

Essays on Protected Area Size: Effects on Ecological and Economic Effectiveness

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Kristen Marie Thiel

May 2017

Copyright © 2017 by Kristen Thiel

All rights reserved.

Acknowledgements

I would like to thankfully acknowledge my advisor, Seong-Hoon Cho, as well as my committee members, Paul Armsworth and Donald Hodges, for their support. I gratefully acknowledge the National Science Foundation (NSF) for funding (Award 1211142) through the project entitled, “CNH-Ex: The Influence of the Size of Protected Areas on Their Ecological and Economic Effectiveness”, The Nature Conservancy (TNC) for providing land acquisition data. I also gratefully acknowledge the Multistate Project (W3133) from the USDA National Institute of Food and Agriculture through the project entitled, “Benefits and Costs of Natural Resources Policies Affecting Ecosystem Services on Public and Private Lands”.

My sincere gratitude also extends to Bradley Wilson for his invaluable ArcGIS advice and guidance. Data sources and preparation protocols for the geophysical, socioeconomic characteristics, and distance-related variables were followed from Kim et al. (2014). Additionally, collection protocols for landscape data for the effective mesh size were created by Heather Jackson (unpublished results). Data to create target species richness was captured from Sutton and Armsworth (2014).

Abstract

Faced with continuing threats to biodiversity, governments are increasingly seeking to expand protected areas. Financial resources are limited, which often spurs conservation planners to prioritize locations for future protection. Thus, prioritization of protected areas is increasingly being evaluated based on the return on investment (ROI) they offer. This thesis consists of two essays analyzing the land acquisitions made by the world's largest conservation organization, The Nature Conservancy (TNC). In the first essay, entitled "Effects of Protected Area Size on Conservation Return on Investment," the increase in effective mesh size per dollar invested to acquire a parcel was greater for larger parcels, implying that the overall ecological and economic effectiveness is higher in protecting larger areas relative to smaller ones. This finding suggests that, all else being equal, conservation organizations have an incentive when selecting parcels for protected area creation to favor larger parcels over smaller ones. Furthermore, given the incentive to favor larger parcels, conservation organizations tend to favor larger parcels more as is the case when they focus on both ecological and economic effectiveness together and not on ecological effectiveness alone. Therefore, a conservation priority decision will be biased toward larger parcels if conservation organizations are interested in achieving ecological and economic effectiveness.

The second essay, entitled "Effects of Parcel Size on Conservation Return on Investment for Protected and Unprotected Matching Sites," provides the first rigorous test of and comparison of the elasticity of size on conservation ROI with area between transactions made by a conservation organization versus transactions without such involvement. This comparison shows that a conservation organization's scale effects with protected area size on conservation benefit and cost are not shown in non-conservation acquisitions in the wider land market. This finding

implies that different preferences lead to scale effects with protected area size on conservation benefit and cost as the general market behavior of the non-conservation buyers does not result in the same scale effects for unprotected sites.

Table of Contents

Chapter 1: Introduction	1
Chapter 2: Effects of Protected Area Size on Conservation Return on Investment	4
Abstract.....	5
1. Introduction	7
2. Literature Review	9
3. Method.....	12
3.1 Conceptual Framework	12
3.2 Model Specification	13
3.3 Model Estimation.....	17
4. Data.....	18
5. Empirical Results.....	20
6. Conclusions	22
References	25
Appendix	34
Supplementary Materials	39
S2.1 Numerical Example of Change in Effective Mesh Size with Adjacent and Non-Adjacent Acquisitions.....	39
S2.2 Calculation of Effective Mesh Size using Probabilities	40
S2.3 Two Stage Least Squares Model	41
Chapter 3: Effects of Parcel Size on Conservation Return on Investment for Protected and Unprotected Matching Sites.....	42
Abstract.....	43
1. Introduction	45
2. Method.....	48
2.1 Statistical Matching	48
2.2 Regression Model Specification	49
2.3 Regression Model Estimation	53
3. Study Area and Data.....	54
4. Empirical Results.....	56
5. Conclusions	59
References	62
Appendix	71
Chapter 4: Summary	77
Vita	80

List of Tables

Chapter 2: Effects of Protected Area Size on Conservation Return on Investment

Table 2.1 Variable Definitions and Descriptive Statistics (n = 82) 35

Table 2.2 Parameter Estimates for Two Stage Model 36

Chapter 3: Effects of Parcel Size on Conservation Return on Investment for Protected and Unprotected Matching Sites

Table 3.1 Variable Definitions and Descriptive Statistics for Protected and Unprotected Matching Sites (n = 82, n = 75) 72

Table 3.2 Goodness of Fit for the Protected and Unprotected Matching Sites using Different Spatial Weight Matrices.....73

Table 3.3 Parameter Estimates from SAC using a Fourth-order KNN Weight Matrix.....75

List of Figures

Chapter 2: Effects of Protected Area Size on Conservation Return on Investment

Figure 2.1 82 Fee Simple Transactions Made by TNC in Central and Southern Appalachian Forest Ecosystems during 2000-2009	37
Figure 2.2 Empirical Results – ROI Regressed on Protected Area Size	38
Figure 2.3 Sample Landscapes before TNC Acquisition	40
Figure 2.4 Sample Landscapes after TNC Acquisition	40
Figure 2.5 Sample Landscape where Divided Areas Represents Parcels (i.e., A_1 , A_2 , and A_3)	42

Chapter 3: Effects of Parcel Size on Conservation Return on Investment for Protected and Unprotected Matching Sites

Figure 3.1 82 Protected Sites Acquired by TNC and 75 Unprotected Matching Sites in Central and Southern Appalachian Forest Ecosystems during 2000-2009.....	76
--	----

Chapter 1: Introduction

Faced with continuing threats to biodiversity and ecosystems (Gaston et al., 2008; Llausas and Nogue, 2012), governments and societies around the world are increasingly seeking to expand protected area networks. Protected areas constitute a centerpiece of conservation strategies intended to slow biodiversity loss and reverse declines in many ecosystem services (Chape et al., 2005). However, resources for creation of new protected areas are limited. Thus, available resources must be allocated effectively, which often spurs conservation planners to prioritize locations for future protection (Naidoo et al., 2006). Thus, land designated for protected area status is increasingly being evaluated based on the return on investment (ROI) they offer (Adams et al., 2010; Ando et al., 1998; Game 2013; Murdoch et al., 2010, Polasky et al., 2001).

ROI varies according to characteristics such as land use, politics and economic conditions, and climate change (Armsworth et al., 2006). One essential feature is size variation of protected areas, which can vary widely both in the same conservation program and across different programs (Kim et al., 2014; Sutton and Armsworth, 2014). The literature commonly finds that the greater the size of the protected area, the more species the protected area contains (Armsworth, et al., 2006). Habitat diversity and species' survival rates also increase with the protected area size (Bender et al., 1998; Burkey, 1997; Debinski and Holt, 2000; Ovaskainen, 2002; Underwood et al., 2008; Wiens, 2009). The effects of protected area size on cost associated with conservation practice implementation have been explored more recently (Armsworth et al., 2011; Balmford et al., 2003; Frazee et al., 2003; James et al., 2000; Kim et al., 2014; Moore et al., 2004; Strange et al., 2006). The literature finds that acquisition costs for protected sites increase with their size but at a decreasing rate (e.g. Frazee et al., 2003; Moore et al., 2004; Strange et al., 2006).

Despite the findings of the scale effects of protected area size on both conservation benefit and cost when they are evaluated separately, little research has evaluated them in a single framework (but see Sutton and Armsworth, 2014). In addition, no research has compared the scale effects of protected area size with those of unprotected areas. The comparison of the scale effects between protected and unprotected areas using ROI as a single framework helps evaluate the influence of protected area size on the ecological and economic effectiveness between fine- and coarse-filter conservation targets relative to the wider land market. Given the gap in the literature and its importance, this thesis consists of two essays which collectively analyze (1) how the size of protected areas influences ecological and economic effectiveness as well as how subsequent changes in ecological and economic effectiveness alter priority decision for protection and (2) how the size of protected areas influences their ecological and economic effectiveness as well as how these effects are different from those of unprotected areas.

Chapter 2: Effects of Protected Area Size on Conservation Return on Investment

Abstract

Conservation return on investment (ROI) varies according to a wide range of characteristics for all spatial scales. One feature that makes conservation ROI at the parcel level different from larger-scale ROI is the impact of parcel size on ecological and economic effectiveness. Protected area size maintains an important role in both the benefit and cost associated with conservation. However, few studies have explicitly focused on the role of protected area size on conservation ROI specifically at the parcel level. Therefore, conservation ROI effectiveness for prioritizing parcels for conservation has been limited. The objective of this research is to examine how protected area size influences a parcel's ecological and economic effectiveness through conservation ROI. This objective is accomplished by analyzing the parcel-level acquisition costs and the conservation benefit of protected areas acquired by a conservation organization, The Nature Conservancy (TNC). How differences in protected area size influence conservation benefit, as an ecological measurement, and how conservation benefit, as a measure of conservation value, subsequently alter conservation costs are examined. By assessing the sequential relationship in a spatial econometric modeling framework, the consequence of the size variation on conservation ROI is studied. Findings include that protected areas acquired by TNC create more connected habitat, thereby improving species protection and mobility in the protected area network that existed prior to the TNC acquisition, an improvement which is a major impetus to determine acquisition cost. Second, the increase in effective mesh size per dollar invested to acquire a parcel is greater for larger parcels than smaller parcels, implying that the overall efficiency that considers both ecological and economic effectiveness is higher for protecting larger areas relative to smaller ones. Third, the ranking of parcels by conservation benefit and subsequently by conservation ROI provides information about which parcels are

negatively affected by acquisition cost. The magnitude of ecological effectiveness is small relative to the magnitude of both ecological and economic effectiveness for these parcels.

1. Introduction

Faced with continuing threats to biodiversity and ecosystems (Gaston et al., 2008; Llausas and Nogue, 2012), governments and societies around the world are increasingly seeking to expand protected area networks. However, financial resources for creation of new protected areas are limited, and thus available resources must be allocated effectively (Naidoo and Ricketts, 2006). Efforts to prioritize locations for protection in an effective way have led to the development of a return on investment (ROI) framework in conservation (e.g., Ando et al., 1998; Possingham et al., 2000; Possingham et al., 2001; Sarkar et al., 2006; Wilson et al., 2006; Murdoch et al., 2007; Withey et al., 2012). ROIs are typically scored by dividing the quantitative measures of conservation outcomes by the cost associated with protected areas for a given unit of area.

Evaluating ROI over different spatial grains varies according to a wide range of characteristics (Armsworth et al., 2006). While conservation ROI analyses over large spatial extents offers broader strategic choices that account for both ecological and economic effectiveness, they do not help conservation action at the finer spatial grain (e.g., parcel level). Parcel-level analyses are critical in conservation decisions because significant real decision-making occurs at the parcel level. One essential feature that makes conservation ROI at the parcel level unique from larger-grain analysis is the ability to evaluate the impact of variations in the size of a parcel, which can vary widely both in the same conservation program and across different programs (Sutton and Armsworth, 2014).

The size of protected areas has been the focus of land conservation strategies. Both the ecological consequences of size variations and the cost of establishing protected areas have been the center of numerous research studies. For example, the single large or several small (SLOSS)

question has long been debated in conservation biology (Diamond, 1975; Simberloff and Abele, 1982), while cost implications of the size of protected areas have been studied in more recent years (Armsworth et al., 2011; Ausden, 2007; Ausden and Hiron, 2002; Balmford, et al., 2003; Frazee et al., 2003; James et al., 1999; Kim et al. 2014; Moore et al., 2004; Strange et al., 2006). The SLOSS debate has addressed different ecosystem functions in larger versus smaller habitat areas. Studies about costs of protected areas have primarily dealt with establishment issues in terms of economies of scale with area. Despite the findings of the important role of protected area size in conservation decisions, little, if any, research has explicitly focused on the role of protected area size on conservation ROI to combine benefit and cost measurements at the real decision-making unit, the parcel level.

