6669.6731	-6416.32687	0.0000000
park:dispersed-network:dispersed	-1058.05	-1184.7231	-931.37687	0.0000000
park:dispersed-none:dispersed	5484.95	5358.2769	5611.62313	0.0000000

ANOVA of HABITATS for RED-LEGGED FROG

Terms:

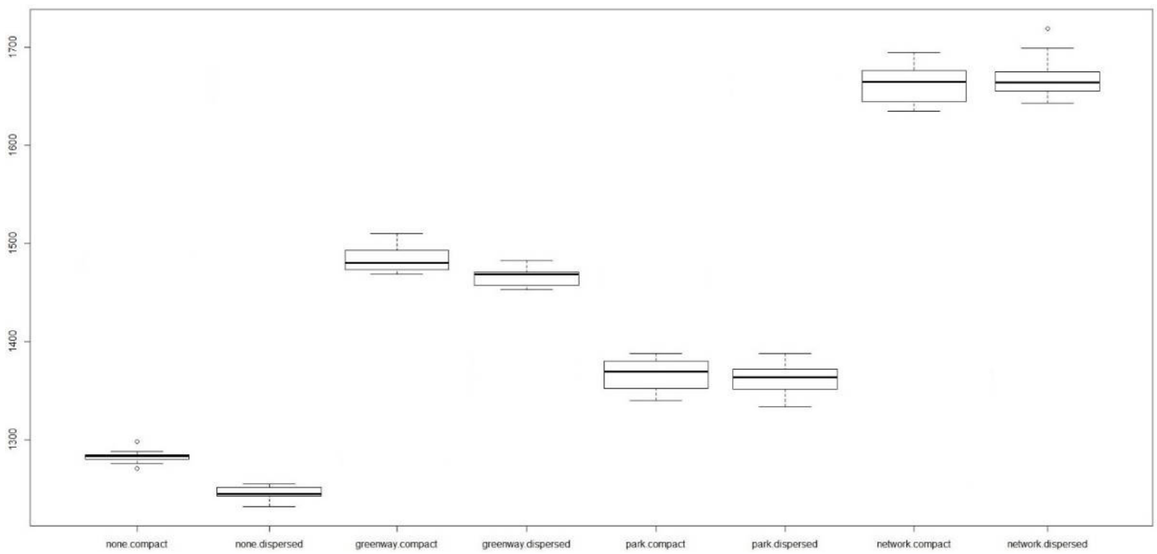
	openspace	development	openspace:development	Residuals
Sum of Squares	3518372	7169	10260	26518
Deg. of Freedom	3	1	3	152

Residual standard error: 13.20829

Summary

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	3518372	1172791	6722.45	< 2e-16 ***
development	1	7169	7169	41.09	1.73e-09 ***
openspace:development	3	10260	3420	19.60	8.50e-11 ***
Residuals	152	26518	174		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1



TukeyHSD(aovamp) - Red=legged frog Habitats

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = amp ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	189.575	181.90285	197.2471	0
none-greenway	-210.250	-217.92215	-202.5779	0
park-greenway	-109.900	-117.57215	-102.2279	0
none-network	-399.825	-407.49715	-392.1529	0
park-network	-299.475	-307.14715	-291.8029	0
park-none	100.350	92.67785	108.0221	0

$development

	diff	lwr	upr	p adj
dispersed-compact	13.3875	-17.51357	-9.261434	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	178.00	165.162026	190.837974	0.0000000
none:compact-greenway:compact	-200.45	-213.287974	-187.612026	0.0000000
park:compact-greenway:compact	-116.55	-129.387974	-103.712026	0.0000000
greenway:dispersed-greenway:compact	-17.60	-30.437974	-4.762026	0.0010956
network:dispersed-greenway:compact	183.55	170.712026	196.387974	0.0000000
none:dispersed-greenway:compact	-237.65	-250.487974	-224.812026	0.0000000
park:dispersed-greenway:compact	-120.85	-133.687974	-108.012026	0.0000000
none:compact-network:compact	-378.45	-391.287974	-365.612026	0.0000000
park:compact-network:compact	-294.55	-307.387974	-281.712026	0.0000000
greenway:dispersed-network:compact	-195.60	-208.437974	-182.762026	0.0000000
network:dispersed-network:compact	5.55	-7.287974	18.387974	**0.8865308**
none:dispersed-network:compact	-415.65	-428.487974	-402.812026	0.0000000
park:dispersed-network:compact	-298.85	-311.687974	-286.012026	0.0000000
park:compact-none:compact	83.90	71.062026	96.737974	0.0000000
greenway:dispersed-none:compact	182.85	170.012026	195.687974	0.0000000
network:dispersed-none:compact	384.00	371.162026	396.837974	0.0000000
none:dispersed-none:compact	-37.20	-50.037974	-24.362026	0.0000000
park:dispersed-none:compact	79.60	66.762026	92.437974	0.0000000
greenway:dispersed-park:compact	98.95	86.112026	111.787974	0.0000000
network:dispersed-park:compact	300.10	287.262026	312.937974	0.0000000
none:dispersed-park:compact	-121.10	-133.937974	-108.262026	0.0000000
park:dispersed-park:compact	-4.30	-17.137974	8.537974	**0.9692468**
network:dispersed-greenway:dispersed	201.15	188.312026	213.987974	0.0000000
none:dispersed-greenway:dispersed	-220.05	-232.887974	-207.212026	0.0000000
park:dispersed-greenway:dispersed	-103.25	-116.087974	-90.412026	0.0000000
none:dispersed-network:dispersed	-421.20	-434.037974	-408.362026	0.0000000
park:dispersed-network:dispersed	-304.40	-317.237974	-291.562026	0.0000000
park:dispersed-none:dispersed	116.80	103.962026	129.637974	0.0000000

ANOVA of HABITATS for WESTERN MEADOWLARK

Terms:

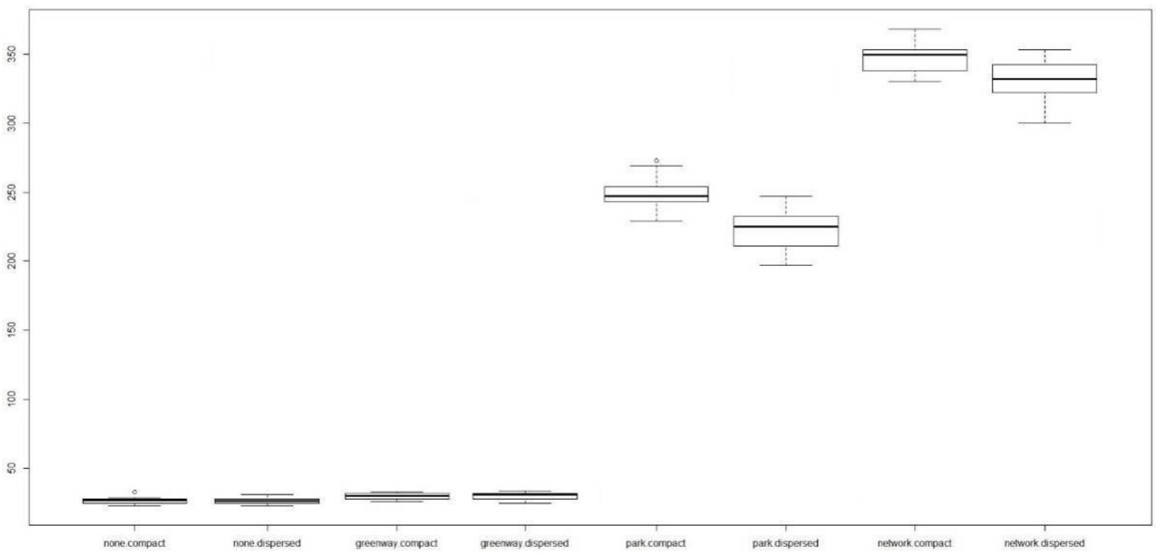
	openspace	development	openspace:development	Residuals
Sum of Squares	2896332.1	4568.9	5299.4	12695.9
Deg. of Freedom	3	1	3	152

Residual standard error: 9.139219

Summary

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	2896332	965444	11558.70	< 2e-16 ***
development	1	4569	4569	54.70	8.82e-12 ***
openspace:development	3	5299	1766	21.15	1.67e-11 ***
Residuals	152	12696	84		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1



TukeyHSD(aovbrd) - Western meadowlark Habitats

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = brd ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	308.800	303.491405	314.108595	0.000000
none-greenway	-3.450	-8.758595	1.858595	**0.333454**
park-greenway	205.825	200.516405	211.133595	0.000000
none-network	-312.250	-317.558595	-306.941405	0.000000
park-network	-102.975	-108.283595	-97.666405	0.000000
park-none	209.275	203.966405	214.583595	0.000000

$development

	diff	lwr	upr	p adj
dispersed-compact	-10.6875	-13.54245	-7.832548	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	317.05	308.167012	325.932988	0.0000000
none:compact-greenway:compact	-3.15	-12.032988	5.732988	**0.9580671**
park:compact-greenway:compact	219.55	210.667012	228.432988	0.0000000
greenway:dispersed-greenway:compact	0.45	-8.432988	9.332988	0.9999999
network:dispersed-greenway:compact	301.00	292.117012	309.882988	0.0000000
none:dispersed-greenway:compact	-3.30	-12.182988	5.582988	**0.9463895**
park:dispersed-greenway:compact	192.55	183.667012	201.432988	0.0000000
none:compact-network:compact	-320.20	-329.082988	-311.317012	0.0000000
park:compact-network:compact	-97.50	-106.382988	-88.617012	0.0000000
greenway:dispersed-network:compact	-316.60	-325.482988	-307.717012	0.0000000
network:dispersed-network:compact	-16.05	-24.932988	-7.167012	0.0000034
none:dispersed-network:compact	-320.35	-329.232988	-311.467012	0.0000000
park:dispersed-network:compact	-124.50	-133.382988	-115.617012	0.0000000
park:compact-none:compact	222.70	213.817012	231.582988	0.0000000
greenway:dispersed-none:compact	3.60	-5.282988	12.482988	**0.9167182**
network:dispersed-none:compact	304.15	295.267012	313.032988	0.0000000
none:dispersed-none:compact	-0.15	-9.032988	8.732988	**1.0000000**
park:dispersed-none:compact	195.70	186.817012	204.582988	0.0000000
greenway:dispersed-park:compact	-219.10	-227.982988	-210.217012	0.0000000
network:dispersed-park:compact	81.45	72.567012	90.332988	0.0000000
none:dispersed-park:compact	-222.85	-231.732988	-213.967012	0.0000000
park:dispersed-park:compact	-27.00	-35.882988	-18.117012	0.0000000
network:dispersed-greenway:dispersed	300.55	291.667012	309.432988	0.0000000
none:dispersed-greenway:dispersed	-3.75	-12.632988	5.132988	**0.8985502**
park:dispersed-greenway:dispersed	192.10	183.217012	200.982988	0.0000000
none:dispersed-network:dispersed	-304.30	-313.182988	-295.417012	0.0000000
park:dispersed-network:dispersed	-108.45	-117.332988	-99.567012	0.0000000
park:dispersed-none:dispersed	195.85	186.967012	204.732988	0.0000000

ANOVA of HABITATS for DOUGLAS SQUIRREL

Terms:

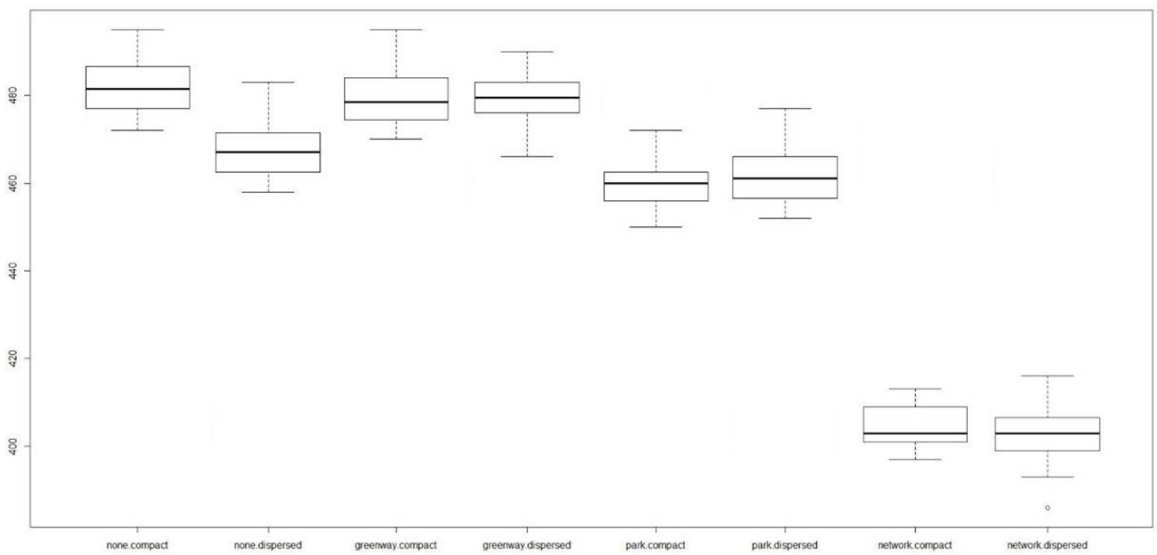
	openspace	development	openspace:development	Residuals
Sum of Squares	146908.10	540.23	1825.88	5703.70
Deg. of Freedom	3	1	3	152

Residual standard error: 6.125712

Summary

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	146908	48969	1305.00	< 2e-16 ***
development	1	540	540	14.40	0.000213 ***
openspace:development	3	1826	609	16.22	3.38e-09 ***
Residuals	152	5704	38		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1



TukeyHSD(aovmam) - Douglas squirrel Habitats

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = mam ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	-75.85	-79.408173	-72.291827	0.0000000
none-greenway	-4.40	-7.958173	-0.841827	0.0086494
park-greenway	-18.85	-22.408173	-15.291827	0.0000000
none-network	71.45	67.891827	75.008173	0.0000000
park-network	57.00	53.441827	60.558173	0.0000000
park-none	-14.45	-18.008173	-10.891827	0.0000000