The objective of this research is to examine how protected area size influences ecological and economic effectiveness as well as how the subsequent changes in ecological and economic effectiveness alter the prioritization decisions for the selection of protected areas. To achieve the objective a case study was developed using fee-simple transactions by The Nature Conservancy (TNC) made without donative intent during 2000-2009 in the central and southern Appalachian forest ecosystems (see Figure 2.1).¹ In this case study, the quantitative measure of the conservation outcome is represented by the degree to which protecting a given parcel changes the effective mesh size of the protected land around the site (referred to as “change in effective mesh size”), and the acquisition cost of protecting a parcel is used as a cost measure associated

¹ TNC acquires land through fee-simple transactions, which transfer the full fee title, and easements, which transfer partial property rights (Dana and Ramsey, 1989; Eagle, 2011; Fishburn et al., 2009). In the case study, only fee-simple transactions without donative intent are used as observations because parcels with donative intent offer poor estimates of acquisition costs and 91% (or 61 of 67) of easements acquired by TNC had donative intent during the study period.

with the protected area. Using these measures and other relevant factors that affect both measures, a regression framework was developed to assess how variations in protected parcel size influence the change in effective mesh size and how changes in the effective mesh size then alter the parcel's acquisition cost. Then, using the results from the regression model, the effect of parcel size variation on conservation ROI that measures ecological and economic effectiveness is examined and sites are ranked for protection based on conservation ROI versus based on conservation outcome. By comparing the two rankings, the differences in priorities are analyzed for protection in relation to the parcel size variation for protected parcels.

2. Literature Review

Four issues associated with the objective have been addressed in the literature: (1) the spatial scale of conservation ROI, (2) the cost component of conservation ROI, (3) the benefit component of conservation ROI, and (4) the role of protected area size in determining conservation ROI. Below, the four branches of literature are discussed in detail.

Studies addressing issue (1) have focused on the importance of the two components of spatial scale used in conservation prioritization decisions, spatial grain and extent, and whether these components are large in geographical area (e.g., global, transnational, ecoregional, or landscape level) (Carwardine et al., 2008a; Murdoch et al., 2007; Naidoo and Iwamura, 2007; Wilson et al., 2009) or small (e.g., parcel or protected area level) (Ferraro, 2003; Messer, 2006; Murdoch et al., 2010; Newburn et al., 2006; Sutton and Armsworth, 2014; Tear et al., 2014). Spatial grain refers to the physical size of the observation unit, whereas extent refers to the overall geographic dimension from which inferences are drawn (McGarigal, 2002).

While large-scale ROI studies can offer prioritization decisions among large political entities or different ecosystems, only parcel-level ROI has the unique ability to help conservation

organizations select individual parcels (Murdoch et al., 2007; Naidoo and Iwamura, 2007; Tear et al., 2014). Thus, parcel-level ROI is especially useful in guiding site prioritization decisions at the local level. Yet estimating site-specific protected area effects has been a major challenge for conservation ROI research, in part because of limitations in collecting appropriate data at the parcel level (Tear et al., 2014).

In relation to issue (2), the literature has emphasized the wide variety of costs used in ROI as well as the considerable range of methods used to calculate them (Adams et al., 2010; Frazee et al., 2003; Murdoch et al., 2010; Naidoo et al., 2006). Some costs in the literature reflect the market value of alternative land uses (e.g., opportunity costs) while others reflect the ecological needs of the protected area (e.g., management costs) (Armsworth et al., 2011). Although many different cost options exist for calculating conservation ROI (e.g., acquisition, transaction, opportunity, damage, and/or management costs), studies rarely include multiple costs due to the difficulty in finding and calculating even one type of conservation cost (Adams et al., 2010; Naidoo et al., 2006) and the redundancy inherent in including every cost category in conservation ROI calculation. A better approach is to include the most relevant and accurately estimable cost considered in conservation decision-making (Game, 2013). In this TNC case study, acquisition cost is most relevant because TNC frequently purchases land with the intent of transferring it to partners and government agencies (Kareiva et al., 2014). Thus, other costs such as management costs are not as critical as acquisition costs are to its decision-making process.

Concerning issue (3), previous literature has commonly quantified conservation benefit by focusing on the biodiversity protection of the greatest number of species or species which have the greatest conservation value (Boyd et al., 2015). To measure the biodiversity conservation that a protected area provides, conservation ROI studies often use species richness

of a select group of rare or targeted species such as vertebrates (Ando et al., 1998; Carwardine et al., 2008b; Murdoch et al., 2007; Polasky et al., 2001). Other studies use habitat protection as a proxy for species protection with the assumption that the protected area will conserve a pre-determined acceptable percentage of species (Balmford et al., 2000; Carwardine et al., 2008b; Naidoo and Iwamura, 2007). Some of these studies set fixed targets of habitat type (Balmford et al., 2000) or species' historic ranges for protection (Kark et al., 2009). In this case study, the change in effective mesh size is estimated as a habitat fragmentation measurement which is affected by environmental and biological factors. This metric is chosen as the quantitative measure of conservation outcome because landscape contiguity is a crucial factor in maintaining many ecological processes and services (Jaeger, 2000), and TNC emphasizes landscape contiguity as an important motivation behind its acquisition practices (TNC, 2000).

Related to issue (4), protected area size and the ecological consequences of size variability has been a central concern of conservation biologists for decades (Diamond, 1975; Higgs, 1981; Lahti and Ranta, 1985; Simberloff and Abele, 1982). The literature commonly finds that the larger the protected area, the greater the number of species (Bender et al., 1998; Debinski and Holt, 2000; Wiens, 2009), although recent literature advocates for the importance of smaller protected areas (Wiens and Bachelet, 2014). The relationship between protected area size and conservation cost has been the focus of both conservation biologists and economists since the early 2000s (Armsworth et al., 2011; Ausden, 2007; Ausden and Hirons, 2002; Balmford et al., 2003; Frazee et al., 2003; James et al., 2000; Kim et al., 2014; Moore et al., 2004; Strange et al., 2006). Recent studies about the cost of protected areas have dealt with establishment issues in terms of economies of scale with area (Kim et al., 2014). Despite numerous findings that suggest the important role of protected area size in both benefit and cost

of protected areas, little research has explicitly focused on the role of protected area size on benefit and cost together (but see Sutton and Armsworth, 2014). By analyzing these relationships in one model framework using ROI at the parcel level, this model contributes valuable information for understanding the influence of protected area size on the ecological and economic effectiveness at the real decision-making unit.

3. Method

3.1. Conceptual Framework

The cost for which a conservation organization like TNC acquires land for protection is dependent on the conservation organization's willingness to pay (WTP) to acquire a particular parcel and the landowner's willingness to accept (WTA) the transaction. TNC's WTP is a function of the protected area's size and other factors that determine the expected conservation outcome (e.g., a habitat fragmentation measurement) (Lennox and Armsworth, 2013; TNC, 2000). The landowner's WTA is, in part, a function of the protected area's size and opportunity cost of alternative land uses (Lennox, Dallimer, and Armsworth, 2012). Given the presumptions about TNC's WTP and a landowner's WTA, the functional relationship for acquisition cost can be expressed as:

$$C_i = C_i[B_i(S_i, Z_i), S_i, X_i], \quad (1)$$

where C_i , B_i , S_i , Z_i , and X_i are acquisition cost, conservation benefit, protected area size, other factors determining conservation benefit, and other factors determining the opportunity cost of alternative land uses, respectively, for protected parcel i . In this functional relationship, acquisition cost is assumed to be a function of conservation benefit because conservation benefit determines TNC's WTP. Acquisition cost is not explicitly hypothesized to have an effect on conservation benefit because acquisition cost itself does not directly contribute to conservation

benefit. (Had the model focused on management cost instead of acquisition cost, conservation benefit would have been hypothesized to be affected by management cost because management cost reflects the ecological needs of the protected area.)

3.2. Model Specification

Given the functional relationship laid out in equation (1), the empirical model assumes change in effective mesh size, reflecting conservation benefit from a protected parcel, is endogenous in the following system of equations explaining change in effective mesh size (the second line of equation (2), referred to as “conservation benefit equation”) and acquisition cost (the first line of equation (2), referred to as “conservation cost equation”):

$$\begin{aligned} \ln Y_C &= \delta \ln y_B + \Omega \ln S + \ln X \Phi + \varepsilon_C \\ \ln Y_B &= \Upsilon \ln S + \ln Z \xi + \varepsilon_B, \end{aligned} \tag{2}$$

where $\ln$ is natural log; Y_C is acquisition cost; Y_B is change in effective mesh size, and δ , Ω , and Υ are scalar parameters; Φ and ξ are vector parameters; and ε_C and ε_B are i.i.d. disturbances with zero mean and variance $\sigma^2 I$.

Here, X and Z include categories of geophysical characteristics (average slope and average elevation), distance-related variables (distance to major city, waterbody, park, and highway), and the initial stock of conservation benefit located in the 5 km radius buffer before the acquisition of the protected parcel (effective mesh size before acquisition, weighted species richness, and percentage of the landscape already protected). X also includes socioeconomic characteristics (median income and population of the census block group in which the parcel is located). The variables for each category are chosen following the general guidance of the literature. For example, the geophysical characteristics of slope and elevation as geophysical

characteristics are included because they have been found to determine acquisition cost and location of protected areas (Andam et al., 2010; Joppa and Pfaff, 2009; Kim et al., 2014; Sims, 2010). Proximity to the nearest major city, waterbody, park, and highway are used as distance-related variables because proximities to these amenities are expected to positively affect acquisition cost through the real estate market (Cho et al., 2006; Kruse and Ahmann, 2009; Land Policy Institute, 2007; McConnell and Walls, 2005; Snyder et al., 2007). Also, they may affect the measure of effective mesh size because habitat size was found to increase with distance to landmarks (Ferraro et al., 2011; Newburn et al., 2006).

Weighted species richness, effective mesh size before acquisition, and percentage of protected area in the landscape surrounding the parcel, which is created by drawing a 5 km radius buffer around the centroid of each protected parcel prior to TNC acquisition, are used to capture the initial stock of conservation benefit. These variables are expected to affect TNC's WTP because TNC is interested in targeting parcels near or adjacent to established protected areas and/or acquiring areas with abundant species richness (TNC, 2000; TNC, 2001; TNC, 2003). Likewise, a landowner's WTA may be influenced by the initial stock of conservation benefit because of the higher land value the real estate market places on parcels near protected or natural areas due to the aesthetic view or potential recreational use (Armsworth et al., 2006).

The socioeconomic characteristics (i.e., population and median household income at the census-block group level) are included in X to capture direct interdependency of acquisition costs within census-block group neighborhoods, which have similar real estate market characteristics. Population is included to measure how population pressure on land and natural resources affects acquisition cost. Median household income is included to capture the effect of the relative

economic status of a neighborhood on acquisition cost. (Definitions of the variables used in the regressions and their detailed statistics are located in Table 2.1.)

The effective mesh size variable quantifies the probability that two random points (i.e., representing the locations of a pair of animals or plants) appear in the same patch of non-fragmented natural cover of land (Jaeger, 2000). Following Jaeger (2000)'s notation, the effective mesh size, M , is obtained by multiplying the total area of the 5 km radius buffer around the centroid of each protected parcel, A_t , by the probability, P , that a pair of animals or plants located randomly in the 5 km radius buffer are present in the same contiguous patch of protected area within the buffer²:

$$M = A_t \cdot P = \frac{1}{A_t} \sum_{j=1}^n A_j^2, \quad (3)$$

where $P = \sum_{j=1}^n \left(\frac{A_j}{A_t}\right)^2$, and A_j = size of patch j ($j = 1, \dots, n$) of protected area within the 5 km radius buffer.

A buffer with a radius of 5 km is used for the measure of effective mesh size because it is the average separation protocol to convert animal survey data (i.e., an individual of a targeted species seen in a particular location) into more meaningful element occurrences (i.e., historic presence and recurrence of a targeted species at a given location) (Nature Serve, 2002). Other measures of initial stock of conservation benefit (i.e., weighted species richness and percentage of the landscape already protected) followed the same 5 km radius buffer to be consistent with the measure of effective mesh size.

² The probability that only one individual of a species is located in A_t is $\frac{A_j}{A_t}$. Therefore, P is the probability that two animals or plants will be in the same parcel where $\frac{A_j}{A_t} \cdot \frac{A_j}{A_t} = \left(\frac{A_j}{A_t}\right)^2$. See Supplementary Materials S2.2 to see how effective mesh size is calculated using probabilities.

By multiplying the total area of the landscape by the probability of two individuals of the same species being located together, the effective mesh size can be interpreted as the expected size of the habitat that is accessible to the individuals without encountering a physical barrier. The change in M depends on M before the TNC acquisition and the size and distribution of protected areas established before the TNC acquisition. (See Supplementary Materials S2.1 for a numerical example of the change in M for adjacent and non-adjacent acquisitions.) The conservation benefit measurement Y_B used in equation (2) is then calculated by estimating equation (3) twice: the landscape with the presence of the parcel and the landscape without the parcel. These two measurements are subtracted from one another to create the change in effective mesh size for each parcel landscape such that:

$$M_A - M_B = Y_B, \quad (4)$$

where M_A is the effective mesh size after acquisition, M_B is the effective mesh size before acquisition, and Y_B is conservation benefit used in equation (2). While conservation benefit is defined as the change in effective mesh size from the introduction of one parcel in the landscape according to the way the variable is calculated in equation (4), Y_B , the change in effective mesh size is always positive. This magnitude, however, will vary according to the size of the new parcel and the amount of existing protected area in the landscape, M_B .

The weighted species richness variable is calculated as part of the initial stock of conservation benefit. The variable is based on element occurrences in Geographic Information Systems (GIS) form that are downloaded from the Biodiversity Information Serving Our Nation (BISON) database (USGS, 2014). Element occurrences of 328 target species were chosen. Targeted species are species listed as high level conservation concerns according to the ecoregional portfolios created by TNC (USGS, 2014) were chosen. Using the downloaded

database, element occurrences of species of conservation concern within each of the 5 km radius buffers prior to the TNC acquisitions (referred to as “target species richness”) were spatially aggregated. Then, the weighted species richness variable was created by multiplying target species richness by the quotient of the size of the protected parcel and the total area of the landscape, or the 78.5 km² within the buffers.

3.3. Model Estimation

In estimating equation (2), Y_B , the change in effective mesh size, is hypothesized to be an endogenous variable. The percentage of protected area within the 5 km radius buffer prior to TNC acquisition and the size of the protected area are used as instruments for the endogeneity test of B . These instruments were tested for validity using three identification tests: under-, weak-, and over-identification. In the under-identification test, Anderson’s (1951) Lagrange Multiplier statistic of 35.68 suggested that the instruments are identified at the 5% significance level. (The 5% level is identified as significant throughout the manuscript.) Cragg-Donald’s (1993) Wald statistic of 17.72 for the weak-identification test suggested that the instruments are not weak. Sargan’s (1958) statistic of 5.22 for the over-identification test implied failure to reject the null hypothesis that the instruments are uncorrelated with the error term. Methods to obtain instruments are described in Supplementary materials S2.3 Two Stage Least Squares Model.

Given the endogeneity test results, a two-stage, instrumental variable regression model with an endogenous variable was used. Predicted quantities of conservation benefit and acquisition cost were then used to predict ROI (i.e., conservation benefit/acquisition cost). Specifically, conservation ROI for each acquired parcel under the observed protected area size was calculated by dividing $\widehat{Y}_B$, the predicted change in effective mesh size, by $\widehat{Y}_C$, the predicted

acquisition cost, in equation (2). The predicted ROIs on parcel size was then regressed to estimate the overall effect of protected area size on predicted ROI. Here, predicted ROI was used instead of observed ROI based on the amount of information that could be observed by TNC. By using predicted ROI, any factors that are not included in the regression (i.e., equation (2)) are assumed to be unobservable to TNC (just as they are to the researcher). Thus, TNC is assumed to make its prioritization decisions based on predicted ROI, absent information on the unobserved factors. Finally, the parcels for protection are ranked based on predicted ROI versus based on predicted change in effective mesh size only. Then, correlation between each of the two rankings and parcel size are examined to understand the difference in the highest priorities for protection in relation to the parcel size variation.

4. Data

For this regression analyses, six data sets were used: TNC acquisition data for the fee simple transactions, landscape data for the effective mesh size, data for geophysical characteristics, data for distance-related variables, data for socioeconomic characteristics, and target species richness data for the weighted species richness variable. The TNC acquisition data were obtained from TNC documents that contain information regarding contract type, acquisition cost, parcel size, and location (TNC, 2000; TNC, 2001; TNC, 2003).

The effective mesh size variables (i.e., effective mesh size before and after TNC acquisition) and percentage of the protected area prior to TNC acquisition were calculated through FRAGSTATS software (McGarigal et al., 2012). The 5 km radius buffer was drawn around each of the 82 protected area centroids to create 82 separate landscapes. First, the centroid of each protected area parcel was identified. Next, a buffer was drawn to create an area of 78.5 km² around each central point. The existing protected areas within a landscape were

downloaded from the Protected Areas Database of the United States (PAD-US) (USGS, 2012). Two maps of protected areas were created using GIS software ArcMap version 10.2 (ESRI, 2012) for each protected area landscape: one immediately prior to TNC acquisition and one immediately after. These maps were then exported into FRAGSTATS where effective mesh size and percentage of protected area within each landscape were calculated. The effective mesh size tables were exported into Excel where effective mesh size before acquisition was subtracted from effective mesh size after acquisition to create the change in effective mesh size variable.

The data for geophysical characteristics (i.e., average slope and elevation) were obtained from the 30-meter Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) Version 2 (V2) (NASA JPL, 2011). Using the data and the Zonal Statistics tool in ArcGIS 10.1 (ESRI, 2012) based on raster grids, the average slope and elevation of the 82 protected areas were calculated. The data for distance-related variables were created using the Near Analysis tool in ArcGIS 10.1 (ESRI, 2012). These variables represent the proximity between parcel centroids and the centroids of the nearest cities with a population of 10,000 or more, or the proximity between parcel centroids and the distance to the nearest water body, park, or major highway. Shapefiles of the cities, water bodies, parks, and major highways were acquired from ESRI Data & Map 10 (ESRI, 2011) and shapefiles of the parcels were obtained from TNC (TNC, 2000; TNC, 2001; TNC, 2003).

The data for socioeconomic characteristics (i.e., population and median household income) were obtained from the 2000 US Census and the 2007 US Census (US Census Bureau, 2000; US Census Bureau, 2007). The 2000 and 2007 census-block group data were assigned to all transactions within a census-block group made during the periods of 2000–2006 and 2007–2009, respectively, to capture either current or lagged socioeconomic effects on acquisition cost.

The weighted species richness variable was calculated using TNC's target species data. Lists of targeted species were obtained through TNC ecoregional plans (TNC, 2000; TNC, 2001; TNC, 2003).

5. Empirical Results

The regression results of the system of equations suggest that 62% of the variability observed in the change in effective mesh size can be explained by the covariates in the conservation benefit equation. Additionally, about 73% of the variability observed in the acquisition cost can be explained by the covariates in the acquisition cost equation. In the conservation benefit equation, the coefficient of protected parcel size was 1.19 and significant, suggesting that a 1% increase in a protected parcel size increases its change in effective mesh size due to TNC acquisition by 1.19% (see Table 2.3). In the acquisition cost equation, the coefficient for change in effective mesh size was 0.61 and significant, suggesting that a 1% increase in the change in the effective mesh size of a protected parcel increases its acquisition cost by 0.61%. These results suggest that, while both effective mesh size and acquisition cost increase due to an increase in protected area size, the changes in effective mesh size increase proportionally more than the increase in acquisition cost.

As a result of the greater effects of protected parcel size on effective mesh size, while both effective mesh size and acquisition cost increase due to protected area size, the numerator of ROI increases proportionally more than the denominator of ROI. Consequently, these results yield greater increases in ROI for larger parcels than for smaller ones. Figure 2.2 shows that a 1% increase in protected area size significantly increases ROI by 0.54 %. These results suggest that when comparing candidate parcels for protected area creation, all else being equal, conservation organizations have an incentive to favor larger parcels over smaller ones.

As a consequence of the proportionally greater effects of protected parcel size on the changes in effective mesh size than on the increase in acquisition cost, the parcels' ranking for protection based on ecological benefit is dominated by protected area size more than the parcels' ranking in terms of conservation ROI. As evidence, the correlation coefficients between rankings for protection (i.e., integer ranking values between 1 and 82) and natural log of protected area size in km² are -0.89 and -0.63, respectively, for the rankings based on ecological benefit and conservation ROIs. These findings imply that, given the incentive to favor larger parcels over smaller ones based on both rankings, if conservation organizations focus on ecological effectiveness, they tend to favor larger parcels more than if they focus on both ecological and economic effectiveness.

To reaffirm the relationship between parcel size and the two rankings, the 82 parcels were sorted into three groups according to comparative rankings between the two parcels' rankings based on ecological benefit and conservation ROI. Among the 82 protected parcels, 33 parcels have lower rankings using the ROIs (referred to as "Group 1"), 27 parcels have higher rankings using ROIs (referred to as "Group 2"), and 22 rankings remain unchanged. The average protected area size for Group 2 (21.76 km² on average) is much smaller than that of Group 1 (182.02 km² on average). These findings reaffirm that larger parcels are perceived to be favorable to conservation organizations if ranking for protection is based on benefit only and relatively smaller parcels are perceived to be favorable if ranking is based on both benefit and cost.

Table 2.3 also reports parameter estimates of other factors from the conservation benefit and acquisition cost equations. In the conservation benefit equation, the coefficient for the percentage of 5 km radius landscape already covered in protected area is significant and positive.

This finding suggests that an increase of the percentage of existing protected area surrounding a protected parcel increases the effective mesh size in the area surrounding the protected parcel.

6. Conclusions

Protected area size maintains an important role in efforts to prioritize areas for protection. I examine how protected area size influences ecological and economic effectiveness and how the subsequent changes in ecological and economic effectiveness alter prioritization for protection. To do that, a uniquely comprehensive dataset provided by TNC was used that details acquisition costs of protected areas and the change in effective mesh size that measures conservation benefit and encapsulates TNC's conservation planning strategies. Using these measures, a regression framework was developed to assess how variations in protected parcel size influence the change in effective mesh size and how that change in effective mesh size alters the parcel's acquisition cost. Using the results from the regression model, the predicted ROIs were then regressed on parcel size to estimate the overall effect of protected area size on predicted ROI. Then, sites for protection were ranked based on conservation ROI and based on ecological benefit only.

The increase in effective mesh size per dollar invested to acquire a parcel was found to be greater for larger parcels than for smaller parcels, implying that the overall ecological and economic effectiveness is higher in protecting larger areas relative to smaller ones. This finding is consistent with previous literature: better ecological effectiveness and better economic effectiveness of larger protected areas than smaller ones occur when they are estimated separately. Recognizing that protected areas of different sizes may protect different species, better ecological and economic effectiveness of protection for larger parcels based on this finding does not mean that larger parcels necessarily provide a better deal for conservation. However, quantifying the influence of protected area size on the increase in effective mesh size

per dollar invested to acquire a parcel, provides a benchmark for evaluating the ecological and economic effectiveness of protected areas. When comparing between candidate parcels for protected area creation, all else being equal, conservation organizations have an incentive to favor larger parcels over smaller ones.