$development

	diff	lwr	upr	p adj
dispersed-compact	-3.675	-5.588578	-1.761422	0.0002133

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	-74.80	-80.753968	-68.8460319	0.0000000
none:compact-greenway:compact	3.05	-2.903968	9.0039681	**0.7647325**
park:compact-greenway:compact	-20.20	-26.153968	-14.2460319	0.0000000
greenway:dispersed-greenway:compact	-0.10	-6.053968	5.8539681	**1.0000000**
network:dispersed-greenway:compact	-77.00	-82.953968	-71.0460319	0.0000000
none:dispersed-greenway:compact	-11.95	-17.903968	-5.9960319	0.0000002
park:dispersed-greenway:compact	-17.60	-23.553968	-11.6460319	0.0000000
none:compact-network:compact	77.85	71.896032	83.8039681	0.0000000
park:compact-network:compact	54.60	48.646032	60.5539681	0.0000000
greenway:dispersed-network:compact	74.70	68.746032	80.6539681	0.0000000
network:dispersed-network:compact	-2.20	-8.153968	3.7539681	**0.9478747**
none:dispersed-network:compact	62.85	56.896032	68.8039681	0.0000000
park:dispersed-network:compact	57.20	51.246032	63.1539681	0.0000000
park:compact-none:compact	-23.25	-29.203968	-17.2960319	0.0000000
greenway:dispersed-none:compact	-3.15	-9.103968	2.8039681	**0.7338347**
network:dispersed-none:compact	-80.05	-86.003968	-74.0960319	0.0000000
none:dispersed-none:compact	-15.00	-20.953968	-9.0460319	0.0000000
park:dispersed-none:compact	-20.65	-26.603968	-14.6960319	0.0000000
greenway:dispersed-park:compact	20.10	14.146032	26.0539681	0.0000000
network:dispersed-park:compact	-56.80	-62.753968	-50.8460319	0.0000000
none:dispersed-park:compact	8.25	2.296032	14.2039681	0.0009198
park:dispersed-park:compact	2.60	-3.353968	8.5539681	**0.8811037**
network:dispersed-greenway:dispersed	-76.90	-82.853968	-70.9460319	0.0000000
none:dispersed-greenway:dispersed	-11.85	-17.803968	-5.8960319	0.0000002
park:dispersed-greenway:dispersed	-17.50	-23.453968	-11.5460319	0.0000000
none:dispersed-network:dispersed	65.05	59.096032	71.0039681	0.0000000
park:dispersed-network:dispersed	59.40	53.446032	65.3539681	0.0000000
park:dispersed-none:dispersed	-5.65	-11.603968	0.3039681	**0.0763487**

ANOVA of Human Population

Terms:

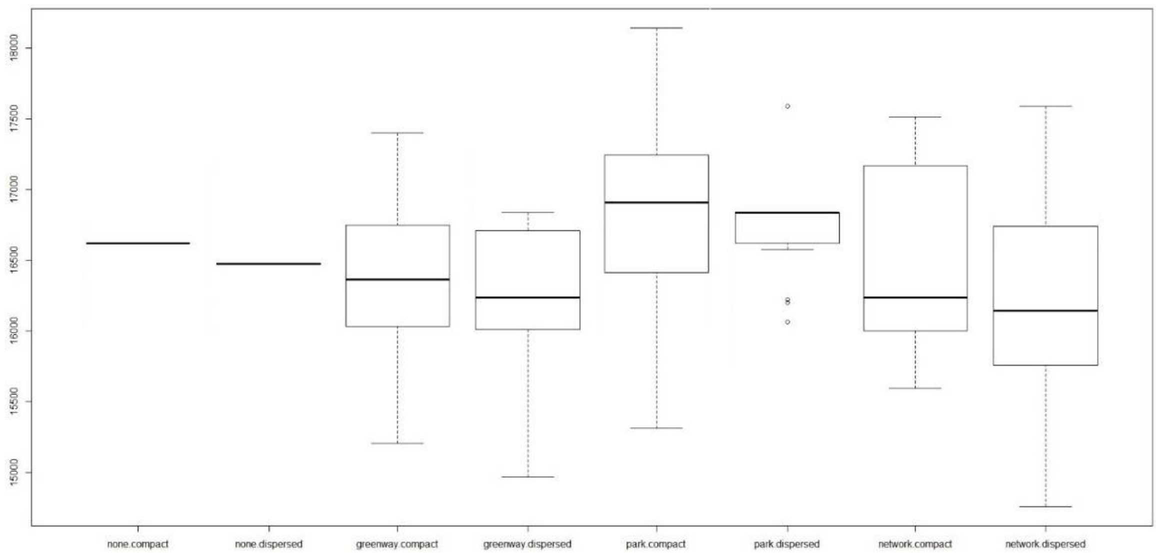
	openspace	development	openspace:development	Residuals
Sum of Squares	6526671	1316783	313599	38553954
Deg. of Freedom	3	1	3	152

Residual standard error: 503.6312

Summary

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	6526671	2175557	8.577	2.69e-05 ***
development	1	1316783	1316783	5.191	0.0241 *
openspace:development	3	313599	104533	0.412	0.7445
Residuals	152	38553954	253644		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1



TukeyHSD(aovpop) - Human Population

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = pop ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	19.600	-272.9386	312.1386	0.9981190
none-greenway	234.900	-57.6386	527.4386	0.1623781
park-greenway	499.875	207.3364	792.4136	0.0001012
none-network	215.300	-77.2386	507.8386	0.2274092
park-network	480.275	187.7364	772.8136	0.0002037
park-none	264.975	-27.5636	557.5136	0.0908552

$development

	diff	lwr	upr	p adj
dispersed-compact	-181.4375	-338.7642	-24.11083	0.0240913

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	103.80	-385.7112	593.3112	0.9980211
none:compact-greenway:compact	226.20	-263.3112	715.7112	0.8466024
park:compact-greenway:compact	466.45	-23.0612	955.9612	0.0739681
greenway:dispersed-greenway:compact	-160.40	-649.9112	329.1112	0.9727696
network:dispersed-greenway:compact	-225.00	-714.5112	264.5112	0.8501475
none:dispersed-greenway:compact	83.20	-406.3112	572.7112	0.9995292
park:dispersed-greenway:compact	372.90	-116.6112	862.4112	0.2784276
none:compact-network:compact	122.40	-367.1112	611.9112	0.9944442
park:compact-network:compact	362.65	-126.8612	852.1612	0.3131337
greenway:dispersed-network:compact	-264.20	-753.7112	225.3112	0.7134817
network:dispersed-network:compact	-328.80	-818.3112	160.7112	0.4426315
none:dispersed-network:compact	-20.60	-510.1112	468.9112	1.0000000
park:dispersed-network:compact	269.10	-220.4112	758.6112	0.6939230
park:compact-none:compact	240.25	-249.2612	729.7612	0.8018356
greenway:dispersed-none:compact	-386.60	-876.1112	102.9112	0.2358486
network:dispersed-none:compact	-451.20	-940.7112	38.3112	0.0945594
none:dispersed-none:compact	-143.00	-632.5112	346.5112	0.9858717
park:dispersed-none:compact	146.70	-342.8112	636.2112	0.9836075
greenway:dispersed-park:compact	-626.85	-1116.3612	-137.3388	0.0030975
network:dispersed-park:compact	-691.45	-1180.9612	-201.9388	0.0006652
none:dispersed-park:compact	-383.25	-872.7612	106.2612	0.2458471
park:dispersed-park:compact	-93.55	-583.0612	395.9612	0.9989862
network:dispersed-greenway:dispersed	-64.60	-554.1112	424.9112	0.9999131
none:dispersed-greenway:dispersed	243.60	-245.9112	733.1112	0.7903221
park:dispersed-greenway:dispersed	533.30	43.7888	1022.8112	0.0223098
none:dispersed-network:dispersed	308.20	-181.3112	797.7112	0.5291268
park:dispersed-network:dispersed	597.90	108.3888	1087.4112	0.0059034
park:dispersed-none:dispersed	289.70	-199.8112	779.2112	0.6082140

ANOVA of URBAN LAND USES

Terms:

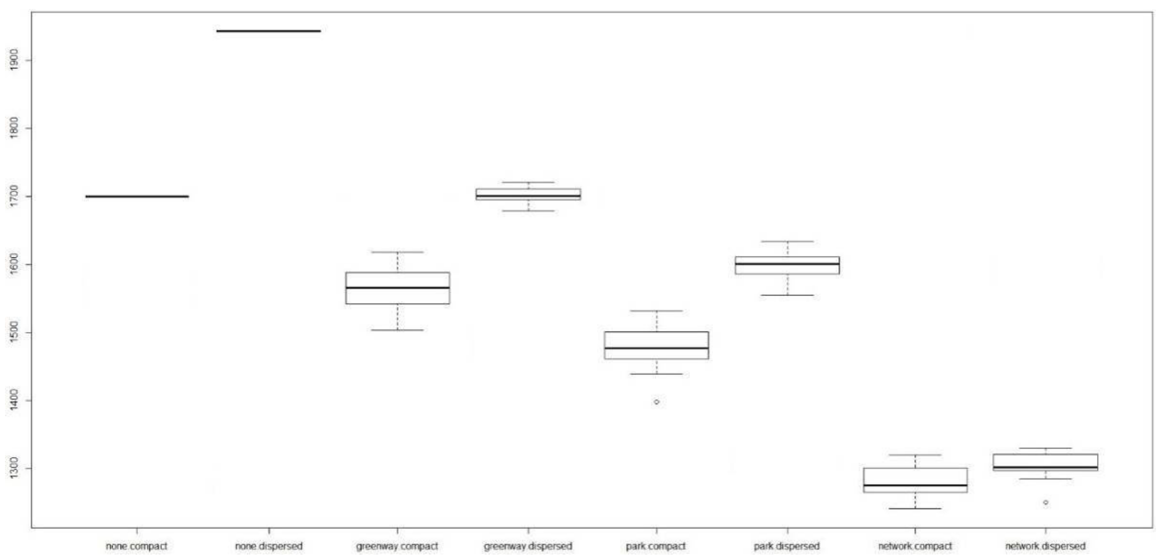
	openspace	development	openspace:development	Residuals
Sum of Squares	5789602	689850	242125	67247
Deg. of Freedom	3	1	3	152

Residual standard error: 21.0336

Summary

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	5789602	1929867	4362.1	<2e-16 ***
development	1	689850	689850	1559.3	<2e-16 ***
openspace:development	3	242125	80708	182.4	<2e-16 ***
Residuals	152	67247	442		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1



TukeyHSD(aovurban) - Urban Land Uses

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = urban ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	-339.600	-351.8176	-327.38245	0
none-greenway	188.575	176.3574	200.79255	0
park-greenway	-94.375	-106.5926	-82.15745	0
none-network	528.175	515.9574	540.39255	0
park-network	245.225	233.0074	257.44255	0
park-none	-282.950	-295.1676	-270.73245	0

$development

	diff	lwr	upr	p adj
dispersed-compact	131.325	124.7544	137.8956	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	-282.15	-302.593896	-261.7061	0.0000000
none:compact-greenway:compact	136.45	116.006104	156.8939	0.0000000
park:compact-greenway:compact	-84.85	-105.293896	-64.4061	0.0000000
greenway:dispersed-greenway:compact	138.75	118.306104	159.1939	0.0000000
network:dispersed-greenway:compact	-258.30	-278.743896	-237.8561	0.0000000
none:dispersed-greenway:compact	379.45	359.006104	399.8939	0.0000000
park:dispersed-greenway:compact	34.85	14.406104	55.2939	0.0000144
none:compact-network:compact	418.60	398.156104	439.0439	0.0000000
park:compact-network:compact	197.30	176.856104	217.7439	0.0000000
greenway:dispersed-network:compact	420.90	400.456104	441.3439	0.0000000
network:dispersed-network:compact	23.85	3.406104	44.2939	0.0104521
none:dispersed-network:compact	661.60	641.156104	682.0439	0.0000000
park:dispersed-network:compact	317.00	296.556104	337.4439	0.0000000
park:compact-none:compact	-221.30	-241.743896	-200.8561	0.0000000
greenway:dispersed-none:compact	2.30	-18.143896	22.7439	**0.9999706**
network:dispersed-none:compact	-394.75	-415.193896	-374.3061	0.0000000
none:dispersed-none:compact	243.00	222.556104	263.4439	0.0000000
park:dispersed-none:compact	-101.60	-122.043896	-81.1561	0.0000000
greenway:dispersed-park:compact	223.60	203.156104	244.0439	0.0000000
network:dispersed-park:compact	-173.45	-193.893896	-153.0061	0.0000000
none:dispersed-park:compact	464.30	443.856104	484.7439	0.0000000
park:dispersed-park:compact	119.70	99.256104	140.1439	0.0000000
network:dispersed-greenway:dispersed	-397.05	-417.493896	-376.6061	0.0000000
none:dispersed-greenway:dispersed	240.70	220.256104	261.1439	0.0000000
park:dispersed-greenway:dispersed	-103.90	-124.343896	-83.4561	0.0000000
none:dispersed-network:dispersed	637.75	617.306104	658.1939	0.0000000
park:dispersed-network:dispersed	293.15	272.706104	313.5939	0.0000000
park:dispersed-none:dispersed	-344.60	-365.043896	-324.1561	0.0000000

APPENDIX H

SUITABILITY MAPS

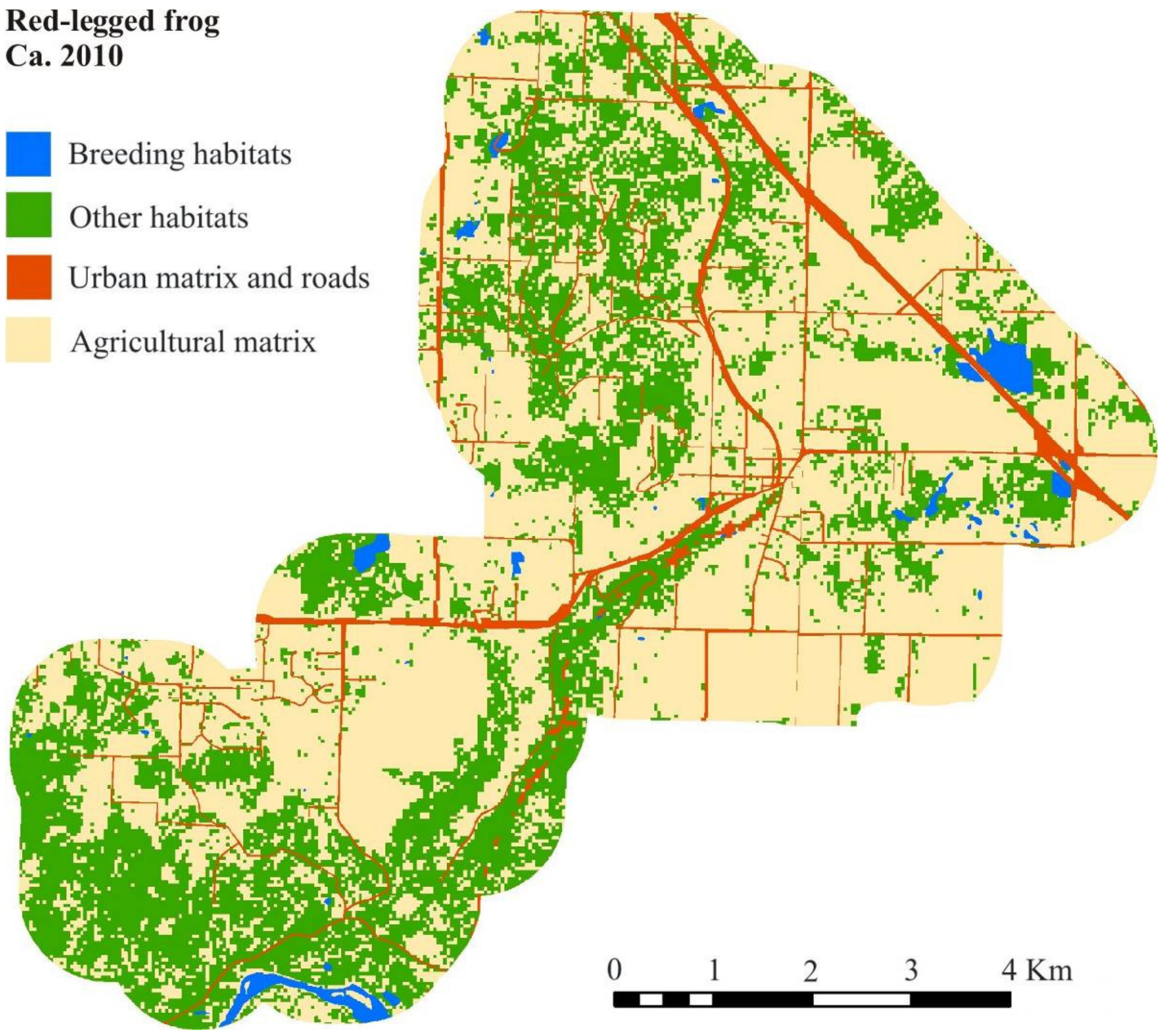


Figure 22. Red-legged frog suitability map: Ca. 2010.