Given the incentive to favor larger parcels over smaller ones, all else being equal, an additional finding is that if conservation organizations focus on ecological effectiveness, they tend to favor larger parcels more than if they focus on both ecological and economic effectiveness. This finding is due to the parcels' ranking for protection based on ecological benefit being dominated by protected area size more than the parcels' ranking based on conservation ROI being dominated by it. The difference in the relative dominance is caused by the proportionally greater effects of protected parcel size on the change in effective mesh size than on acquisition cost.

In conclusion, the impact of this research relevant for conservation planning is that larger parcels exhibit greater ecological and economic effectiveness. Conservation benefit per additional km² of protected area increases at a higher rate than the increase of acquisition cost per additional km² of protected area. Thus, all else being equal, the acquisition of parcels of larger size is an advisable conservation strategy. Further, the degree of preference for larger parcels is greater if the priority decision is based on conservation benefit only rather than if it is done based on conservation benefit per unit invested. Therefore, the conservation priority decision will be biased toward larger parcels if conservation organizations are interested in achieving ecological and economic effectiveness, yet their decisions are based on conservation benefit only instead of based on conservation ROI.

Although this case study provides useful research that examines the relationship between the size of protected areas and ecological and economic effectiveness in relation to prioritization when decision making for protection, the relationship is established based on change in effective mesh size as a quantitative measure of conservation benefit. The change in effective mesh size was chosen because landscape contiguity is a crucial factor in maintaining many ecological processes and services and TNC emphasizes landscape contiguity as one of the important motivations behind its acquisition practices. However, under the given objective, what ecological indicators should be used as well as how they should be measured and over what scales are still open for debate. Therefore, an improvement from the current research can be made by duplicating the same analysis for different ecological benefit metrics as a sensitivity analysis.

References

- Adams, V. M., R. L. Pressey, and R. Naidoo. 2010. "Opportunity costs: Who really pays for conservation?" *Biological Conservation* 143(2):439– 448
- Andam, K. S., P. J. Ferraro, A. Pfaff, G. A. Sanchez-Azofeifa, and J.A. Robalino. 2008. "Measuring the effectiveness of protected area networks in reducing deforestation." *Proceedings of the National Academy of Sciences, USA* 105(42):16089–16094.
- Andam, K., P. Ferraro, K. Sims, A. Healy, and M. Holland. 2010. "Protected areas reduced poverty in Costa Rica and Thailand." *Proceedings of the National Academy of Sciences of the United States of America* 107(22): 9996–10001.
- Ando A., J. Camm, S. Polasky, and A. Solow. 1998. "Species distributions, land values, and efficient conservation." *Science*. 279(5359):2126-2128.
- Anselin, L. 1988. *Spatial Econometrics: Methods and Models*. Kluwer Academic Publishers, Dordrecht.
- Anselin, L, and N. Lozano-Gracia. 2008. "Errors in variables and spatial effects in hedonic house price models of ambient air quality." *Empirical Economics* 34(1): 5–34
- Armenteras, D., F. Gast, and H. Villareal. 2003. "Andean forest fragmentation and the representativeness of protected natural areas in the eastern Andes, Colombia." *Biological Conservation* 113(2): 245-256.
- Armsworth, P.R., L. Cantu-Salazar, M. Parnell, Z.G. Davies, and R. Stoneman. 2011. "Management costs for small protected areas and economies of scale in habitat conservation." *Biological Conservation* 144(1): 423-429.
- Armsworth P.R. 2014. "Inclusion of costs in conservation planning depends on limited datasets and Hopeful assumptions." *Annals of the New York Academy of Sciences* 1322(1):61-76.

- Ayan, E., and H.C. Erkin, 2014. "Hedonic Modeling for a Growing Housing Market: Valuation of Apartments in Complexes." *International Journal of Economics and Finance* 6(3):188–199.
- Balmford, A., K.J. Gaston, A.S.L. Rodrigues, and A. James. 2000. "Integrating costs of conservation into international priority setting." *Conservation Biology* 14(3):597–605.
- Balmford, A, K.J. Gaston, S. Blyth, A. James, and V. Kapos. 2003. "Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs." *Proceedings of the National Academies of Sciences of the United States of America* 100(3):1046-1050.
- Bender, D., T. Contreras, and L. Fahrig. 1998. "Habitat loss and population decline: a meta-analysis of the patch size effect." *Ecology* 79: 517–533.
- Boyd, J., R. Epanchin-Niell, and J. Siikamaki. 2015. "Conservation Planning: A Review of Return on Investment Analysis." *Review of Environmental Economics and Policy* 9(1):23-42.
- Carwardine, J., K.A. Wilson, G. Ceballos, P.R. Ehrlich, R. Naidoo, T. Iwamura, S.A. Hajkowicz, and H.P. Possingham. 2008a. "Cost-effective priorities for global mammal conservation." *Proceedings of the National Academy of Sciences of the United States of America* 105(32):11446.
- Carwardine, J., K.A. Wilson, M. Watts, A. Etter, C.J. Klein, and H.P. Possingham. 2008b. "Avoiding costly conservation mistakes: the importance of defining actions and costs in spatial priority setting." *PLoS One* 3(7): 2586.
- Dana, A., Ramsey, M. 1989. "Conservation Easements and the common law." *Stanford Environmental Law Journal* 8(2) 2-45.

- Debinski, D., Holt, R. 2000. "A survey and overview of habitat fragmentation experiments." *Conservation Biology*. 14 342–355.
- Diamond, D. 1975. "The island dilemma: lessons of modern biogeographic studies for the design of Natural reserves." *Biological Conservation* 7(2): 129-136.
- Eagle, J. 2011. "Notional generosity: explaining charitable donors' high willingness to part with Conservation Easements. *Harvard Environmental Law Review* 35(1): 47-90.
- ESRI. Data Maps For ArcGIS (2011), p. 10
- ESRI. ArcGIS Help 10.1: Spatial Analyst Toolsets, ArcGIS Resources Internet site:
<http://www.esri.com/> (Accessed April 12, 2013)
- Ferraro, P.J. 2003. "Conservation contracting in heterogeneous landscapes: an application to watershed protection with threshold constraints. " *Agricultural and Resource Economics Review* 32(1): 53-64.
- Ferraro, P.J., M.M. Hanauer, and K.R.E. Sims. 2011. "Conditions associated with protected area success in conservation and poverty reduction." *Proceedings of the National Academies of Sciences of the United States of America* 108(34): 13913–13918.
- Fisburn, I., P. Kareiva, K. Gaston, and P. Armsworth. 2009. "The Growth of Easements as a Conservation Tool." *PLoS One* 4(3): 1-6.
- Frazee, S.R., R.M. Cowling, R.L. Pressey, J.K. Turpie, and N. Lindenberg. 2003. "Estimating the costs of conserving a biodiversity hotspot: a case study of the Cape Floristic Region, South Africa." *Biological Conservation* 112(2): 275–290.
- Game, E. 2013. "Identifying Conservation Priorities using a Return on Investment Analysis." *Encyclopedia of Biodiversity*, second edition, Volume 4, S. Levin, ed., Waltham, MA: Academic Press.

- Gao, J. and S. Li. 2011. "Detecting spatially non-stationary and scale-dependent relationships between urban landscape fragmentation and related factors using Geographically Weighted Regression." *Applied Geography* 31(1): 292-302.
- Hernandez-Marique, O., D. Sanchez-Fernandez, J. Verdu, C. Numa, E. Galante, and J. Lobo. 2012. "Using local autocorrelation analysis to identify conservation areas: an example considering threatened invertebrate species in Spain." *Biodiversity and Conservation* 21(9):2127-2137.
- Higgs, A.J. 1981. "Island biogeography theory and nature reserve design." *Journal of Biogeography* 8(2):117-124.
- Jaeger, J. 2000. "Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation." *Landscape Ecology* 15(2):115-130
- James, A.N, K.J. Gaston, and A. Balmford. 2000. "Integrating costs of conservation into international Priority setting." *Conservation Biology* 14(3):597-605.
- Joppa, L. N. and A. Pfaff. 2009. "Global protected area impacts." *Proceedings of the Royal Society* 278:1633–1638.
- Kareiva, P., C. Groves, and M. Marvier. 2014. "The evolving linkage between conservation science and practice at The Nature Conservancy." *Journal of Applied Ecology* 51(5):1137-1147.
- Kark, S., N. Levin, H.S. Grantham, and H.P. Possingham. 2009. "Between-country collaboration and consideration of costs increase conservation planning efficiency in the Mediterranean Basin." *Proceedings of the National Academy of Sciences* 106(36): 15368
- Kelejian, H.H. and I.R. Prucha. 1999. "A generalized moments estimator for the autoregressive parameter in a spatial model." *International Economic Review* 40(2):509–533.

- Kim, T, Cho, S.H., Larson, E.R., and P.R. Armsworth. 2014. "Protected area acquisition costs show economies of scale with area." *Ecological Economics* 107(1):122-132.
- Kruse, S.A. and J. Ahmann. 2009. "The value of lake adjacency: a hedonic pricing analysis on the Klamath river, California." Working Paper Series No. 5. Ecotrust.
- Kukkala, A., and A. Moilanen. 2013. "Core concepts of site prioritization in systematic conservation planning." *Biological Reviews* 88(2):443-464.
- Lahti, T., and E. Ranta. 1985. "The SLOSS principle and conservation practice: an example." *Oikos* 44(3):369-370.
- Lennox, G.D. and P.R. Armsworth. 2013. "The ability of landowners and their cooperatives to gain surplus from conservation contracts: worst-case scenarios, auctions and conservation objectives." *Conservation Biology* 27(3):625-634.
- Lennox, G.D., M. Dallimer, and P.R. Armsworth. 2012. "Landowners' ability to leverage in negotiations over habitat conservation." *Theoretical Ecology* 5(1):115-128.
- Llausas, A. and J. Nogue. 2012. "Indicators of landscape fragmentation: The case for combining ecological indices and the perceptive approach." *Ecological Indicators* 15(1): 85-91.
- McConnell, V. and M. Walls. 2005. "The Value of Open Space: Evidence from Studies of Nonmarket Benefits." Resources for the Future, Washington D.C.
- McGarigal, K., SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Internet site: <http://www.umass.edu/landeco/research/fragstats/fragstats.html> (Accessed May 15, 2015)
- Merenlender, A., L. Huntsinger, G. Guthey, and S. Fairfax. 2004. "Land Trusts and Conservation Easements: Who Is Conserving What for Whom?" *Conservation Biology* 18(1): 65-75

- Messer, K.D. 2006. "The conservation benefits of cost-effective land acquisition: A case study in Maryland." *Journal of Environmental Management* 79(3):305-315.
- Moore, J., A. Balmford, T. Allnut, and N. Burgess. 2004. "Integrating costs into conservation planning across Africa." *Biological Conservation* 117(3):343-350.
- Mueller, J.M., and J.B. Loomis. 2008. "Spatial Dependence in Hedonic Property Models: Do Different Corrections for Spatial Dependence Result in Economically Significant Differences in Estimated Implicit Prices?" *Journal of Agricultural and Resource Economics* 33(2): 212–231.
- Murdoch, W., S. Polasky, K.A. Wilson, H.P. Possingham, P. Karieva, and R. Shaw. 2007. "Maximizing return on investment in conservation." *Biological Conservation* 39(3-4):375-388.
- Murdoch W., J. Ranganathan, S. Polasky, and J. Regetz. 2010. "Using return on investment to Maximize conservation effectiveness in Argentine grasslands." *Proceedings of the National Academy of Sciences* 107(49):855-862.
- Naidoo R., A. Balmford, P. Ferraro, S. Polasky, T. Ricketts, and M. Rouget. 2006. "Integrating economic costs into conservation planning." *Trends in Ecology and Evolution* 21(12):681-87.
- Naidoo, R. and T. Iwamura. 2007. "Global-scale mapping of economic benefits from agricultural lands: implications for conservation priorities." *Biological Conservation* 140(1-2):40-49.
- Naidoo, R. and T. Ricketts. 2006. "Mapping the economic costs and benefits of conservation." *PLoS Biology* 4(1):2153-2164.
- National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA JPL). 2011.