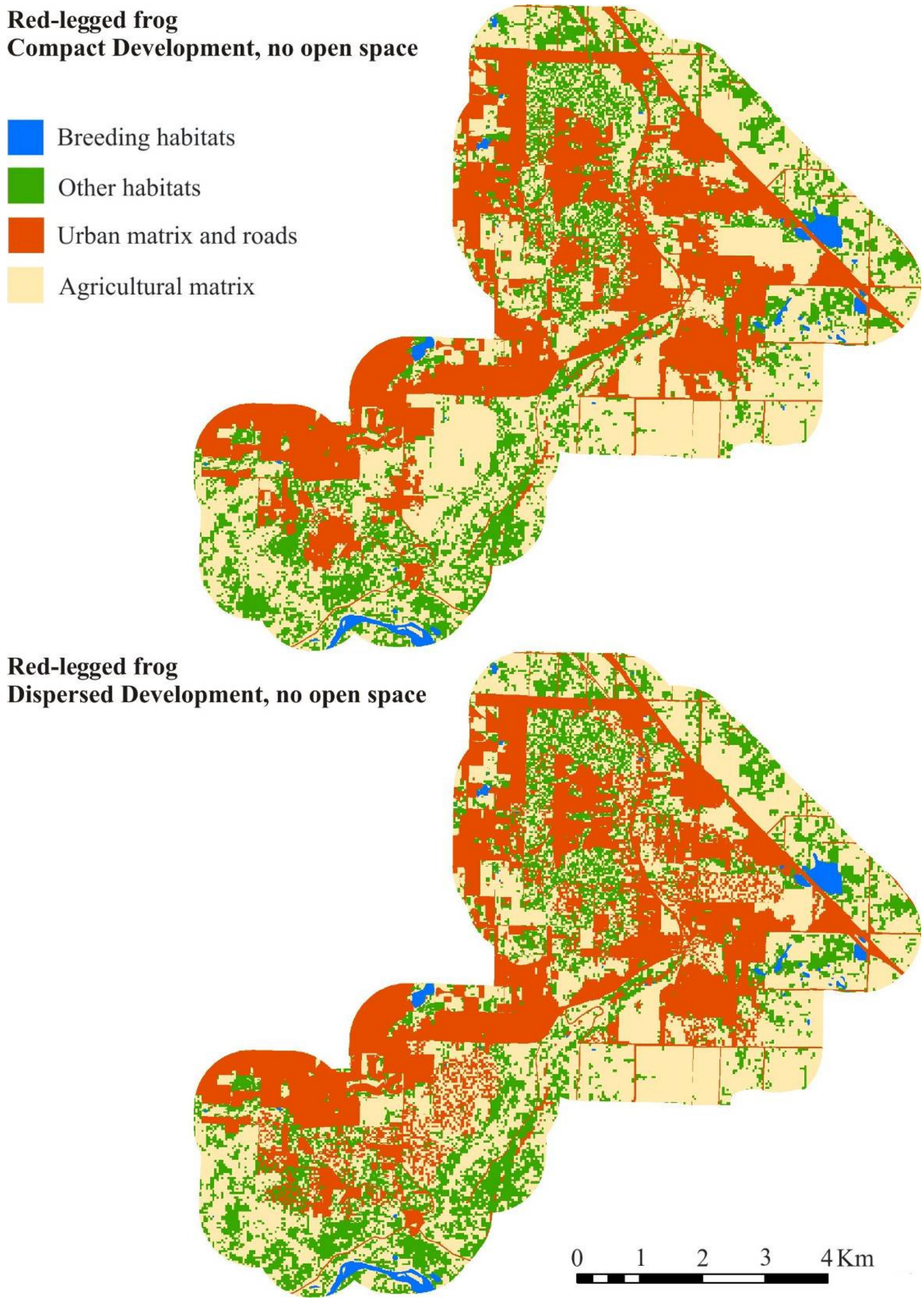


Figure 23. Red-legged frog suitability maps: No open space scenarios.

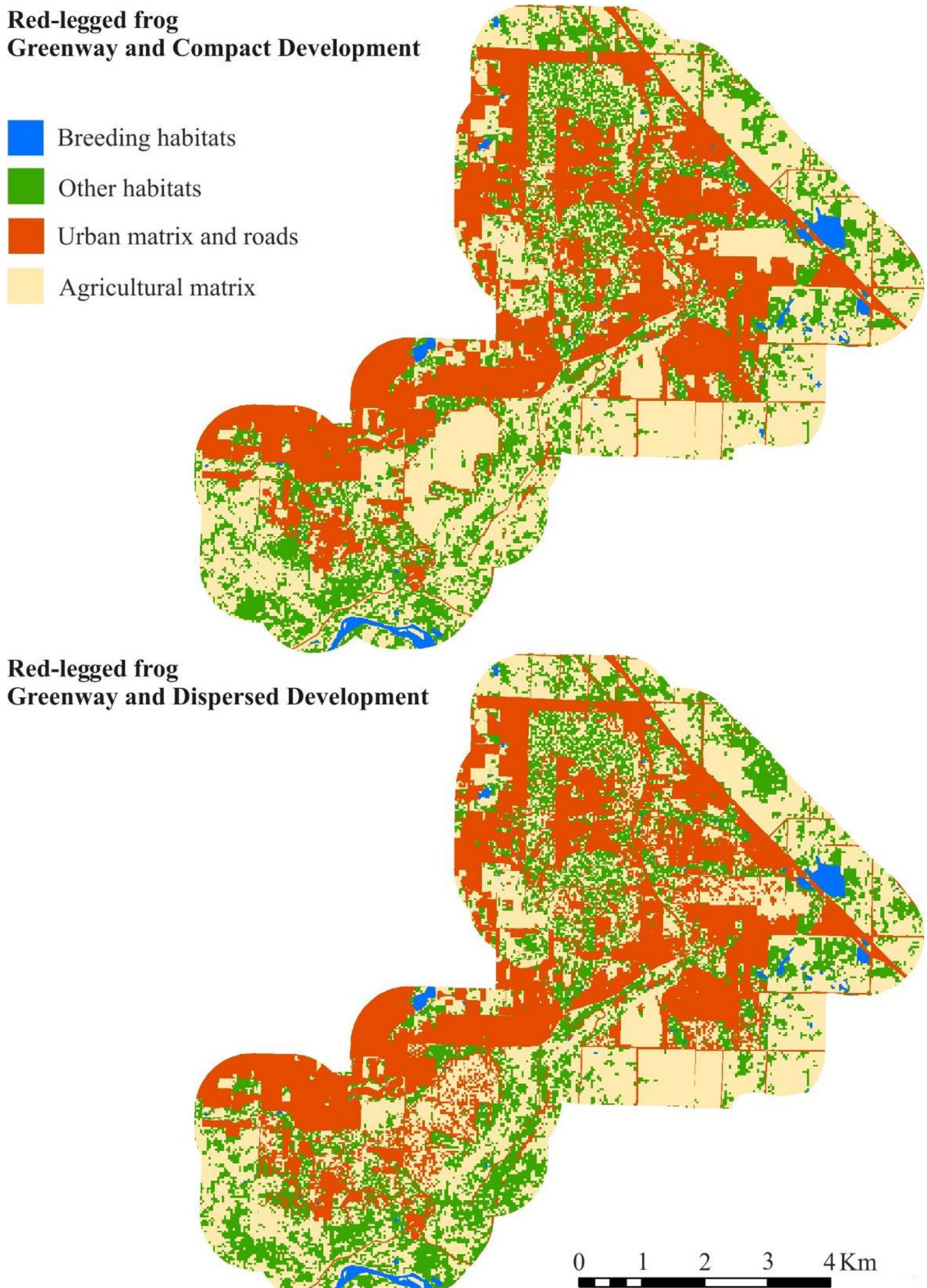


Figure 24. Red-legged frog suitability maps: Greenway scenarios

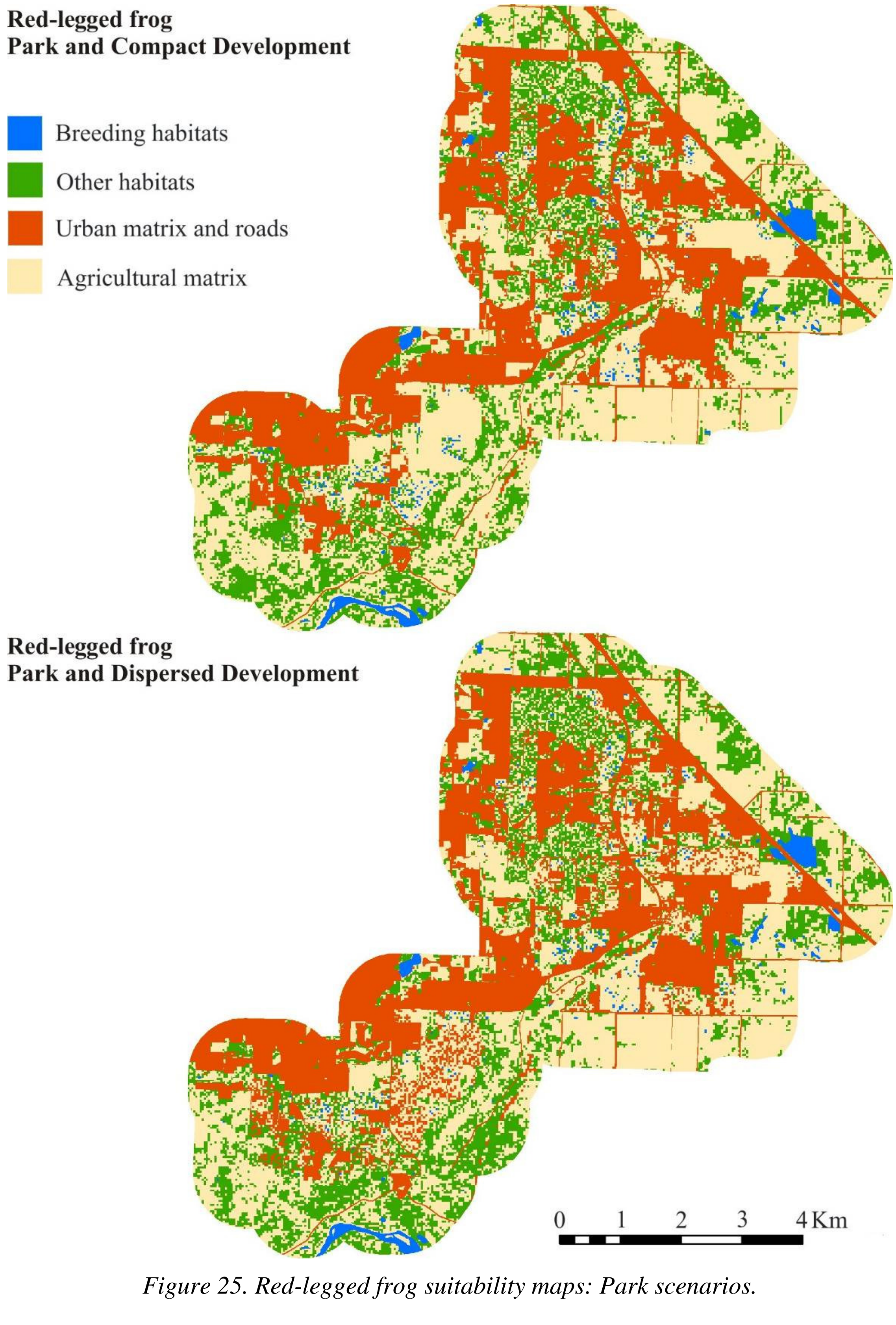


Figure 25. Red-legged frog suitability maps: Park scenarios.

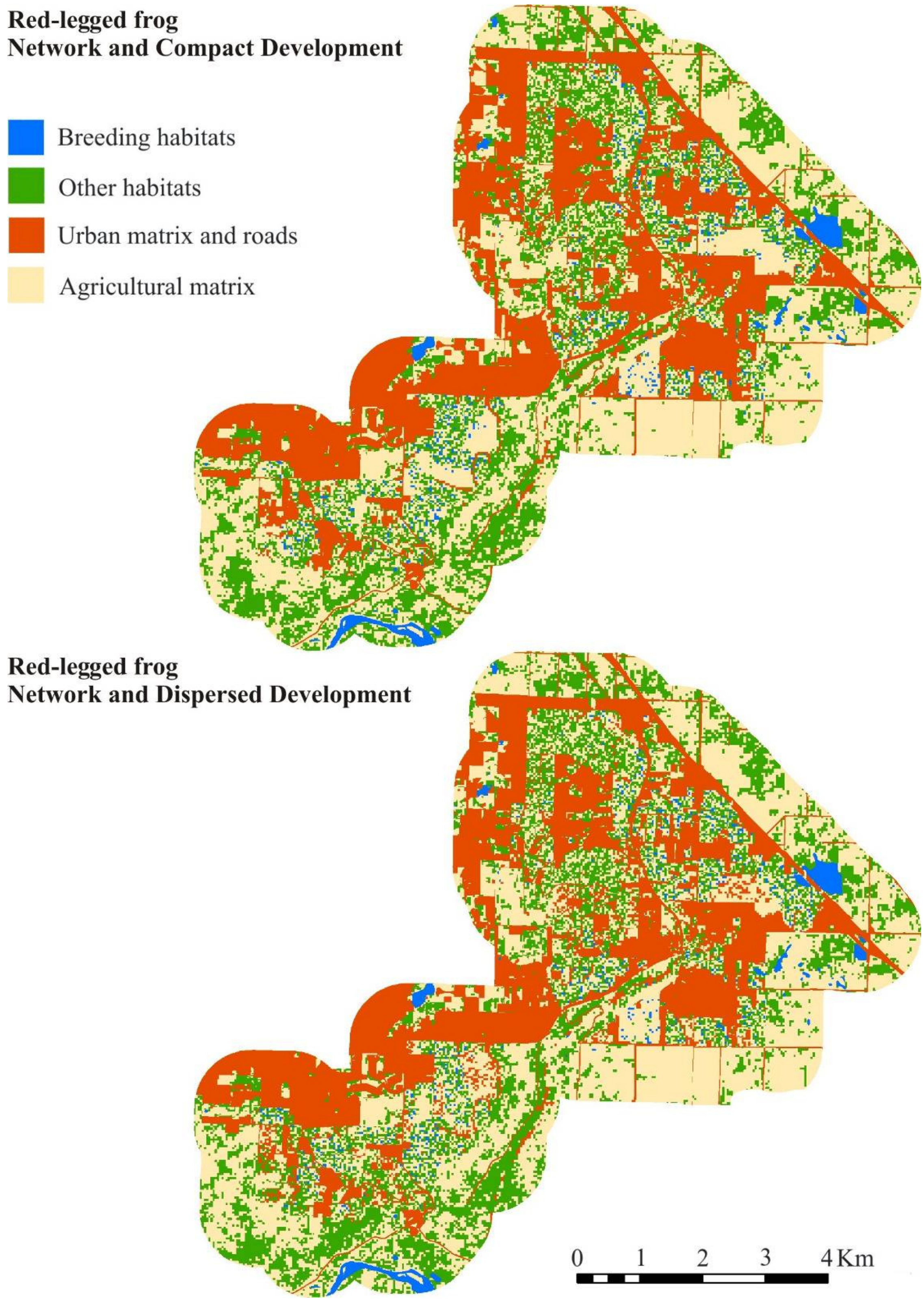


Figure 26. Red-legged frog suitability maps: Network scenarios.

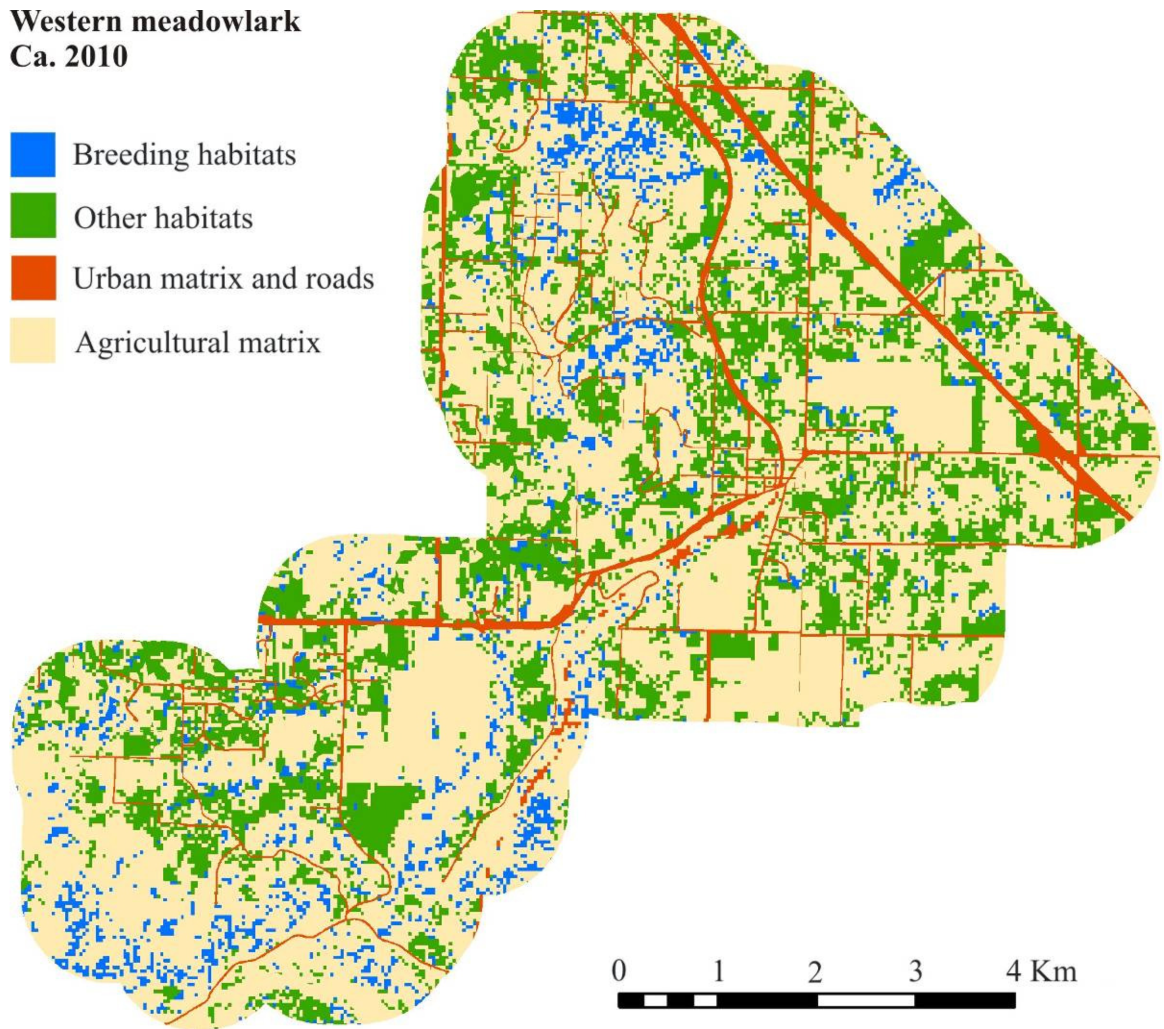


Figure 27. Western meadowlark suitability map: Ca. 2010.

Figure 28. Western meadowlark suitability maps: No open space scenarios.

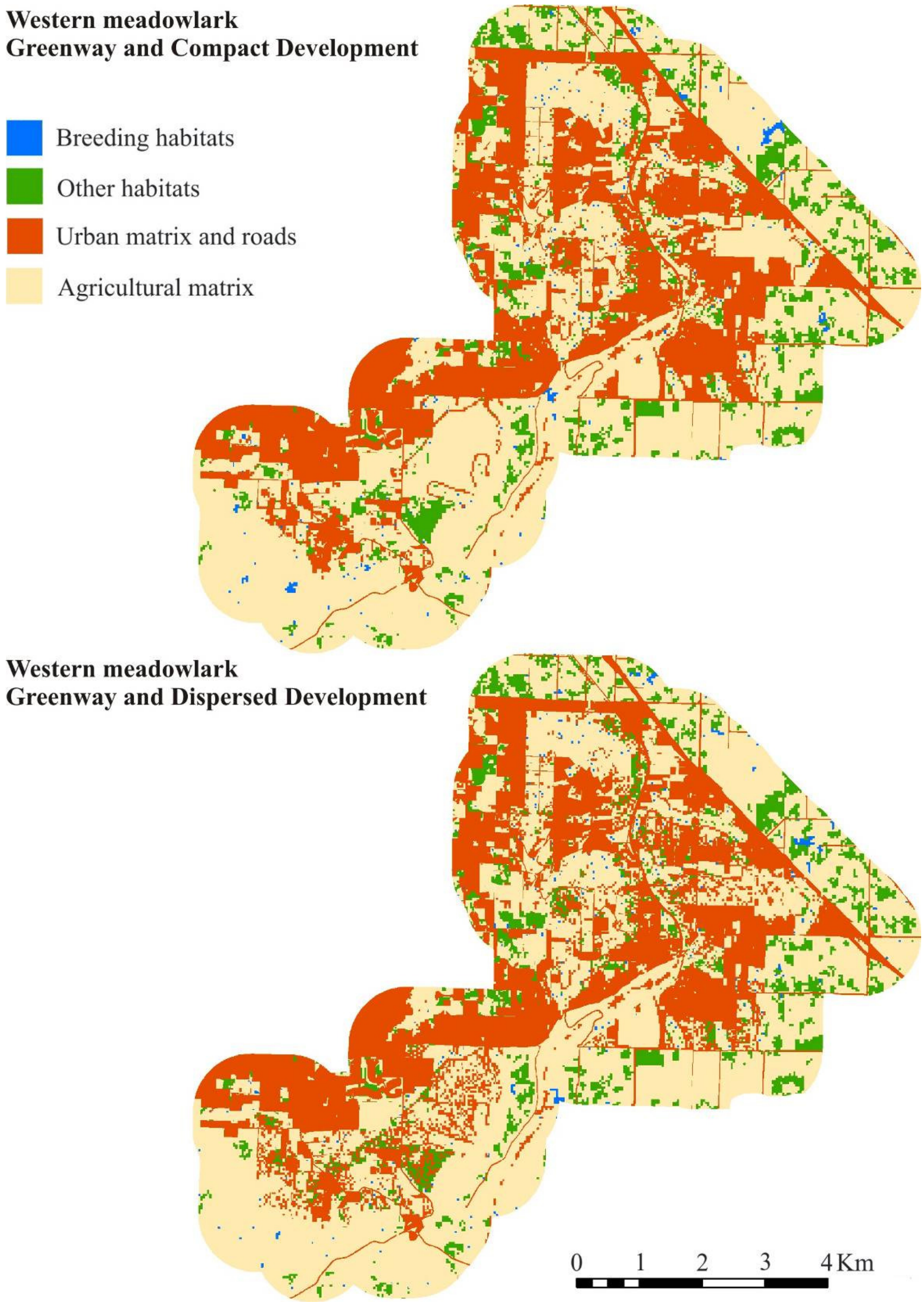


Figure 29. Western meadowlark suitability maps: Greenway scenarios.

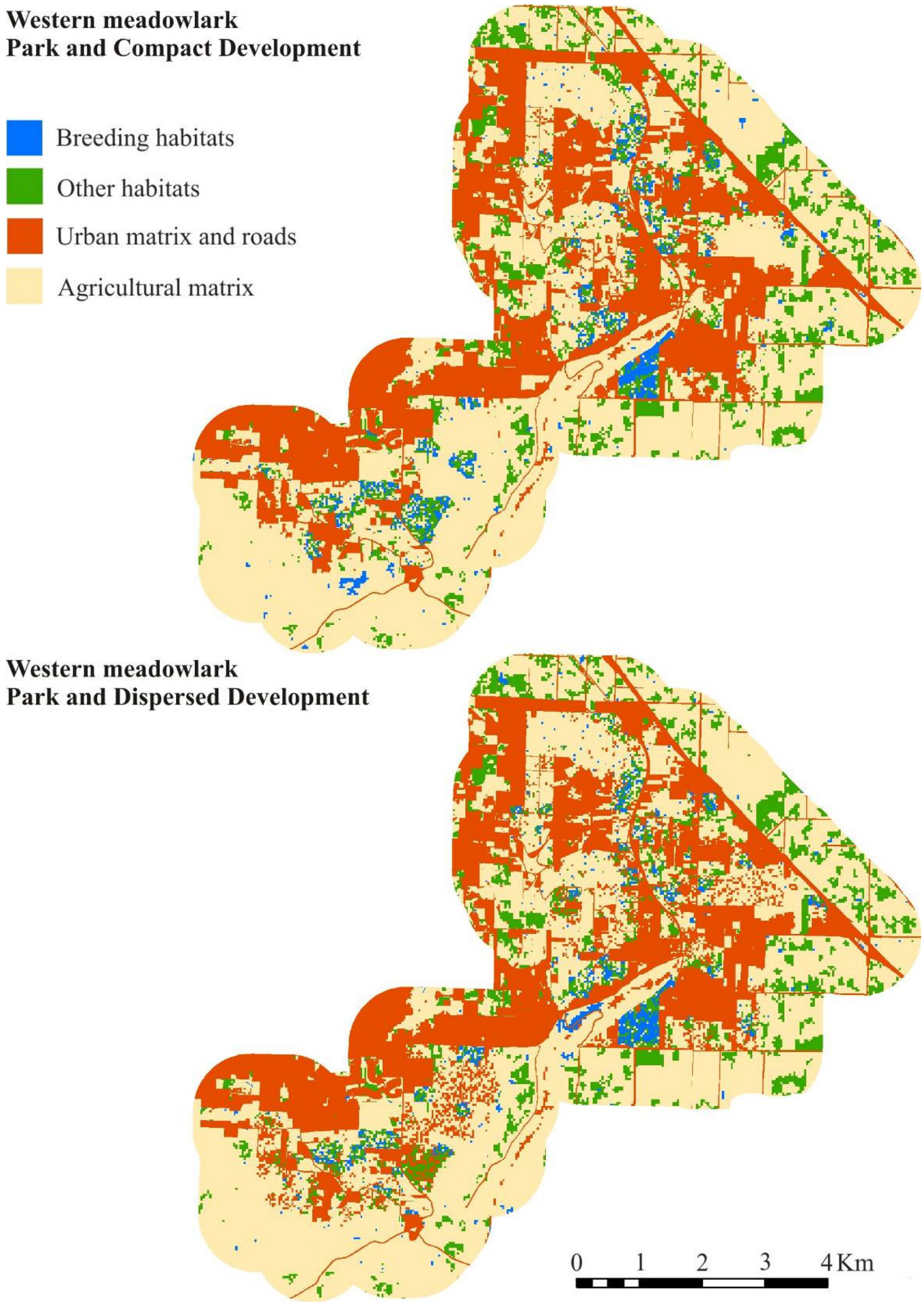


Figure 30. Western meadowlark suitability maps: Park scenarios.

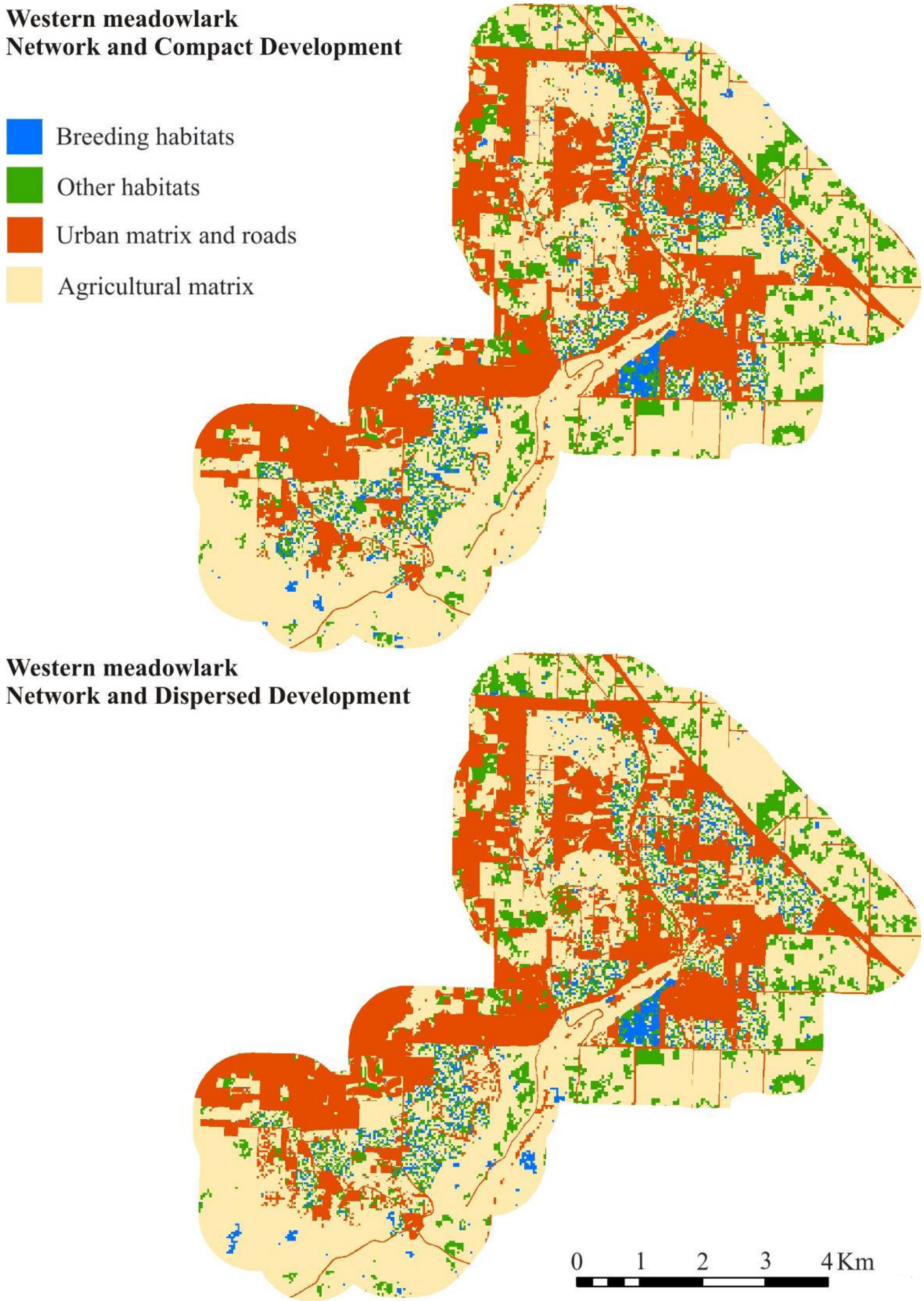


Figure 31. Western meadowlark suitability maps: Network scenarios.