“ASTER Global Digital Elevation Map Announcement.”

<http://asterweb.jpl.nasa.gov/gdem.asp>

Nature Serve. 2002. “Element Occurrence Data Standard.”

http://downloads.natureserve.org/conservation_tools/element_occurrence_data_standard.pdf

Newburn, D.A., P. Berck, and A. M. Merenlender. 2006. “Habitat and open space at risk of landuse conversion: targeting strategies for land conservation.” *American Journal of Agricultural Economics* 88(1):28-42.

Nhancale, B. and R. Smith. 2011. “The influence of planning unit characteristics on the efficiency and spatial pattern of systematic conservation planning assessments.” *Biodiversity and Conservation* 20(8): 1821-1835.

Noss, R.F. 2001. “Forest Fragmentation in the Southern Rocky Mountains.” *Landscape Ecology* 16(4):371-372.

Polasky S., J.D. Camm, and B. Garber-Yonts. 2001. “Selecting biological reserve cost-effectively: an application to terrestrial vertebrate conservation in Oregon.” *Land Economics* 77(1):68-78.

Polasky, S., Lewis, D., A. Plantinga and E. Nelson. 2009. “Implementing the optimal provision of ecosystem services.” *Proceedings of the National Academy of Sciences* 111(2009): 6248-6253.

Salafsky, N., and R. Margoulis. 1998. “Measures of success: designing, managing, and monitoring conservation and development projects.” Washington, DC: Island Press.

Simberloff, D. S. and L. G. Abele. 1982. “Refuge design and island biogeographic theory - effects of fragmentation.” *American Naturalist* 120(1):41-56.

Sims, K. 2010. “Conservation and development: Evidence from Thai protected areas.” *Journal of*

- Environmental Economics and Management* 62(1):94-114.
- Snyder, S.A., Kilgore, M.A., Hudson, R., and J. Donnay. 2007. "Determinants of forest land prices in Northern Minnesota: a hedonic pricing approach." *Forest Science* 53(1):25–36.
- Sutton, N. and P. Armsworth. 2014. "The Grain of Spatially Referenced Economic Cost and Biodiversity Benefit Data and the Effectiveness of a Cost Targeting Strategy." *Conservation Biology* 28(6):1451-1461.
- Tear, T., B.N. Stratton, E.T. Game, M.A. Brown, C.D. Apse and R.R. Shirer. 2014. "A return-on-investment framework to identify conservation priorities in Africa." *Biological Conservation* 173(1):42-52.
- The Nature Conservancy. 2000. Southern blue ridge ecoregional conservation plan. Technical report, The Nature Conservancy and the Southern Appalachian Forest Coalition.
- The Nature Conservancy. 2001. Central Appalachian forest ecoregional plan. Technical report. The Nature Conservancy.
- The Nature Conservancy. 2003. The Cumberlands and Southern Ridge and Valley ecoregion: A plan for biodiversity conservation. Technical report. The Nature Conservancy.
- US Census Bureau. Census 2000 Summary File 3 (SF 3). Generated by Dr. Tae-young Kim. using American FactFinder. Internet site: <http://factfinder2.census.gov>. (accessed February 15, 2013).
- US Census Bureau. TIGER/Line Shapefile. American Community Survey 5-year estimates. 2007-2011. Internet site: <http://census.gov/geo/maps-data/tiger-data.html> (accessed February 15, 2013).
- Underwood, E.C., M.R. Shaw, K.A. Wilson, P. Kareiva, K.R. Klausmeyer, M.F. McBride, M.

- Bode, S.A. Morrison, J.M. Hoekstra, and H.P. Possingham. 2008. Protecting biodiversity when money matters: maximizing return on investment. *PLoS One* 3(1): e1515.
- United States Geological Survey (USGS). Biodiversity information serving our nation database. (BISON). Washington, D.C. Internet site: <http://www.bison.ornl.gov> (accessed August 20, 2013).
- United States Geological Survey (USGS). Gap Analysis Program (GAP). Protected Areas Database of the United States (PADUS), version 1.3. (accessed November 10, 2012).
- Wiens, J. 2009. "Landscape ecology as a foundation for sustainable conservation." *Landscape Ecology* (2009) 24:1053–1065
- Wiens, J. and D. Bachelet. 2014. "Matching the Multiple Scales of Conservation with the Multiple Scales of Climate Change." *Conservation Biology* 24, 51-62.
- Wilson, K. A., J. Carwardine, and H. P. Possingham. 2009. "Setting conservation priorities." *Annals of the New York Academy of Sciences* 1162, 237–64.
- Wooldridge, J.M. 2010. *Econometric Analysis of Cross Section and Panel Data* 2nd ed. MIT Press, Cambridge, MA, 201

Appendix

Table 2.1. Variable Definitions and Descriptive Statistics (n = 82)

Variables	Definition	Mean (Std Dev)
<i>Dependent variables</i>		
Acquisition cost	Acquisition cost of protected area (2000 US dollar)	424,414.08 (849,426.70)
Change in effective mesh size	Difference between the effective mesh size within a 5 km radius buffer around the centroid of a protected parcel after and before acquisition (kilometer ²)	24.02 (68.21)
<i>Geophysical variables</i>		
Protected area size	Size of protected area (kilometer ²)	108.82 (233.08)
Average slope	Average slope (degree)	12.53 (7.08)
Average elevation	Average elevation (meter)	519.87 (287.25)
<i>Distance-related variables</i>		
Proximity to city	Distance to nearest major city with 10,000 or more population (kilometer)	26.52 (11.65)
Proximity to water body	Distance to nearest water body (kilometer)	17.51 (11.00)
Proximity to park	Distance to nearest state or national park (kilometer)	6.94 (5.87)
Proximity to major highway	Distance to nearest interstate or state highway (kilometer)	2.79 (2.11)
<i>Socioeconomic variables</i>		
Population	Population within census block-group	1,361.39 (575.45)
Median household income	Median household income within census block-group (2000 US dollar)	35,570.76 (9,258.60)
<i>Initial stock of conservation benefit</i>		
Weighted species richness	Target species richness multiplied by the quotient of the size of the protected parcel and the 5 km buffer	0.007 (5.311)
Effective mesh size before acquisition	Effective mesh size before acquisition of the protected area (kilometer ²)	225.41 (532.38)
Percentage of protected area prior to acquisition	Percentage of 5 km buffer that is protected area before acquisition (percentage)	12.64 (13.04)

Table 2.2. Parameter Estimates from Two Stage Model

Variables	Change in Effective Mesh Size	Acquisition Cost
Constant	-4.391 (3.754)	11.983 (6.380)
Change in effective mesh size	-----	0.134 (0.208)
<i>Geophysical variables</i>		
Protected area size	1.185* (0.196)	0.615* (0.279)
Average slope	-0.010 (0.083)	-0.042 (0.040)
Average elevation	-0.179 (0.424)	0.001 (0.192)
<i>Distance-related variables</i>		
Proximity to city	0.371 (0.467)	-0.400 (0.255)
Proximity to water body	-0.409 (0.325)	-0.303 (0.166)
Proximity to park	-0.008 (0.054)	0.018 (0.024)
Proximity to major highway	0.318 (0.200)	-0.150 (0.115)
<i>Socioeconomic variables</i>		
Population	-----	0.499 (0.279)
Median household income	-----	-0.363 (0.497)
<i>Initial stock of conservation benefit</i>		
Weighted species richness	0.063 (0.219)	-0.009 (0.093)
Effective mesh size before acquisition	0.021 (0.156)	0.031 (0.070)
Percentage of protected area prior to acquisition	0.830* (0.407)	-----
Adjusted R ²	0.623	0.731
AIC	362.526	221.260

Note: Numbers in parentheses are standard errors, and * denotes significance at the 5% level.

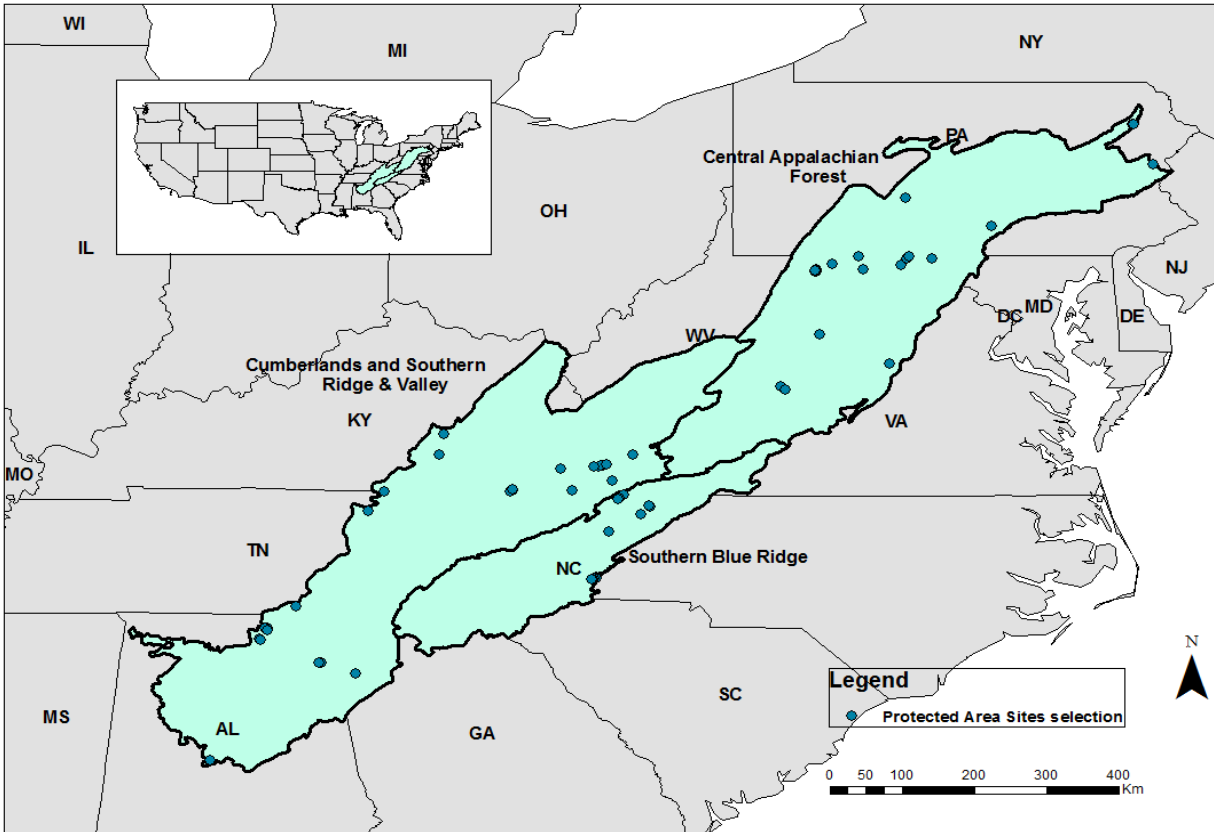


Figure 2.1. 82 Fee Simple Transactions Made by TNC in Central and Southern Appalachian Forest Ecosystems during 2000-2009