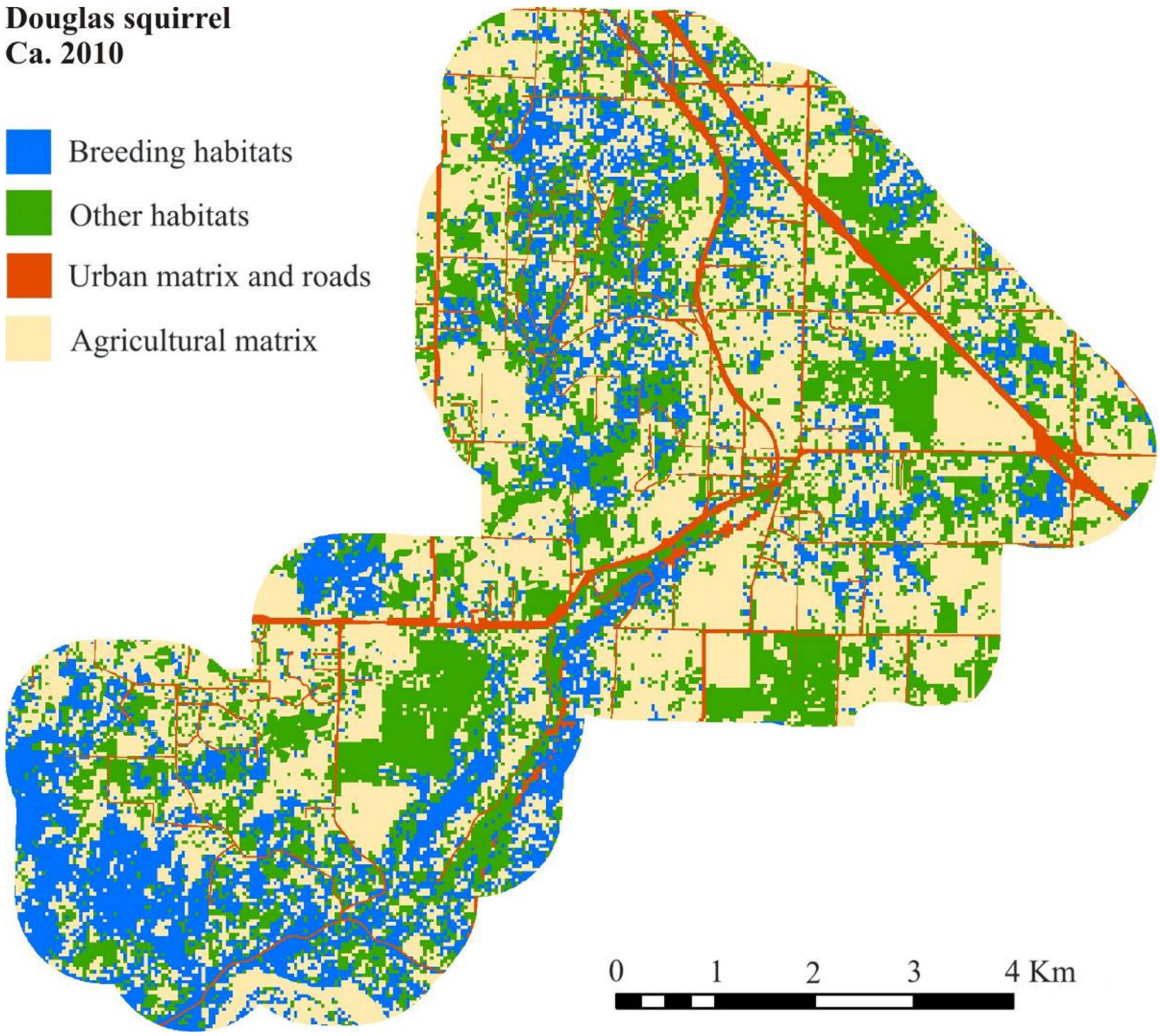


Figure 32. Douglas squirrel suitability map: Ca. 2010.

Figure 33. Douglas squirrel suitability maps: No open space scenarios

Figure 34. Douglas squirrel suitability maps: Greenway scenarios.

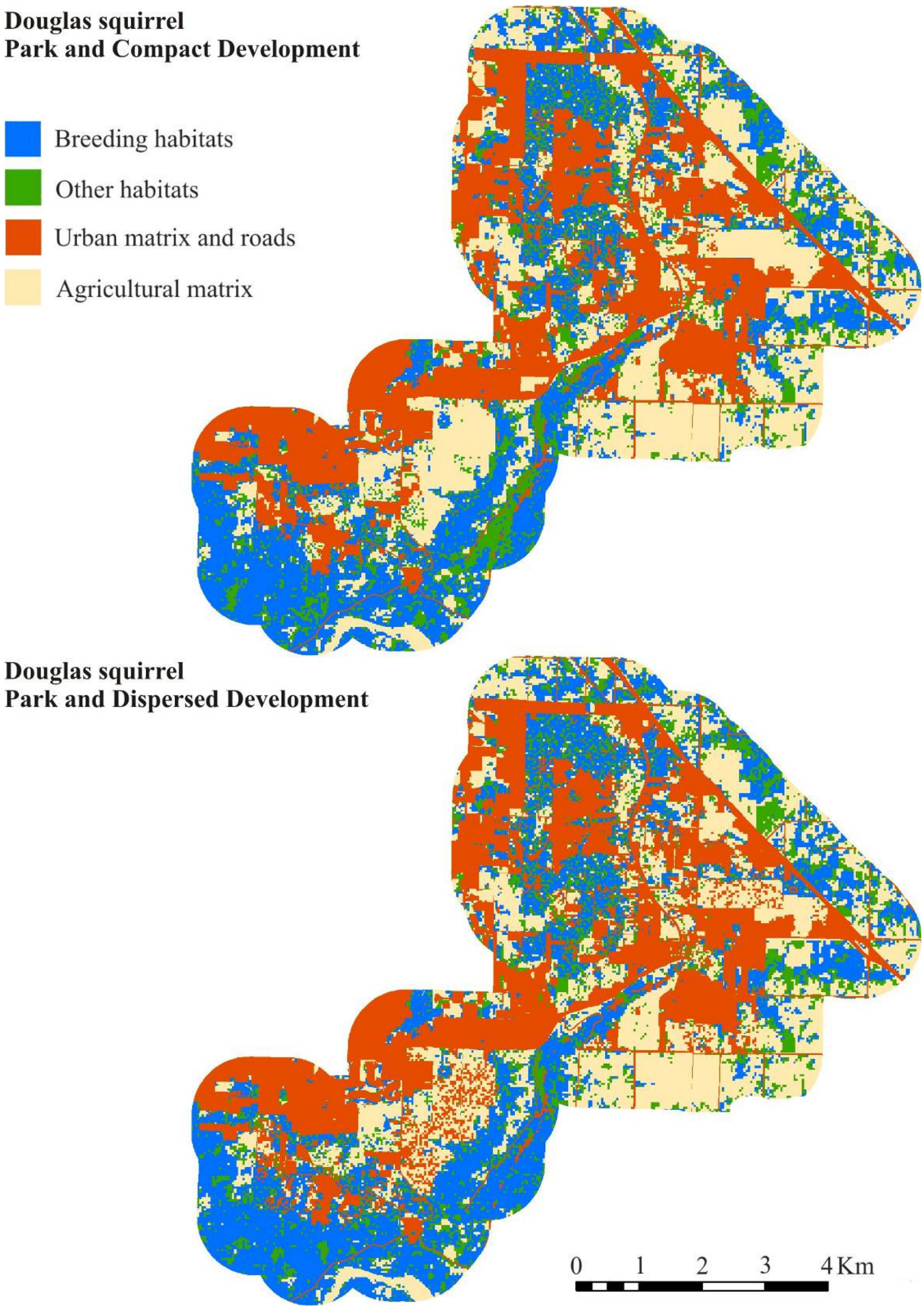


Figure 35. Douglas squirrel suitability maps: Park scenarios.

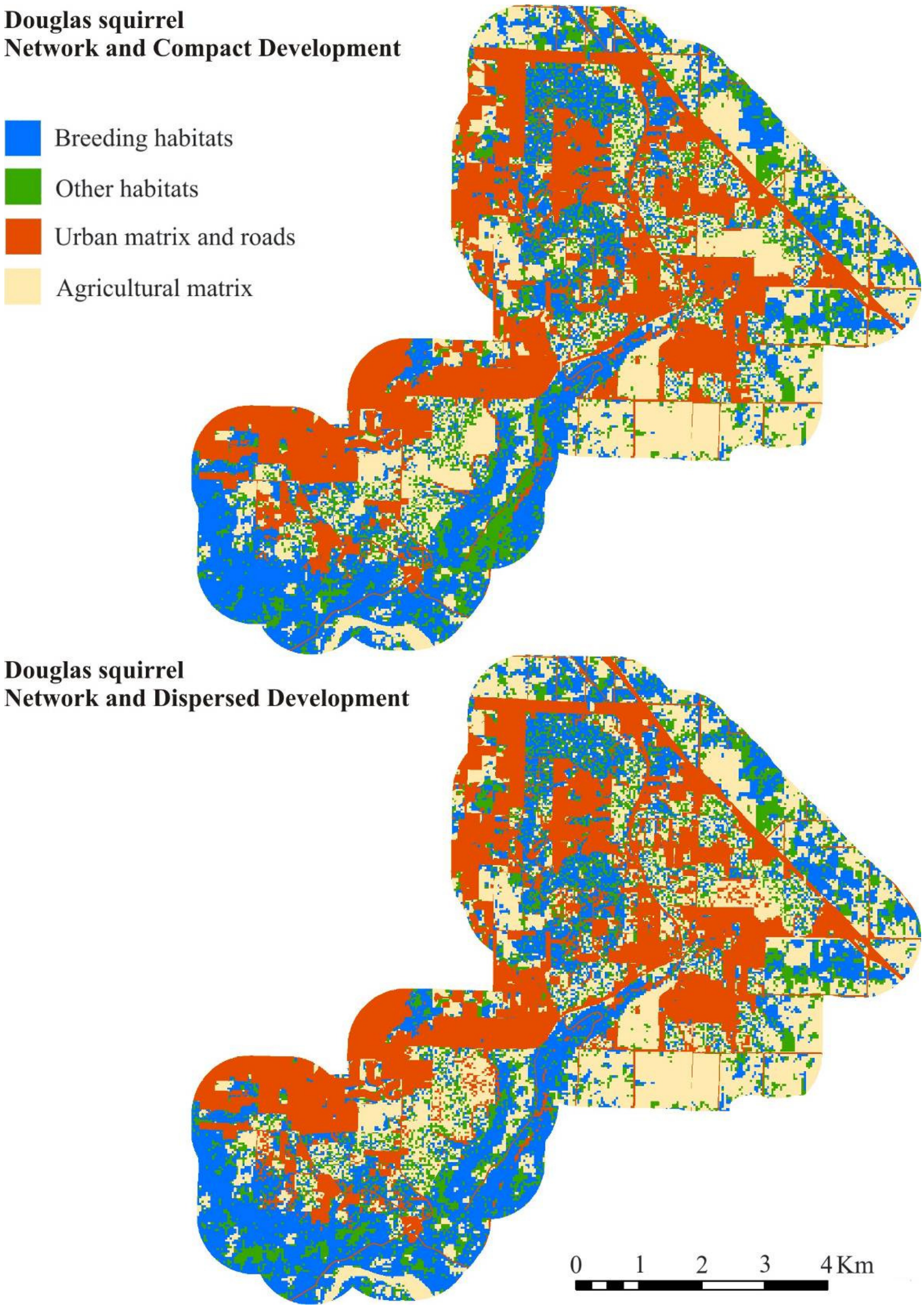


Figure 36. Douglas squirrel suitability maps: Network scenarios

APPENDIX I

STATISTIC TESTS OF WILDLIFE POPULATION

Red-legged frog (*Rana aurora aurora*)

ANOVA of BREEDING INDIVIDUALS (breeding individuals)

Terms:

	openspace	development	openspace:development	Residuals
Sum of Squares	2431554.5	63880.1	62840.6	17570.2
Deg. of Freedom	3	1	3	152

Residual standard error: 10.75145
Estimated effects may be unbalanced

Summarize ANOVA of BREEDING INDIVIDUALS

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	2431555	810518	7011.8	<2e-16 ***
development	1	63880	63880	552.6	<2e-16 ***
openspace:development	3	62841	20947	181.2	<2e-16 ***
Residuals	152	17570	116		

ANOVA of FLOATERS

Terms:

	openspace	development	openspace:development	Residuals
Sum of Squares	1964343502	78222301	42201831	12567878
Deg. of Freedom	3	1	3	152

Residual standard error: 287.5472
Estimated effects may be unbalanced

Summarize statistics ANOVA of FLOATERS with development

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	1.964e+09	654781167	7919.1	<2e-16 ***
development	1	7.822e+07	78222301	946.0	<2e-16 ***
openspace:development	3	4.220e+07	14067277	170.1	<2e-16 ***
Residuals	152	1.257e+07	82683		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey tests
Breeding individuals

TukeyHSD(aovgmembers)
Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = gmembers ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	285.100	278.85492	291.34508	0
none-greenway	-29.100	-35.34508	-22.85492	0
park-greenway	59.375	53.12992	65.62008	0
none-network	-314.200	-320.44508	-307.95492	0
park-network	-225.725	-231.97008	-219.47992	0
park-none	88.475	82.22992	94.72008	0

$development

	diff	lwr	upr	p adj
dispersed-compact	-39.9625	-43.32109	-36.60391	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	306.75	296.2999796	317.20002	0.0000000
none:compact-greenway:compact	-5.85	-16.3000204	4.60002	**0.6738519**
park:compact-greenway:compact	114.90	104.4499796	125.35002	0.0000000
greenway:dispersed-greenway:compact	10.25	-0.2000204	20.70002	**0.0587923**
network:dispersed-greenway:compact	273.70	263.2499796	284.15002	0.0000000
none:dispersed-greenway:compact	-42.10	-52.5500204	-31.64998	0.0000000
park:dispersed-greenway:compact	14.10	3.6499796	24.55002	0.0014135
none:compact-network:compact	-312.60	-323.0500204	-302.14998	0.0000000
park:compact-network:compact	-191.85	-202.3000204	-181.39998	0.0000000
greenway:dispersed-network:compact	-296.50	-306.9500204	-286.04998	0.0000000
network:dispersed-network:compact	-33.05	-43.5000204	-22.59998	0.0000000
none:dispersed-network:compact	-348.85	-359.3000204	-338.39998	0.0000000
park:dispersed-network:compact	-292.65	-303.1000204	-282.19998	0.0000000
park:compact-none:compact	120.75	110.2999796	131.20002	0.0000000
greenway:dispersed-none:compact	16.10	5.6499796	26.55002	0.0001325
network:dispersed-none:compact	279.55	269.0999796	290.00002	0.0000000
none:dispersed-none:compact	-36.25	-46.7000204	-25.79998	0.0000000
park:dispersed-none:compact	19.95	9.4999796	30.40002	0.0000007
greenway:dispersed-park:compact	-104.65	-115.1000204	-94.19998	0.0000000
network:dispersed-park:compact	158.80	148.3499796	169.25002	0.0000000
none:dispersed-park:compact	-157.00	-167.4500204	-146.54998	0.0000000
park:dispersed-park:compact	-100.80	-111.2500204	-90.34998	0.0000000
network:dispersed-greenway:dispersed	263.45	252.9999796	273.90002	0.0000000
none:dispersed-greenway:dispersed	-52.35	-62.8000204	-41.89998	0.0000000
park:dispersed-greenway:dispersed	3.85	-6.6000204	14.30002	**0.9486674**
none:dispersed-network:dispersed	-315.80	-326.2500204	-305.34998	0.0000000
park:dispersed-network:dispersed	-259.60	-270.0500204	-249.14998	0.0000000
park:dispersed-none:dispersed	56.20	45.7499796	66.65002	0.0000000

Floaters

TukeyHSD(aovfloaters)
Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = floaters ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	7701.850	7534.826	7868.874	0
none-greenway	-1520.600	-1687.624	-1353.576	0
park-greenway	1526.475	1359.451	1693.499	0
none-network	-9222.450	-9389.474	-9055.426	0
park-network	-6175.375	-6342.399	-6008.351	0
park-none	3047.075	2880.051	3214.099	0

$development

	diff	lwr	upr	p adj
dispersed-compact	-1398.412	-1488.238	-1308.587	0

$\`openspace:development\`

	diff	lwr	upr	p adj
network:compact-greenway:compact	8362.80	8083.31459	8642.2854	0.0000000
none:compact-greenway:compact	-609.20	-888.68541	-329.7146	0.0000000
park:compact-greenway:compact	2953.65	2674.16459	3233.1354	0.0000000
greenway:dispersed-greenway:compact	101.35	-178.13541	380.8354	**0.9527706**
network:dispersed-greenway:compact	7142.25	6862.76459	7421.7354	0.0000000
none:dispersed-greenway:compact	-2330.65	-2610.13541	-2051.1646	0.0000000
park:dispersed-greenway:compact	200.65	-78.83541	480.1354	**0.3537174**
none:compact-network:compact	-8972.00	-9251.48541	-8692.5146	0.0000000
park:compact-network:compact	-5409.15	-5688.63541	-5129.6646	0.0000000
greenway:dispersed-network:compact	-8261.45	-8540.93541	-7981.9646	0.0000000
network:dispersed-network:compact	-1220.55	-1500.03541	-941.0646	0.0000000
none:dispersed-network:compact	-10693.45	-10972.93541	-10413.9646	0.0000000
park:dispersed-network:compact	-8162.15	-8441.63541	-7882.6646	0.0000000
park:compact-none:compact	3562.85	3283.36459	3842.3354	0.0000000
greenway:dispersed-none:compact	710.55	431.06459	990.0354	0.0000000
network:dispersed-none:compact	7751.45	7471.96459	8030.9354	0.0000000
none:dispersed-none:compact	-1721.45	-2000.93541	-1441.9646	0.0000000
park:dispersed-none:compact	809.85	530.36459	1089.3354	0.0000000
greenway:dispersed-park:compact	-2852.30	-3131.78541	-2572.8146	0.0000000
network:dispersed-park:compact	4188.60	3909.11459	4468.0854	0.0000000
none:dispersed-park:compact	-5284.30	-5563.78541	-5004.8146	0.0000000
park:dispersed-park:compact	-2753.00	-3032.48541	-2473.5146	0.0000000
network:dispersed-greenway:dispersed	7040.90	6761.41459	7320.3854	0.0000000
none:dispersed-greenway:dispersed	-2432.00	-2711.48541	-2152.5146	0.0000000
park:dispersed-greenway:dispersed	99.30	-180.18541	378.7854	**0.9576317**
none:dispersed-network:dispersed	-9472.90	-9752.38541	-9193.4146	0.0000000
park:dispersed-network:dispersed	-6941.60	-7221.08541	-6662.1146	0.0000000
park:dispersed-none:dispersed	2531.30	2251.81459	2810.7854	0.0000000

>

Western Meadowlark

ANOVA of BREEDING INDIVIDUALS

Terms:

	openspace	development	openspace:development	Residuals
Sum of Squares	8151.225	112.225	132.225	23.300
Deg. of Freedom	3	1	3	152

Residual standard error: 0.391522
Estimated effects may be unbalanced

Summary ANOVA of BREEDING INDIVIDUALS

	Df	Sum Sq	Mean Sq	F value Pr(>F)
openspace	3	8151	2717.1 17725.1	<2e-16 ***
development	1	112	112.2 732.1	<2e-16 ***
openspace:development	3	132	44.1 287.5	<2e-16 ***
Residuals	152	23	0.2	

ANOVA of FLOATERS

Terms:

	openspace	development	openspace:development	Residuals
Sum of Squares	194919.92	3715.26	3755.87	996.15
Deg. of Freedom	3	1	3	152

Residual standard error: 2.560004
Estimated effects may be unbalanced

Summary statistics ANOVA of FLOATERS

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	194920	64973	9914.1	<2e-16 ***
development	1	3715	3715	566.9	<2e-16 ***
openspace:development	3	3756	1252	191.0	<2e-16 ***
Residuals	152	996	7		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey Tests

Breeding individuals

TukeyHSD(aovgmembers)
Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = gmembers ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	1.422500e+01	13.997581	14.452419	0.0000000
none-greenway	-2.267075e-14	-0.227419	0.227419	1.0000000
park-greenway	1.432500e+01	14.097581	14.552419	0.0000000
none-network	-1.422500e+01	-14.452419	-13.997581	0.0000000
park-network	1.000000e-01	-0.127419	0.327419	0.6640067
park-none	1.432500e+01	14.097581	14.552419	0.0000000

$development

	diff	lwr	upr	p adj
dispersed-compact	1.675	1.552695	1.797305	0

$\`openspace:development\`

	diff	lwr	upr	p adj
network:compact-greenway:compact	1.205000e+01	11.6694549	12.4305451	0
none:compact-greenway:compact	-2.706724e-14	-0.3805451	0.3805451	1
park:compact-greenway:compact	1.315000e+01	12.7694549	13.5305451	0
greenway:dispersed-greenway:compact	-6.217249e-15	-0.3805451	0.3805451	1
network:dispersed-greenway:compact	1.640000e+01	16.0194549	16.7805451	0
none:dispersed-greenway:compact	-2.475797e-14	-0.3805451	0.3805451	1
park:dispersed-greenway:compact	1.550000e+01	15.1194549	15.8805451	0
none:compact-network:compact	-1.205000e+01	-12.4305451	-11.6694549	0
park:compact-network:compact	1.100000e+00	0.7194549	1.4805451	0
greenway:dispersed-network:compact	-1.205000e+01	-12.4305451	-11.6694549	0
network:dispersed-network:compact	4.350000e+00	3.9694549	4.7305451	0
none:dispersed-network:compact	-1.205000e+01	-12.4305451	-11.6694549	0
park:dispersed-network:compact	3.450000e+00	3.0694549	3.8305451	0
park:compact-none:compact	1.315000e+01	12.7694549	13.5305451	0
greenway:dispersed-none:compact	2.084999e-14	-0.3805451	0.3805451	1
network:dispersed-none:compact	1.640000e+01	16.0194549	16.7805451	0
none:dispersed-none:compact	2.309264e-15	-0.3805451	0.3805451	1
park:dispersed-none:compact	1.550000e+01	15.1194549	15.8805451	0
greenway:dispersed-park:compact	-1.315000e+01	-13.5305451	-12.7694549	0
network:dispersed-park:compact	3.250000e+00	2.8694549	3.6305451	0
none:dispersed-park:compact	-1.315000e+01	-13.5305451	-12.7694549	0
park:dispersed-park:compact	2.350000e+00	1.9694549	2.7305451	0
network:dispersed-greenway:dispersed	1.640000e+01	16.0194549	16.7805451	0
none:dispersed-greenway:dispersed	-1.854072e-14	-0.3805451	0.3805451	1
park:dispersed-greenway:dispersed	1.550000e+01	15.1194549	15.8805451	0
none:dispersed-network:dispersed	-1.640000e+01	-16.7805451	-16.0194549	0
park:dispersed-network:dispersed	-9.000000e-01	-1.2805451	-0.5194549	0
park:dispersed-none:dispersed	1.550000e+01	15.1194549	15.8805451	0

Floaters

TukeyHSD(aovfloaters)
Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = floaters ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	6.862500e+01	67.1379996	70.112	0.0000000
none-greenway	-1.136868e-14	-1.4870004	1.487	1.0000000
park-greenway	7.095000e+01	69.4629996	72.437	0.0000000
none-network	-6.862500e+01	-70.1120004	-67.138	0.0000000
park-network	2.325000e+00	0.8379996	3.812	0.0004486
park-none	7.095000e+01	69.4629996	72.437	0.0000000

$development

	diff	lwr	upr	p adj
dispersed-compact	9.6375	8.837794	10.43721	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	5.970000e+01	57.21177	62.18823	0.0000000
none:compact-greenway:compact	-2.002842e-14	-2.48823	2.48823	**1.0000000**
park:compact-greenway:compact	6.060000e+01	58.11177	63.08823	0.0000000
greenway:dispersed-greenway:compact	-3.108624e-14	-2.48823	2.48823	**1.0000000**
network:dispersed-greenway:compact	7.755000e+01	75.06177	80.03823	0.0000000
none:dispersed-greenway:compact	-2.131628e-14	-2.48823	2.48823	**1.0000000**
park:dispersed-greenway:compact	8.130000e+01	78.81177	83.78823	0.0000000
none:compact-network:compact	-5.970000e+01	-62.18823	-57.21177	0.0000000
park:compact-network:compact	9.000000e-01	-1.58823	3.38823	**0.9534061**
greenway:dispersed-network:compact	-5.970000e+01	-62.18823	-57.21177	0.0000000
network:dispersed-network:compact	1.785000e+01	15.36177	20.33823	0.0000000
none:dispersed-network:compact	-5.970000e+01	-62.18823	-57.21177	0.0000000
park:dispersed-network:compact	2.160000e+01	19.11177	24.08823	0.0000000
park:compact-none:compact	6.060000e+01	58.11177	63.08823	0.0000000
greenway:dispersed-none:compact	-1.105782e-14	-2.48823	2.48823	**1.0000000**
network:dispersed-none:compact	7.755000e+01	75.06177	80.03823	0.0000000
none:dispersed-none:compact	-1.287859e-15	-2.48823	2.48823	**1.0000000**
park:dispersed-none:compact	8.130000e+01	78.81177	83.78823	0.0000000
greenway:dispersed-park:compact	-6.060000e+01	-63.08823	-58.11177	0.0000000
network:dispersed-park:compact	1.695000e+01	14.46177	19.43823	0.0000000
none:dispersed-park:compact	-6.060000e+01	-63.08823	-58.11177	0.0000000
park:dispersed-park:compact	2.070000e+01	18.21177	23.18823	0.0000000
network:dispersed-greenway:dispersed	7.755000e+01	75.06177	80.03823	0.0000000
none:dispersed-greenway:dispersed	9.769963e-15	-2.48823	2.48823	**1.0000000**
park:dispersed-greenway:dispersed	8.130000e+01	78.81177	83.78823	0.0000000
none:dispersed-network:dispersed	-7.755000e+01	-80.03823	-75.06177	0.0000000
park:dispersed-network:dispersed	3.750000e+00	1.26177	6.23823	0.0002044
park:dispersed-none:dispersed	8.130000e+01	78.81177	83.78823	0.0000000

Douglas squirrel (*Tamasciurus douglasii)*

ANOVA of BREEDING INDIVIDUALS

Terms:

	openspace	development	openspace:development	Residuals
Sum of Squares	627055.0	11679.3	67122.4	3361.6
Deg. of Freedom	3	1	3	152

Residual standard error: 4.702708
Estimated effects may be unbalanced

Summarize ANOVA of BREEDING INDIVIDUALS

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	627055	209018	9451.2	<2e-16 ***
development	1	11679	11679	528.1	<2e-16 ***
openspace:development	3	67122	22374	1011.7	<2e-16 ***
Residuals	152	3362	22		

ANOVA of FLOATERS

Terms:

	openspace	development	openspace:development	Residuals
Sum of Squares	1726786.0	303717.8	804529.7	62342.2
Deg. of Freedom	3	1	3	152

Residual standard error: 20.25207
Estimated effects may be unbalanced

Summarize statistics ANOVA of FLOATERS with development

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
openspace	3	1726786	575595	1403.4	<2e-16 ***
development	1	303718	303718	740.5	<2e-16 ***
openspace:development	3	804530	268177	653.9	<2e-16 ***
Residuals	152	62342	410		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey tests
Breeding individuals

TukeyHSD(aovgmembers)
Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = gmembers ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	-176.675	-179.40661	-173.943391	0
none-greenway	-79.075	-81.80661	-76.343391	0
park-greenway	-89.275	-92.00661	-86.543391	0
none-network	97.600	94.86839	100.331609	0
park-network	87.400	84.66839	90.131609	0
park-none	-10.200	-12.93161	-7.468391	0