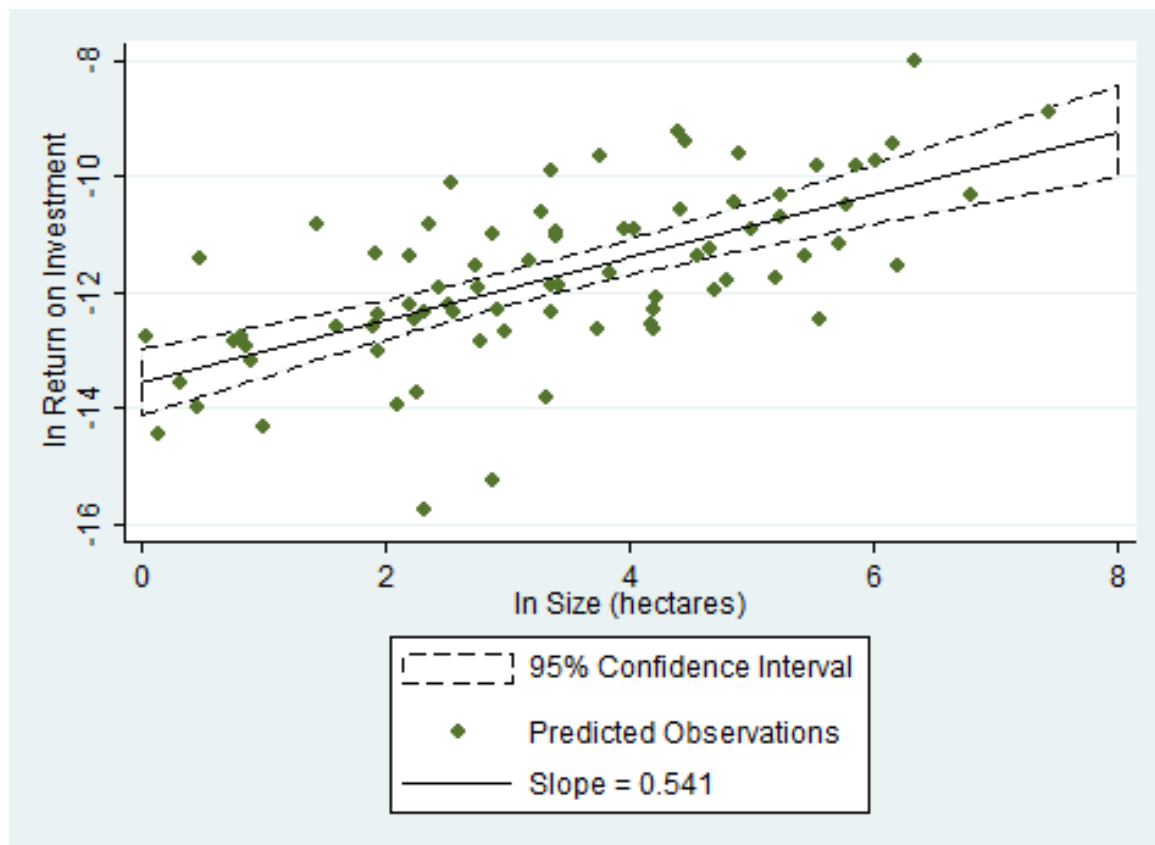


Figure 2.2. Empirical Results – ROI Regressed on Protected Area Size

Supplementary Materials

S2.1. Numerical Example of Change in Effective Mesh Size with Adjacent and Non-Adjacent Acquisitions

Suppose Figure 2.3 illustrates a sample landscape before TNC acquisition where protected areas are 1 km^2 and 1 km^2 in size and the total area of the landscape is 5 km^2 . Here, the effective mesh size is $(1^2 + 1^2)/5 = 0.40 \text{ km}^2$.

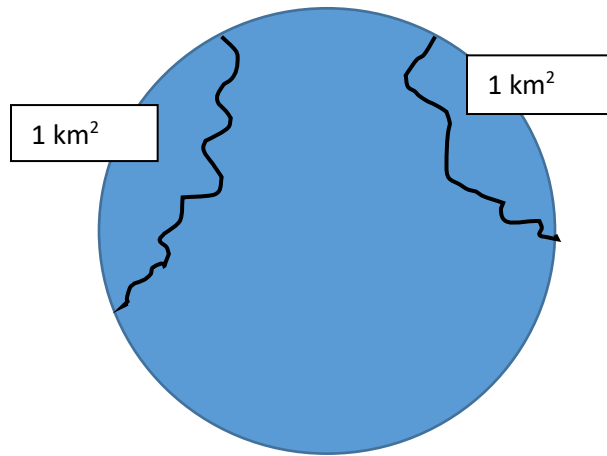


Figure 2.3. Sample Landscapes before TNC Acquisition

Now, suppose TNC acquired an additional 1 km^2 for the case of a small increase in effective mesh size (left in Figure 2.4) and a large increase in effective mesh size (right in Figure 2.4).

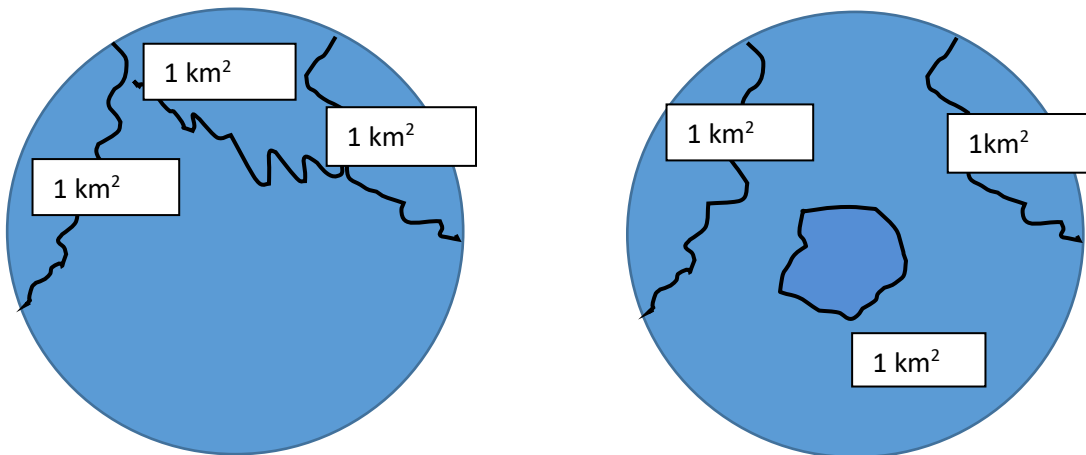


**Figure 2.4.
Sample Landscapes after TNC Acquisition**

The effective mesh size for the cases of connected parcel acquisitions and non-connected parcel acquisitions are, respectively, $((1+1+1)^2)/5 = 1.8 \text{ km}^2$ and $(1^2 + 1^2 + 1^2)/5 = 0.6 \text{ km}^2$. The change in effective mesh size for the case of an acquisition that connects previously established protected areas is much larger (i.e., $1.8 \text{ km}^2 - 0.40 \text{ km}^2 = 1.4 \text{ km}^2$) than the change in effective mesh size for the case of an acquisition that does not connect established protected areas (i.e., $0.60 \text{ km}^2 - 0.40 \text{ km}^2 = 0.20 \text{ km}^2$). As illustrated in this numerical example, the effective mesh size will increase with the acquisition of a new protected area, and will increase more when a new protected area can physically connect with other protected areas already in the landscape.

As shown in Figure 2.4 above, the change in effective mesh size related to a parcel that is completely detached from the other protected areas is exceptionally small, thereby bringing down the overall average patch size and decreasing the likelihood that two individuals dropped randomly into habitat in the landscape would be in the same patch.

S2.2. Calculation of Effective Mesh Size using Probabilities

Given the sample landscapes in Figure 2.3, the effective mesh size is 2.2 km^2 (i.e. $(1^2 + 1^2 + 3^2)/5 = 2.2 \text{ km}^2$) using the second part of equation (3), $M = \frac{1}{A_t} \sum_{j=1}^n A_j^2$. Alternatively, the effective mesh size can be calculated by multiplying the total area by the probability of two individual animals or plants being in the same parcel using the first part of equation (3), $M = A_t \cdot P$. In this application, the following logic is used to calculate the effective mesh size. The probabilities of one animal being in parcels A_1 , A_2 , and A_3 are $\frac{1}{5}$, $\frac{1}{5}$, and $\frac{3}{5}$, respectively. Then, the probabilities of two animals being in parcels A_1 , A_2 , and A_3 are $\frac{1}{25}$, $\frac{1}{25}$, and $\frac{9}{25}$, respectively. Consequently, the total probability of two animals being in the same parcel in this landscape is

the sum of two animals being in parcels A_1 , A_2 and A_3 (i.e., $\frac{1}{25} + \frac{1}{25} + \frac{9}{25} = \frac{11}{25}$). To convert this probability to effective mesh size, this total probability is multiplied by total landscape size (i.e. $\frac{11}{25} \times 5 \text{ km}^2 = 2.2 \text{ km}^2$). This numerical exercise shows how the effective mesh size represents the conversion of total probability of two animals being in the same parcel in a given landscape into the size of connected habitat necessary for species survival.

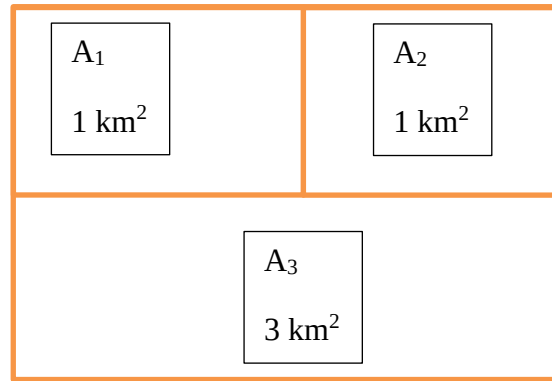


Figure 2.5. Sample Landscape Where Divided Areas Represents Parcels (i.e., A_1 , A_2 , and A_3)

S2.3. Two Stage Least Squares Model

In the first stage of the two stage least squares model in equation (2), B is regressed on a set of instruments that consists of exogenous variables S and Z (referred to as “reduced form equation”) to predict $\hat{B}$. Equation (2) is re-estimated using Ordinary Least Squares (OLS) after substituting the predicted values from the reduced form equation $\hat{B}$. The corrected standard errors for the acquisition cost equation are calculated as $V_e(\Phi') = \hat{\sigma}^2[X'X]^{-1}$ where $\hat{\sigma}^2 = \varepsilon'\varepsilon/(N - K_1)$, N is the number of observations, K_1 is the number of variables in the vector of exogenous and predetermined variables X in the second-stage cost equation and $\varepsilon = C - \Sigma B + X\Phi$ (Wooldridge, 2002, p. 100).

Chapter 3: Effects of Parcel Size on Conservation Return on Investment for Protected and Unprotected Matching Sites

Abstract

Despite the findings of the scale effects with protected area size on conservation benefit and cost, when these effects are evaluated separately, little research has evaluated them in a single framework. In addition, no research has compared the scale effects with protected area size with those for unprotected areas. The comparison of the scale effects between protected and unprotected areas using ROI as a single framework helps evaluate the influence of protected area size on the ecological and economic effectiveness between fine- and coarse-filter conservation targets relative to that of the wider land market.

Given the gap in the literature and its importance, this research seeks to examine how protected area size influences their ecological and economic effectiveness, as measured by ROI, and how these effects compare to those of unprotected areas. Formally, the elasticity of conservation ROI with respect to protected area is examined to determine whether significance is greater than zero, as well as if it differs from that of the unprotected areas. If conservation benefit increases at a faster rate than conservation cost increases, ROI increases with size, reflecting positive scale effects with protected area size on ROI. The elasticity of size on conservation ROI for protected areas is also tested to determine whether the difference from the elasticity of size on conservation ROI is significant for comparable unprotected areas. These determinations will help conservation organizations account and plan for variation in the protected area size relative to conservation benefit and cost of protecting land toward ensuring more efficient prioritization decisions.

The elasticity of parcel size on conservation ROI was found to be positive and significant, suggesting that as parcel size grows, ecological and economic effectiveness increase as well. This finding suggests that a conservation organization's investment effectiveness is

higher in continuous habitat of larger scale, favoring larger parcels over smaller ones. The comparison of the elasticities of conservation ROI with respect to size between the protected and unprotected areas shows that a conservation organization's scale effects with protected area size on conservation benefit and cost are not shown in non-conservation acquisitions in the wider land market. This finding implies that having different preferences potentially tied to protected area size leads to scale effects with protected area size on conservation benefit and cost, while the general market behavior of the non-conservation buyers do not result in the same scale effects for unprotected matching sites.

1. Introduction

Land use change is recognized as a major cause of recent declines in biodiversity and ecosystem services (Newbold et al., 2015). Protected areas constitute a centerpiece of conservation strategies intended to slow biodiversity losses and reverse declines of many ecosystem services (Chape et al., 2005). Financial resources to support the establishment of new protected areas are limited, which often spurs conservation planners to prioritize locations for future protection (Naidoo et al., 2006). Thus, prioritization of protected areas is increasingly being evaluated based on the return on investment (ROI) they offer (Adams et al., 2010; Ando et al., 1998; Game, 2013; Murdoch et al., 2010; Polasky et al., 2001).

ROI varies by a number of characteristics (e.g., land use, politics and economic conditions, and climate change) (Armsworth et al., 2006). One essential feature is the size variation of protected areas, which can vary widely both in the same conservation program and across different programs (Kim et al., 2014; Sutton and Armsworth, 2014). The effects of protected area size on conservation benefit have been a research issue since the mid-1970s (Diamond, 1975; Simberloff and Abele, 1982; Soule and Simberloff, 1986). The literature commonly finds that the greater the size of the protected area, the more species the protected area contains (Armsworth, et al., 2006). Habitat diversity and species' survival rates also increase when protected area size increases (Bender et al., 1998; Burkey, 1997; Debinski and Holt, 2000; Ovaskainen, 2002; Underwood et al., 2008; Wiens, 2009).

The effects of protected area size on cost associated with conservation practice implementation have been explored more recently (Armsworth et al., 2011; Balmford et al., 2003; Frazee et al., 2003; James et al., 2000; Kim et al., 2014; Moore et al., 2004; Strange et al., 2006). The literature finds that acquisition cost for protected sites increases with their size but at

a decreasing rate (e.g. Frazee et al., 2003; Moore et al., 2004; Strange et al., 2006). For example, acquisition costs for protected areas show pronounced economies of scale with area. Specifically, ten times the protected area can be purchased for seven times the cost of a smaller site, according to findings (Kim et al., 2014). Comparable pronounced economies of scale with area have been captured in the wider land market as well. For example, elasticities of land prices with respect to parcel sizes are found to be less than one, suggesting land price of unprotected matching sites increases with their size but also at a decreasing rate (e.g., Braden et al., 2008; Cho et al., 2009; Colwell and Munneke, 1995; Colwell and Munneke, 1997; Peiser, 1987).

Despite the findings of the scale effects with protected area size on conservation benefit and cost, when these effects are evaluated separately, little research has evaluated them in a single framework (but see Sutton and Armsworth, 2014). In addition, no research has compared the scale effects with protected area size with those for unprotected areas. The comparison of the scale effects between protected and unprotected areas using ROI as a single framework helps evaluate the influence of protected area size on the ecological and economic effectiveness between fine- and coarse-filter conservation targets relative to that of the wider land market. Such differences would exist if a conservation organization as a buyer leads to deviations from general market behavior because the conservation buyer has quite different goals and thus different preferences tied to protected area size relative to non-conservation buyers.

Given the gap in the literature and its importance, this research seeks to examine how protected area size influences their ecological and economic effectiveness, as measured by ROI, and how these effects compare to those of unprotected areas. Formally, the elasticity of conservation ROI with respect to protected area is examined to determine whether significance is greater than zero, as well as if it differs from that of the unprotected areas. If conservation benefit

increases at a faster rate than conservation cost increases, ROI increases with size, reflecting positive scale effects with protected area size on ROI. The elasticity of size on conservation ROI for protected areas is also tested to determine whether the difference from the elasticity of size on conservation ROI is significant for comparable unprotected areas. These determinations will help conservation organizations account and plan for variation in the protected area size relative to conservation benefit and cost of protecting land toward ensuring more efficient prioritization decisions.

The parcels acquired through fee simple acquisitions during 2000-2009 by The Nature Conservancy (TNC) to protect central and southern Appalachian forest ecosystems of the US (referred to as “protected sites”) were compared with unprotected sites selected by statistical techniques to match each protected site with similar land transactions not purchased for conservation (referred to as “unprotected matching sites”). The statistical techniques of matching have been used in conservation studies to evaluate protected area characteristics and protected area impact (Joppa and Pfaff, 2011). For each protected area location that is included within such an evaluation, the statistical matching technique chooses the most similar unprotected sites to best provide appropriate comparisons.

The first rigorous test and comparison of the elasticity of size on conservation ROI with area between transactions made by a conservation organization (the treatment group) versus transactions without such involvement (the control group) is provided. The technique has been used to estimate benefits of conservation programs by comparing what has happened to the conservation target in the treatment group and what would have happened to the conservation target in the absence of protection for the control group (Andam et al., 2008; Joppa and Pfaff, 2011; Nelson and Chomitz, 2011; Sims, 2010).

2. Method

To achieve the objective of this study, unprotected matching sites were first identified using the statistical matching technique. Then a regression framework was developed that estimates elasticities of conservation ROI with respect to parcel size for the protected and unprotected matching sites. Finally, I compared the difference in the elasticity of conservation ROI with respect to parcel size between the protected and unprotected matching sites.

2.1. Statistical Matching

In preparation for the statistical matching, unprotected non-conservation parcels were identified based on a specific procedure that would identify parcels according to criteria that affect parcel cost. Real estate transaction data were collected from a subset of the counties used in this case study (i.e., 25 of the 70 counties where TNC protected area transactions were made). Parcel-level data were only available for 25 of the 70 counties mainly due to the inconsistency in data management and storage between counties. Consequently, 70 counties were grouped into three submarkets which shared reasonably close characteristics to one another relative to the other submarkets (Grigsby et al., 1987).

This submarket delineation was done using a two-step clustering method. First, county submarkets were clustered by constructing a likelihood function and selecting the optimal number of clusters using the Akaike Information Criterion (AIC). Clustered counties were then put into a matrix based on their Euclidean distances. Second, clustered counties were re-grouped using agglomerative hierarchical clustering and treated as individual observations. The counties were then subdivided into 3 submarkets based on the following: population density, per capita

income, average agricultural land value, and ecoregion location of the parcel. The assumption underlying the county subdivision into three separate markets was that similar properties of parcels are shared within each submarket.

Once the 70 counties were divided into the three submarkets, a group of candidate parcels was chosen for the matching protocol use by screening out the sales of parcels unlikely to share similar attributes with the protected parcels toward achieving balance in the number of protected and unprotected parcels for each county (i.e., each county has 1–12 protected parcels vs. 40,900–119,151 unprotected parcels). Parcels were eliminated from the candidate pool if their sale of acquisition: (1) was not included in the same 2000-2009 timeframe in which TNC parcels were purchased in order to mimic market conditions, (2) was below \$1,000 to eliminate any possible transactions made with donative intent or that were below fair market value, or (3) was defined as developed by the land use classification system recorded by county officers and/or the National Land Cover Database (2001; 2006).

Parcels were then screened to eliminate any acquisitions that fell on federal-, state-, or privately-owned protected lands (i.e., Protected Areas Database of the United States–PAD–US (USGS, 2013)). This was done to eliminate the possibility of including parcels with protected areas acquired by organizations other than TNC. Finally, protected sites were paired with unprotected matching sites by characteristics such as parcel size, year of acquisition, average slope and elevation, population density and median income at the census block-group level, and distance of parcel centroid to nearest city with a population over 10,000.

2.2 Regression Model Specification

Log-log regression models for protected and unprotected matching sites at the parcel level were specified to test the hypotheses laid out in the introduction. In developing the models, an issue of spatial dependencies that are likely inherent in parcel-level regression models was accounted for. Specifically, land parcels located near one another may have unobserved characteristics that are correlated across parcels. These unobserved characteristics represent the spatial structure of the decision-making units (parcels) as an unobservable spatial process. The effect of parcel size variation on conservation ROI with considering spatial spillovers in conservation ROI was examined by assessing the relationship in a spatial econometric modeling framework for both protected and unprotected matching sites separately as follows:

$$\ln ROI = \rho W \ln ROI + \beta \ln S + \Phi \ln X + \varepsilon, \quad \varepsilon = \theta W \varepsilon + u \quad (1)$$

where $\ln$ is natural log, ROI is represented by conservation benefit (see below for details) for a protected or unprotected parcel divided by acquisition cost; S is size of a protected or unprotected parcel; X is a matrix of exogenous variables; W is a nonstochastic, positive definite, exogenous matrix defining interrelationships between spatial units of protected or unprotected parcels; ρ is a spatial lag parameter; β is a scalar parameter and Φ is a vector parameter; θ is a spatial autocorrelation coefficient; ε is a spatial autocorrelated disturbance; and u is i.i.d. disturbance with zero mean and variance $\sigma^2 I$.

The change in effective mesh size for a parcel is calculated by subtracting the effective mesh size before the acquisition from that of after the acquisition within a 5 km radius buffer around the parcel centroid for both protected and unprotected matching sites. The 5 km radius buffer is used for the measure of effective mesh size because it is the average separation protocol to convert survey data (i.e., targeted species observed in particular locations) into more

meaningful element occurrences (i.e., historic presence and recurrence of species at given locations) (Sutton and Armsworth, 2014). The effective mesh size is chosen as the quantitative measure of conservation benefit because landscape contiguity is a crucial factor in maintaining many ecological processes and services (Jaeger, 2000). The changes in effective mesh size for protected and unprotected matching sites, respectively, reflect the degree to which a parcel acquired by TNC affects the change in effective mesh size of protected land around the parcel and the degree to which a parcel acquired by a non-conservation buyer affects the change in effective mesh size of unprotected land around the parcel.

The effective mesh size quantifies the probability that two random points (i.e., representing the locations of a pair of animals or plants) appear in the same patch of non-fragmented natural cover of land (Jaeger, 2000). The metric addresses both species and habitat protection. Effective mesh size, M , is obtained by multiplying the total area of a 5 km radius buffer drawn around the centroid of each parcel, A_t , by the probability, P , that a pair of animals or plants located randomly will be placed in the same contiguous patch of protected area within the landscape:

$$M = A_t \cdot P = \frac{1}{A_t} \sum_{j=1}^n A_j^2 \quad (2)$$

where $P = \sum_{j=1}^n \left(\frac{A_j}{A_t} \right)^2$, A_j = size of patch j ($j = 1, \dots, n$) within the 5 km radius buffer (Jaeger 2000).

The exogenous variable, X , includes geophysical characteristics, distance-related variables, socioeconomic characteristics, and the initial stock of conservation benefit that existed in the landscape before the acquisition of the parcels. The variables are chosen following the general guidance of the literature. For example, geophysical characteristics of the landscape—average slope and average elevation—are included because they have been found to influence

land values that determine acquisition costs for both protected and unprotected matching sites (Andam et al., 2010; Joppa and Pfaff, 2009; Kim et al., 2014; Sims, 2010). Slope and elevation have also been important factors for protected area location decisions, as highlighted in the literature, because lower acquisition costs are associated with steep slope and high elevation (Joppa and Pfaff, 2009). Distance-related variables, or proximity to landmarks such as the nearest hospital, golf course, highway, and water body, are included because these proximities are expected to affect change in effective mesh size and acquisition cost for both protected and unprotected matching sites (Cho et al., 2006; Ferraro et al., 2011; Kim et al., 2014; Kruse and Ahmann, 2009; McConnell and Walls, 2005; Newburn et al., 2006; Sander and Polasky, 2009; Snyder et al., 2007).