$development

	diff	lwr	upr	p adj
dispersed-compact	17.0875	15.61845	18.55655	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	-175.10	-179.67086	-170.52914	0.0000000
none:compact-greenway:compact	-58.65	-63.22086	-54.07914	0.0000000
park:compact-greenway:compact	-125.45	-130.02086	-120.87914	0.0000000
greenway:dispersed-greenway:compact	10.00	5.42914	14.57086	0.0000000
network:dispersed-greenway:compact	-168.25	-172.82086	-163.67914	0.0000000
none:dispersed-greenway:compact	-89.50	-94.07086	-84.92914	0.0000000
park:dispersed-greenway:compact	-43.10	-47.67086	-38.52914	0.0000000
none:compact-network:compact	116.45	111.87914	121.02086	0.0000000
park:compact-network:compact	49.65	45.07914	54.22086	0.0000000
greenway:dispersed-network:compact	185.10	180.52914	189.67086	0.0000000
network:dispersed-network:compact	6.85	2.27914	11.42086	0.0002278
none:dispersed-network:compact	85.60	81.02914	90.17086	0.0000000
park:dispersed-network:compact	132.00	127.42914	136.57086	0.0000000
park:compact-none:compact	-66.80	-71.37086	-62.22914	0.0000000
greenway:dispersed-none:compact	68.65	64.07914	73.22086	0.0000000
network:dispersed-none:compact	-109.60	-114.17086	-105.02914	0.0000000
none:dispersed-none:compact	-30.85	-35.42086	-26.27914	0.0000000
park:dispersed-none:compact	15.55	10.97914	20.12086	0.0000000
greenway:dispersed-park:compact	135.45	130.87914	140.02086	0.0000000
network:dispersed-park:compact	-42.80	-47.37086	-38.22914	0.0000000
none:dispersed-park:compact	35.95	31.37914	40.52086	0.0000000
park:dispersed-park:compact	82.35	77.77914	86.92086	0.0000000
network:dispersed-greenway:dispersed	-178.25	-182.82086	-173.67914	0.0000000
none:dispersed-greenway:dispersed	-99.50	-104.07086	-94.92914	0.0000000
park:dispersed-greenway:dispersed	-53.10	-57.67086	-48.52914	0.0000000
none:dispersed-network:dispersed	78.75	74.17914	83.32086	0.0000000
park:dispersed-network:dispersed	125.15	120.57914	129.72086	0.0000000
park:dispersed-none:dispersed	46.40	41.82914	50.97086	0.0000000

Floaters

TukeyHSD(aovfloaters)
Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = floaters ~ openspace * development)

$openspace

	diff	lwr	upr	p adj
network-greenway	-235.900	-247.66359	-224.13641	0
none-greenway	-64.050	-75.81359	-52.28641	0
park-greenway	33.725	21.96141	45.48859	0
none-network	171.850	160.08641	183.61359	0
park-network	269.625	257.86141	281.38859	0
park-none	97.775	86.01141	109.53859	0

$development

	diff	lwr	upr	p adj
dispersed-compact	-87.1375	-93.46394	-80.81106	0

$`openspace:development`

	diff	lwr	upr	p adj
network:compact-greenway:compact	-308.15	-327.8342741	-288.465726	0.0000000
none:compact-greenway:compact	-15.75	-35.4342741	3.934274	**0.2212230**
park:compact-greenway:compact	-104.65	-124.3342741	-84.965726	0.0000000
greenway:dispersed-greenway:compact	-168.30	-187.9842741	-148.615726	0.0000000
network:dispersed-greenway:compact	-331.95	-351.6342741	-312.265726	0.0000000
none:dispersed-greenway:compact	-280.65	-300.3342741	-260.965726	0.0000000
park:dispersed-greenway:compact	3.80	-15.8842741	23.484274	**0.9989176**
none:compact-network:compact	292.40	272.7157259	312.084274	0.0000000
park:compact-network:compact	203.50	183.8157259	223.184274	0.0000000
greenway:dispersed-network:compact	139.85	120.1657259	159.534274	0.0000000
network:dispersed-network:compact	-23.80	-43.4842741	-4.115726	0.0067286
none:dispersed-network:compact	27.50	7.8157259	47.184274	0.0008020
park:dispersed-network:compact	311.95	292.2657259	331.634274	0.0000000
park:compact-none:compact	-88.90	-108.5842741	-69.215726	0.0000000
greenway:dispersed-none:compact	-152.55	-172.2342741	-132.865726	0.0000000
network:dispersed-none:compact	-316.20	-335.8842741	-296.515726	0.0000000
none:dispersed-none:compact	-264.90	-284.5842741	-245.215726	0.0000000
park:dispersed-none:compact	19.55	-0.1342741	39.234274	**0.0529950**
greenway:dispersed-park:compact	-63.65	-83.3342741	-43.965726	0.0000000
network:dispersed-park:compact	-227.30	-246.9842741	-207.615726	0.0000000
none:dispersed-park:compact	-176.00	-195.6842741	-156.315726	0.0000000
park:dispersed-park:compact	108.45	88.7657259	128.134274	0.0000000
network:dispersed-greenway:dispersed	-163.65	-183.3342741	-143.965726	0.0000000
none:dispersed-greenway:dispersed	-112.35	-132.0342741	-92.665726	0.0000000
park:dispersed-greenway:dispersed	172.10	152.4157259	191.784274	0.0000000
none:dispersed-network:dispersed	51.30	31.6157259	70.984274	0.0000000
park:dispersed-network:dispersed	335.75	316.0657259	355.434274	0.0000000
park:dispersed-none:dispersed	284.45	264.7657259	304.134274	0.0000000

REFERENCES CITED

Ahern, J. (2002). *Greenways as strategic landscape planning: theory and application* (PhD Dissertation, Wageningen University, Wageningen).

Ahern, J. (1999). Spatial concepts, planning strategies and future scenarios: a framework method for integrating landscape ecology and landscape planning. In J. Klopatek & R. Gardner (Eds.), *Landscape ecological analysis: issues and applications* (pp. 175-201). New York: Springer-Verlag Inc.

Ahern, J. (2005). Integration of landscape ecology and landscape architecture: an evolutionary and reciprocal process. In J. Wiens & M. R. Moss (Eds.), *Issues and perspectives in landscape ecology* (pp. 311-319). Cambridge: Cambridge University Press.

Ahern, J. (1991). Planning for an extensive open space system: linking landscape structure and function. *Landscape and Urban Planning, 21*(1-2), 131-145.

Alberti, M. (2005). The effects of urban patterns on ecosystem function. *International Regional Science Review, 28*(2), 168-192.

Alberti, M. (1999, WIN). Urban patterns and environmental performance: What do we know? *Journal of Planning Education and Research, 19*(2), 151-163.

Altman, B., Blakeley-Smith, M., Halstead, K., & Kreager, A. (2011). *Western Meadowlarks and Wet Prairie Habitat in the Willamette Valley: Population Enhancement through Private Land Habitat Restoration*: Avifauna Northwest, Institute for Applied Ecology, Oregon Department of Fish and Wildlife.

Arendt, R., Brabec, E. A., Dodson, H. L., Reid, C., & Yaro, R. D. (1994). *Rural by design: maintaining small town character*. Chicago, Ill.: Planners Press, American Planning Association.

Baker, J. P., Hulse, D. W., Gregory, S. V., White, D., Van Sickle, J., Berger, P. A. et al. (2004). Alternative futures for the Willamette River Basin, Oregon. *Ecological Applications, 14*(2), 313-324.

Baker, J. P., & Landers, D. H. (2004). Alternative-futures analysis for the Willamette River Basin, Oregon. *Ecological Applications, 14*(2), 311-312.

Beardsley, K., Thorne, J. H., Roth, N. E., Gao, S., & McCoy, M. C. (2009). Assessing the influence of rapid urban growth and regional policies on biological resources. *Landscape and Urban Planning, 93*(3-4), 172-183.

Bengston, D. N., Fletcher, J. O., & Nelson, K. C. (2004). Public policies for managing urban growth and protecting open space: policy instruments and lessons learned in the United States. *Landscape and Urban Planning, 69*(2-3), 271-286.

Beyard, M. D., Pawlukiewicz, M., & Urban Land Institute. (2001). *Ten principles for reinventing America's suburban strips*. Washington, D.C.: Urban Land Institute.

Bolte, J. (2009a). Envision cases studies. *http://envision.bioe.orst.edu/caseStudies.htm*. Retrieved from http://envision.bioe.orst.edu/caseStudies.htm

Bolte, J. (2009b). *ENVISION - Software for Alternative Futuring Applications - A guide to application development* Corvallis, OR: Oregon State University.

Bolte, J. P., Hulse, D. W., Gregory, S. V., & Smith, C. (2007). Modeling biocomplexity - actors, landscapes and alternative futures. *Environmental Modelling & Software, 22*(5), 570-579.

Botequilha Leitão, A., & Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and Urban Planning, 59*(2), 65-93.

Briffett, C. (2001). Is Managed Recreational Use Compatible with Effective Habitat and Wildlife Occurrence in Urban Open Space Corridor Systems? *Landscape Research, 26*(2), 137-163.

Bryant, M. M. (2006). Urban landscape conservation and the role of ecological greenways at local and metropolitan scales. *Landscape and Urban Planning, 76*(1-4), 23-44.

Burrows, R., & Gilligan, J. (2003). *Birds of Oregon*. Auburn, WA; Edmonton: Lone Pine Pub.

Calkin, D. E., Montgomery, C. A., Schumaker, N. H., Polasky, S., Arthur, J. L., & Nalle, D. J. (2002). Developing a production possibility set of wildlife species persistence and timber harvest value. *Canadian Journal of Forest Research, 32*(8), 1329.

Calthorpe Associates, Cooper Roberts Simonsen Architects, Bear West, Fehr and Peers Associates, & Strategic Economics. (2002). *Wasatch Front Transit Oriented Development Guidelines* Salt Lake: Envision Utah. Retrieved from: http://www.envisionutah.org/Wasatch%20Front%20Transit%20Oriented%20Development%20Guidelines_2002.pdf

Calthorpe, P. (2010). *Urbanism in the Age of Climate Change*. Washington, DC: Island Press.

Calthorpe, P., & Fulton, W. B. (2001). *The Regional City: planning for the end of sprawl*. Washington, DC: Island Press.

Carroll, C., Noss, R. F., Paquet, P. C., & Schumaker, N. H. (2004). Extinction Debt of Protected Areas in Developing Landscapes. *Conservation Biology, 18*(4), 1110-1120.

Carroll, C., Noss, R. F., Paquet, P. C., & Schumaker, N. H. (2003a). Use of Population Viability Analysis and Reserve Selection Algorithms in Regional Conservation Plans. *Ecological Applications, 13*(6), 1773-1789.

Carroll, C., Phillips, M. K., Schumaker, N. H., & Smith, D. W. (2003b). Impacts of Landscape Change on Wolf Restoration Success: Planning a Reintroduction Program Based on Static and Dynamic Spatial Models. *Conservation Biology, 17*(2), 536.

Center for Biological Diversity, Oregon Chapter of the Sierra Club, Audubon Society of Portland, Cascadia Wildlands Project, & OregonWild. (2007). *Petition to List the Dusky Tree Vole (Arborimus longicaudus silvicola) as Threatened or Endangered under the Endangered Species Act* Portland, OR.

Chan Mcleod, A. C. A., & Moy, A. R. N. (2009). Evaluating Residual Tree Patches as Stepping Stones and Short-Term Refugia for Red-Legged Frogs. *Journal of Wildlife Management, 71*(6), 1836-1844.

Chelgren, N. D., Rosenberg, D. K., Heppell, S. S., & Gitelman, A. I. (2006). Carryover Aquatic Effects on Survival of Metamorphic Frogs during Pond Emigration. *Ecological Applications, 16*(1), 250-261.

City of Damascus. (2010). *Envision Damascus: Comprehensive Plan* Damascus, Oregon.

Collinge, S. K. (1996). Ecological consequences of habitat fragmentation: implications for landscape architecture and planning. *Landscape and Urban Planning, 36*(1), 59-77.

Cook, E. A. (1991). Urban landscape networks: an ecological framework. *Landscape Research, 16*(3), 7-15.

Corry, R. C., & Nassauer, J. I. (2005). Limitations of using landscape pattern indices to evaluate the ecological consequences of alternative plans and designs. *Landscape and Urban Planning, 72*(4), 265-280.

COSEWIC. (2004). *COSEWIC assessment and update status report on the Red-legged Frog Rana aurora in Canada* Ottawa: Committee on the Status of Endangered Wildlife in Canada. Retrieved from: www.sararegistry.gc.ca/status/status_e.cfm

Davidson, C., Shaffer, H. B., & Jennings, M. R. (2001). Declines of the California Red-Legged Frog: Climate, UV-B, Habitat, and Pesticides Hypotheses. *Ecological Applications, 11*(2), 464-479.

Davis, S. K., Brigham, R. M., Shaffer, T. L., James, P. C., & Stouffer, P. C. (2006). Mixed-grass prairie passerines exhibit weak and variable responses to patch size. *The Auk, 123*(3), 807-821.

Davis, S. K., & Brittingham, M. (2004). Area sensitivity in grassland passerines: effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewn. *The Auk, 121*(4), 1130-1145.

Donaldson, B. M. (2005). *Use of Highway Underpasses by Large Mammals and Other Wildlife in Virginia: Factors Influencing Their Effectiveness* (VTRC 06-R2). Charlottesville, VA. Retrieved from: http://www.virginiadot.org/vtrc/main/online_reports/pdf/06-r2.pdf

Doubledee, R. A., Muller, E. B., & Nisbet, R. M. (2003). Bullfrogs, disturbance regimes, and the persistence of California red-legged frogs. *Journal of Wildlife Management, 67*(2), 424-438.

Dramstad, W. E., Olson, J. D., & Forman, R. T. T. (1996). *Landscape ecology principles in landscape architecture and land-use planning*. [Cambridge Mass.]; Washington, DC; [Washington, D.C.]: Harvard University Graduate School of Design ; Island Press ; American Society of Landscape Architects.

Duncan, S. (2004). Squirrels cannot live by truffles alone: a closer look at a northwest keystone complex. *Science Findings,*(60).

Dunham-Jones, E., & Williamson, J. (2009). *Retrofitting suburbia: urban design solutions for redesigning suburbs*. Hoboken, N.J.: John Wiley & Sons.

Erickson, D. (2006). *MetroGreen: connecting open space in North American cities*. Washington, DC: Island Press.

Fellers, G. M., & Kleeman, P. M. (2009). California Red-legged Frog (Rana Draytonii) Movement and Habitat Use: Implications for Conservation. *Journal of Herpetology, 41*(2), 276-286.

Forman, R. T. T. (2008a). The urban region: natural systems in our place, our nourishment, our home range, our future. *Landscape Ecology, 23*(3), 251-253.

Forman, R. T. T. (2008b). *Urban regions: ecology and planning beyond the city*. Cambridge, UK: Cambridge University Press.

Forman, R. T. T., & Collinge, S. K. (1997). Nature conserved in changing landscapes with and without spatial planning. *Landscape and Urban Planning, 37*(1-2), 129-135.

Forman, R. T. T., & Godron, M. (1981). Patches and Structural Components for A Landscape Ecology. *Bioscience, 31*(10), 733-740.

Forman, R. T. T. (1995). *Land mosaics: the ecology of landscapes and regions*. Cambridge [England]; New York: Cambridge University Press.

Forman, R. T. T. (2004). *Mosaico territorial para la region metropolitana de Barcelona*. Barcelona: Editorial Gustavo Gili.

Girling, C. L., & Helphand, K. I. (1997). Retrofitting suburbia. Open space in Bellevue, Washington, USA. *Landscape and Urban Planning, 36*(4), 301-313.

Girling, C. L., & Kellett, R. (2005). *Skinny streets and green neighborhoods: design for environment and community*. Washington, DC: Island Press.

Gonzales, E. K., Wiersma Y.F., & Maher A.I., N. T. D. (2008). Positive relationship between non-native and native squirrels in an urban landscape. *Canadian Journal of Zoology, 86*(5), 356-363.

Haire, S. L., Bock, C. E., Cade, B. S., & Bennett, B. C. (2000). The role of landscape and habitat characteristics in limiting abundance of grassland nesting songbirds in an urban open space. *Landscape and Urban Planning, 48*(1-2), 65-82.

Hargrove, W. W., Hoffman, F. M., & Efroymson, R. A. (2005). A Practical Map-Analysis Tool for Detecting Potential Dispersal Corridors. *Landscape Ecology, 20*(4), 361-373.

Heinrichs, J. A., Bender, D. J., Gummer, D. L., & Schumaker, N. H. (2010). Assessing critical habitat: Evaluating the relative contribution of habitats to population persistence. *Biological Conservation, 143*(9), 2229-2237.

Hennings, L., & Soll, J. (2010). *Wildlife corridors and permeability: A literature review* Portland, OR: Metro Sustainability Center.

Hilty, J. A., Lidicker, W. Z., & Merenlender, A. M. (2006). *Corridor ecology: the science and practice of linking landscapes for biodiversity conservation*. Washington, DC: Island Press.

Hodgson, J. A., Moilanen, A., Wintle, B. A., & Thomas, C. D. (2011). Habitat area, quality and connectivity: striking the balance for efficient conservation. *Journal of Applied Ecology, 48*(1), 148-152.

Hough, M. (2004). *Cities and natural process: a basis for sustainability* (2nd ed.). New York: Routledge.

Hulse, D., Eilers, J., Freemark, K., Hummon, C., & White, D. (2000). Planning alternative future landscapes in Oregon: evaluating effects on water quality and biodiversity. *Landscape Journal, 19*(1/2), 1-19.

Hulse, D., Gregory, S., & Baker, J. (2002). *Willamette River Basin Planning Atlas: trajectories of environmental and ecological change*. Corvallis: Oregon State University Press.

Hulse, D., Branscomb, A., Enright, C., & Bolte, J. (2009). Anticipating floodplain trajectories: a comparison of two alternative futures approaches. *Landscape Ecology, 24*(8), 1067-1090.

Hulse, D. W., Branscomb, A., & Payne, S. G. (2004). Envisioning alternatives: using citizen guidance to map future land and water use. *Ecological Applications, 14*(2), 325-341.

Johnson, B. R. (2010). Making Enduring Cities in an area of Rapid Changing Climate. Lecture, Eugene, OR.

Johnson, D. H., & Igl, L. D. (2001). Area requirements of grassland birds: a regional perspective. *The Auk, 118*(1), 24-34.

Jones, Z. F., & Bock, C. E. (2002). Conservation of grassland birds in an urbanizing landscape: a historical perspective. *The Condor, 104*(3), 643-651.

Kaplan, R., & Austin, M. E. (2004). Out in the country: sprawl and the quest for nature nearby. *Landscape and Urban Planning, 69*(2-3), 235-243.

Kaplan, R., Austin, M. E., & Kaplan, S. (2004). Open Space Communities: Resident Perceptions, Nature Benefits, and Problems with Terminology. *Journal of the American Planning Association, 70*(3), 300-312.

Kiesecker, J. M., & Blaustein, A. R. (1998). Effects of Introduced Bullfrogs and Smallmouth Bass on Microhabitat Use, Growth, and Survival of Native Red-Legged Frogs (Rana aurora). *Conservation Biology, 12*(4), 776-787.

Kiesecker, J. M., Blaustein, A. R., & Miller, C. L. (2001). Potential Mechanisms Underlying the Displacement of Native Red-Legged Frogs by Introduced Bullfrogs. *Ecology, 82*(7), 1964-1970.

Kok, K., Biggs, R., & Zurek, M. (2007). Methods for developing multiscale participatory scenarios: Insights from southern Africa and Europe. *Ecology and Society, 12*(1).

Kok, K., & van Delden, H. (2009). Combining two approaches of integrated scenario development to combat desertification in the Guadalentin watershed, Spain. *Environment and Planning B-Planning & Design, 36*(1), 49-66.

Oregon's Statewide Planning Goals & Guidelines, Goal 14: Urbanization/OAR 660-015-0000(14) (2006).

Lannoo, M. J. (2005). *Amphibian declines: the conservation status of United States species*. Berkeley: University of California Press.

LeClerc, J. E., & Cristol, D. A. (2005). Are Golf Courses Providing Habitat for Birds of Conservation Concern in Virginia? *Wildlife Society Bulletin, 33*(2), 463-470.

Lindenmayer, D. B., & Fischer, J. (2007). Tackling the habitat fragmentation panchreston. *Trends in Ecology & Evolution, 22*(3), 127-132.

Lukez, P. (2007). *Suburban transformations*. New York: Princeton Architectural Press.

Lyle, J. T. (1985). *Design for human ecosystems : landscape, land use, and natural resources*. New York: Van Nostrand Reinhold.

Lynch, K. (1972). The openness of open space. In G. Kepes (Ed.), *Arts of the environment* (pp. 108-124). New York: George Braziller.

MacKenzie, A., & Barnett, G. (2006). The Bush Capital-A Complex Urbanising Landscape. *The Landscape Architect,* 201-213.

Mahmoud, M., Liu, Y. Q., Hartmann, H., Stewart, S., Wagener, T., Semmens, D. et al. (2009). A formal framework for scenario development in support of environmental decision-making. *Environmental Modelling & Software, 24*(7), 798-808.

Marcot, B. G., Raphael, M. G., Schumaker, N. H., & Galleher, B. (2012). How big and how close? Habitat patch size and spacing to conserve a threatened species. *Natural Resource Modeling*.

Marcus, C. C., & Francis, C. (1998). *People places: design guidelines for urban open space*. New York: Van Nostrand Reinhold.

Maruani, T., & mit-Cohen, I. (2007). Open space planning models: A review of approaches and methods. *Landscape and Urban Planning, 81*(1-2), 1-13.

Marzluff, J. M., & Ewing, K. (2001). Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. *Restoration Ecology, 9*(3), 280-292.

Mason, C. F. (2006). Avian species richness and numbers in the built environment: can new housing developments be good for birds? *Biodiversity and Conservation, 15*(8), 2365-2378.

McRae, B. H., Dickson, B. G., Keitt, T. H., & Shah, V. B. (2008a). Using Circuit Theory to Model Connectivity in Ecology, Evolution, and Conservation. *Ecology, 89*(10), 2712-2724.

McRae, B. H., Schumaker, N. H., McKane, R. B., Busing, R. T., Solomon, A. M., & Burdick, C. A. (2008b). A multi-model framework for simulating wildlife population response to land-use and climate change. *Ecological Modelling, 219*(1GÇô2), 77-91.

Metro. (2011). RLIS Discovery. *Metro RLIS Discovery*. Retrieved from http://rlisdiscovery.oregonmetro.gov/

Metro. (1992). *Metropolitan Greenspaces Master Plan: a Cooperative Regional System of Natural Areas, Open Space, Trails and Greenways for Wildlife and People* Portland, OR: Metro.

Miller, J. R., & Hobbs, N. T. (2000). Recreational trails, human activity, and nest predation in lowland riparian areas. *Landscape and Urban Planning, 50*(4), 227-236.

Morrison, G. (1993). Western meadowlark. *Horticulture, 71*(8), 57.

Myers, A. M., & Kreager, A. (2010). *Declining and State Sensitive Bird Species Breeding in Willamette Valley Grasslands: 2008/09 Status Update* Oregon Department of Fish and Wildlife.

Nassauer, J. I., & Corry, R. C. (2004). Using normative scenarios in landscape ecology. *Landscape Ecology, 19*(4), 343-356.

Nassauer, J. I. (2012). Landscape as medium and method for synthesis in urban ecological design. *Landscape and Urban Planning, 106*(3), 221-229.

Ndubisi, F. (2002). Managing Change in the Landscape: A Synthesis of Approaches for Ecological Planning. *Landscape Journal, 21*(1), 138-155.

Ndubisi, F., DeMeo, T., & Ditto, N. D. (1995). Environmentally sensitive areas: a template for developing greenway corridors. *Landscape and Urban Planning, 33*(1-3), 159-177.

O'Neil, T. A. (2001). *Matrixes for Wildlife-habitat relationships in Oregon and Washington*. Corvallis, OR: Northwest Habitat Institute.

Opdam, P., Steingrover, E., & Rooij, S. v. (2006). Ecological networks: A spatial concept for multi-actor planning of sustainable landscapes. *Landscape and Urban Planning, 75*, 322-332.

Oregon Department of Fish and Wildlife. (2006). *The Oregon Conservation Strategy*. Salem, OR: Oregon Dept. of Fish and Wildlife.

Payne, S. (2002). Urban land use. In D. Hulse, S. Gregory, & J. Baker (Eds.), *Willamette River Basin Planning Atlas: trajectories of environmental and ecological change* (pp. 106-107). Corvallis: Oregon State University Press.

Penteado, H. M., & Alvarez, C. E. (2007). Corredores verdes urbanos: estudo da viabilidade de conexão das áreas verdes de Vitória. *Paisagem e Ambiente, 24*, 57-68.

Penteado, H. (2013). Assessing the effects of applying landscape ecological spatial concepts on future habitat quantity and quality in an urbanizing landscape. *Landscape Ecol, 28*(10), 1909-1921.

Pickett, S. T. A., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C. et al. (2001). Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics, 32*, 127-157.

Ransome, D. B., & Sullivan, T. P. (2004). Effects of food and den-site supplementation on populations of Glaucomys sabrinus and Tamiasciurus douglasii. *Journal of Mammalogy, 85*(2), 206-215.

Reid, G. W. (2007). *From concept to form in landscape design*. Hoboken, NJ: Wiley.

Rodiek, J. (2008). Protecting ecosystems and open spaces in urbanizing environments. *Landscape and Urban Planning, 84*(1), 3-6.

Rottle, N., & Maryman, B. (2006). *Envisioning Seattle's Green Future* Seattle, WA: Open Space Seattle 2100 Project.

Rubino, M. J., & Hess, G. R. (2003). Planning open spaces for wildlife 2: modeling and verifying focal species habitat. *Landscape and Urban Planning, 64*(1-2), 89-104.

Schumaker, N., Ernst, T., Haggerty, P., Baker, J., & White, D. (2002). Terrestrial wildlife - populations. In D. Hulse, S. Gregory, & J. Baker (Eds.), *Willamette River Basin Planning Atlas: trajectories of environmental and ecological change* (pp. 126-127). Corvallis, OR: Oregon State University Press.

Schumaker, N. H. (2011). *HexSim (Version 2.1)* Corvallis, OR: U.S. Environmental Protection Agency. Retrieved from: http://www.epa.gov/hexsim

Schumaker, N. H. (1996). Using Landscape Indices to Predict Habitat Connectivity. *Ecology, 77*(4), 1210-1225.

Schumaker, N. H., Ernst, T., White, D., Baker, J., & Haggerty, P. (2004). Projecting wildlife responses to alternative future landscapes in Oregon's Willamette Basin. *Ecological Applications, 14*(2), 381-400.

Steinitz, C. (2001). Landscape ecology and landscape planning: Links and gaps and common dilemmas. *Publicaciones Instituti Geographici Universitatis Tartuensis, 92*, 48-50.

Steinitz, C., Arias, H., Bassett, S., Flaxman, M., Goode, T., Maddock, T. et al. (2002). *Alternative futures for changing landscapes: the Upper San Pedro River Basin in Arizona and Sonora*. Washington, DC: Island Press.

Steinitz, C., Bilda, E., Ellis, J., Johnson, T., Hung, Y., Katz, E. et al. (1994). *Alternative futures for Monroe County, Pennsylvania*. Cambridge, MA: Harvard University, Graduate School of Design.

Steinitz, C., Binford, M., Cote, P., Edwards Jr., T., Ervin, S., Forman, R. T. T. et al. (1996). *Biodiversity and landscape planning: alternative future scenarios for the region of Camp Pendleton, California*. Corvallis, OR: National Health and Environmental Effects Research Laboratory, Western Ecology Division.

Steinitz, C., Faris, R., Flaxman, M., Karish, K., Mellinger, A. D., Canfield, T. et al. (2005). A delicate balance: Conservation and development scenarios for Panama's Coiba National Park. *Environment, 47*(5), 24-39.

Stronen, A., Schumaker, N., Forbes, G., Paquet, P., & Brook, R. (2012). Landscape resistance to dispersal: simulating long-term effects of human disturbance on a small and isolated wolf population in southwestern Manitoba, Canada. *Environmental Monitoring Assessment, 184*(11), 6923-6934.

Sullivan, T. P., & Sullivan, D. S. (1982). Population Dynamics and Regulation of the Douglas Squirrel (Tamiasciurus douglasii) with Supplemental Food. *Oecologia, 53*(2), 264-270.

Swaffield, S. R. (2002). *Theory in landscape architecture : a reader*. Penn studies in landscape architecture. Philadelphia: University of Pennsylvania Press.

Swart, R. J., Raskin, P., & Robinson, J. (2004). The problem of the future: sustainability science and scenario analysis. *Global Environmental Change-Human and Policy Dimensions, 14*(2), 137-146.

Termorshuizen, J. W., Opdam, P., & van den Brink, A. (2007). Incorporating ecological sustainability into landscape planning. *Landscape and Urban Planning, 79*(3GÇô4), 374-384.

The R Foundation for Statistical Computing. (2011). R (Version 2.14.1).

Thompson, J. R., Wiek, A., Swanson, F. J., Carpenter, S. R., Fresco, N., Hollingsworth, T. et al. (2012). Scenario Studies as a Synthetic and Integrative Research Activity for Long-Term Ecological Research. *Bioscience, 62*(4), 367-376.

Turner, M. G. (1989). Landscape Ecology: The Effect of Pattern on Process. *Annual Review of Ecology and Systematics, 20*, 171-197.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kazmierczak, A., Niemela, J. et al. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landscape and Urban Planning, 81*(3), 167-178.

Verts, B. J., & Carraway, L. N. (1998). Land mammals of Oregon. Retrieved from http://www.netlibrary.com/urlapi.asp?action=summary&v=1&bookid=9480

Vogt, C. A., & Marans, R. W. (2004). Natural resources and open space in the residential decision process: a study of recent movers to fringe counties in southeast Michigan. *Landscape and Urban Planning, 69*(2-3), 255-269.

Wu, J. (2008). Making the Case for Landscape Ecology: An Effective Approach to Urban Sustainability. *Landscape Journal, 27*(1), 41-50.