The socioeconomic characteristics (i.e., city population density and median household income at the census-block group level) are included in X to capture direct interdependency of acquisition costs within census-block group neighborhoods. The city population per hectare is included as a measure of how population pressure on land and natural resources affects acquisition costs. Population density is also hypothesized to affect change in effective mesh size, as population density is lower in rural areas, which are predicted to experience increased change of effective mesh size (Beasley et al., 2011). The median household income is included to capture the effect of relative economic status of a neighborhood on acquisition cost.

The initial stock of conservation benefit is captured through the inclusion of two variables: weighted species richness and effective mesh size within an equal area 5 km radius buffer around the centroid of each protected parcel prior to the TNC acquisition. These two variables are expected to affect TNC's WTP for continuous landscape with high ecological benefit because TNC is interested in targeting parcels in proximity to natural areas and/or

acquiring parcels with abundant species richness (TNC, 2000; TNC, 2001; TNC, 2003).

Likewise, landowners' WTA payment for parcels is also expected to be affected by the initial stock of conservation benefit because of the higher land value placed on parcels near protected or natural areas (Armsworth et al., 2006). (See the definitions of the variables used in the regressions and their detailed statistics in Table 3.1.)

2.3. Regression Model Estimation

Two types of tests were performed (i.e., multicollinearity tests and spatial tests) before estimating equation (1). Multicollinearity tests were conducted by using variance inflation factors (VIFs), which are a scaled version of the multiple correlation coefficients (Maddala, 1992). While there is no clear threshold to signify the existence of multicollinearity, a rule of thumb is that multicollinearity may be problematic if the VIFs are greater than 5 or 10 (Maddala, 1992). The VIFs of the variables used in the regression for the protected and unprotected matching sites were, respectively, 1.18-2.86 and 1.29-4.34; thus, multicollinearity was not a problem in the regressions for both protected and unprotected matching sites.

Robust spatial LM-lag statistics of 159.63-613.48 and robust spatial LM-error statistics of 168.97-635.49 for the protected sites indicated rejection of the aspatial model in favor of the spatial lag and error model for all different assumed spatial structures of the regression models (i.e., nine row-standardized spatial weight matrices). Additionally, robust spatial LM-lag statistics of 171.20-1044.01 and robust spatial LM-error statistics of 189.94-1065.05 for the unprotected matching sites indicated rejection of the aspatial model in favor of the spatial lag and spatial error models for all of the nine row-standardized spatial weight matrices. These spatial

LM test results support using the spatial lag and error model to estimate equation (1) for both protected and unprotected matching sites.

3. Study Area and Data

The study area covers 82 protected sites that were acquired by TNC through fee simple transactions and 74 unprotected matching sites that were acquired by non-conservation buyers. All sites were acquired during the period of 2000-2009 across the central and southern Appalachian region, an area consisting of three ecoregions (i.e., Cumberlands and Southern Ridge and Valley, Southern Blue Ridge, and Central Appalachian Forest, see Figure 1).

For the regression analysis of the protected and unprotected matching sites, 7 different types of data were used: TNC acquisition data for the fee simple transactions, non-conservation acquisition data for the unprotected matching sites, landscape data for the effective mesh size variable, data for geophysical characteristics, data for distance-related variables, data for socioeconomic characteristics, and target species richness data for the weighted species richness variable. TNC documents supplied parcel size, location, and acquisition cost.

Landscape data were used to create the effective mesh size before acquisition and change in effective mesh size variables. These variables were created using FRAGSTATS software (McGarigal et al., 2012). First, landscapes were created in ArcGIS 10.2 for each of the protected and unprotected matching sites. To create the landscapes, a 5 km radius buffer was drawn around each of the parcel's centroids. Using ArcGIS 10.2 (ESRI, 2013), two maps were created from these landscapes: one containing all protected areas in the landscape prior to parcel acquisition and one containing all protected areas after parcel acquisition. These landscapes were then exported to FRAGSTATS where the effective mesh size for both maps for each parcel landscape

was calculated. The change in the effective mesh size variable was then computed by subtracting effective mesh size with the parcel from the effective mesh size without the parcel.

Geophysical data, or data used to create the average slope and elevation variables, were acquired through the 30-meter Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) Version 2 (V2) (NASA JPL, 2011). Average slope and elevation for protected and unprotected matching sites were then calculated using ArcGIS 10.1 (ESRI, 2011) via raster grids. Distance-related data for protected and unprotected matching sites were created from downloaded shapefiles from ESRI Data & Map 10 (ESRI, 2011). Variables were created using the Near Analysis tool in ArcGIS 10.0 including distance from parcel centroid to nearest hospital, distance to golf course, water body, and highway.

Socioeconomic data, which were used to calculate city population density and median household income at the census block group-level, were obtained from 2000 and 2007 US Census data. The data for the specific year of acquisition were often unobtainable (i.e. population figures for parcel acquisitions do not exist in years when the Census Bureau does not gather data) so data included in the study were used in the years corresponding to the nearest year the Census Bureau collected data. The socioeconomic data of the closest census year prior to the transaction to both protected and unprotected matching sites within the boundaries of the census-block groups were assigned to capture either current or lagged socioeconomic effects on acquisition costs. For example, acquisitions made between 2000-2006 use 2000 US Census data for city population density and median household income values and acquisitions made between 2007-2009 use 2007 US Census data for city population density and median household income values.

The weighted species richness variable was calculated as part of the initial stock of conservation benefit for the protected and unprotected matching sites. Weighted species richness was derived from the location of element occurrences in GIS form downloaded from the Biodiversity Information Serving Our Nation (BISON) database (USGS, 2014). Element occurrences of 328 target species that are listed as high level conservation concerns according to the ecoregional portfolios created by TNC (USGS, 2014) were chosen. Using the downloaded database, the element occurrences of species of conservation concern within each of the 5 km radius buffers prior to the TNC acquisitions (referred to as “target species richness”) and non-conservation acquisitions, were spatially aggregated, respectively, for the protected and unprotected matching sites. Then, the weighted species richness variable was created by multiplying target species richness by the quotient of the size of the acquisition parcel and the total area of the 5 km radius buffer.

Data sources and preparation protocols for the geophysical, socioeconomic characteristics, and distance-related variables followed Kim et al. (2014). Further, collection protocols for landscape data for the effective mesh size were created by Heather Jackson (unpublished results). The framework developed by Heather Jackson (unpublished results) was adapted to build a comparable dataset for the unprotected, matching sites. Data to create target species richness was captured with Sutton and Armsworth (2014).

4. Empirical Results

The selection of a spatial weight matrix had little effect on the overall goodness of fit for the regression results for both protected and unprotected matching sites (see Table 3.2). This finding suggests that the definition of spatial neighborhood does not appear to be a crucial factor

in terms of model identification. A spatial weight matrix of KNN=4 was chosen, given the model's overall goodness of fit. About 11% of the variation observed in conservation ROI was explained by the covariates for the protected sites. Also, about 13% of the variation observed in conservation ROI was explained by the covariates for the unprotected matching sites (see Table 3.1 for adjusted R^2).

The spatial lag and spatial error coefficients for the protected sites are both significant at the 5% significance level (hereafter referred to as “significant”); they are not significant for the unprotected matching sites. The spatial lag coefficient was 0.40, meaning a 1% increase in a parcel's ROI increases its neighboring parcel's ROI by 0.40%. This makes sense, as the landscapes used to create conservation benefit overlap one another, making protected area landscapes intersect. The overlap of landscape means that habitat that is used to calculate the change in effective mesh size of one protected site is, in part, used to calculate the change in effective mesh size of another protected site. This spatial dependence has a positive effect on species mobility and survival because, after the new TNC acquisition is established, species have access to additional 5 km buffer landscapes and increased unfragmented habitat in which to thrive. This positive spatial lagged effect for the protected sites was explained by the fact that protected parcels are purchased by a single buyer (i.e., TNC) who acquires parcels with a similar conservation goal and coordinates efforts and strategies when acquiring parcels. On the other hand, there was no indication of spatial dependency (i.e. not significant spatial lag or error coefficients) in the conservation ROI of unprotected matching sites.

The coefficient for parcel size was 0.32 and significant for the protected sites (see Table 3.3.). This finding suggests that a 1% increase in parcel size increases conservation ROI by 0.32% for the protected sites. This finding implies that as size of parcels grows, conservation

ROI grows, and thus TNC's investment effectiveness is higher on continuous habitat with larger scale, favoring larger parcels over smaller ones. In contrast, the effect of size on conservation ROI for unprotected matching sites was not found to be significant. This difference in significance between protected and unprotected matching sites suggests that parcels acquired for conservation purposes differ from parcels acquired for non-conservation purposes in terms of the selected parcel size's effects on ecological and economic effectiveness.

Table 3.3. also reports parameter estimates of other factors in the regression results for the protected and unprotected matching sites. For the protected sites, the coefficients of average elevation, distance to golf course, median income, and effective mesh size before acquisition were positive and significant, indicating these characteristics are important to the acquisition of sites for the conservation market as they are important to the selection of ecological and economic effectiveness of the protected parcels. Specifically, the coefficient for average elevation was 1.49, suggesting that a 1% increase in average elevation increases conservation ROI by 1.49%. Areas of higher elevation have fewer alternative uses, and thus opportunity cost is lower than areas of lower elevation (Norton-Griffiths and Southey, 1995). In addition, greater biodiversity occurs at higher elevations (Poveda, et al., 2012). These combined effects result in greater ecological and economic effectiveness of parcels at higher elevations.

The coefficient for distance to golf course was 0.57, suggesting that a 1% increase in distance from a protected parcel to the nearest golf course increases conservation ROI by 0.57%. Typically, golf courses are located in relatively urban settings, and thus protected parcels away from golf courses may have lower unit acquisition costs than those closer to them, yielding greater economic effectiveness. Also, due to the rural settings farther away from golf courses, there may be a greater amount of land available for conservation acquisitions to allow for large

protected areas, thereby creating a higher ecological effectiveness. The coefficient for median income in the census-block group was 2.20, suggesting that a 1% increase in median income increases conservation ROI by 2.20%. This finding suggests that protected sites closer to affluent areas have higher conservation ROI and as median income increases, sites become ecologically and economically more effective.

The coefficient for effective mesh size before acquisition was 0.28, suggesting that a 1% increase in effective mesh size before acquisition increases conservation ROI by 0.28%. This finding suggests that the more initial stock of conservation benefit in the landscape, the higher the conservation ROI. This is an important finding, implying that TNC targets landscapes with high amounts of existing protected areas and attempts to purchase the remaining parcels in the landscape. TNC examines the landscape prior to new acquisitions because increasing habitat connectivity is dependent on the amount of habitat that already exists in the landscape, which was captured by the effective mesh size before acquisition. For unprotected matching sites, the same significant relationship of effective mesh size on conservation ROI was not found. This lack of significance for unprotected matching sites suggests that the initial stock of benefit does not play a role in site selection.

5. Conclusions

Prioritization of protected areas is increasingly being evaluated based on ROI offered because the ecological and economic effectiveness of protected areas has become progressively more important given limited resources available to support the establishment of new protected areas. One essential feature is the size variation of protected areas while ROI varies according to many characteristics. Little research has evaluated the scale effects of protected area size on

conservation benefit and cost in a single framework and no research has compared the scale effects of protected area size with those for unprotected matching sites. Given the limitation in the literature, this research examines how protected area size influences ecological and economic effectiveness, as measured by ROI, and how these effects are different from those of unprotected areas.

The elasticity of parcel size on conservation ROI was found to be positive and significant, suggesting that as parcel size grows, ecological and economic effectiveness increase as well. This finding suggests that a conservation organization's investment effectiveness is higher in continuous habitat of larger scale, favoring larger parcels over smaller ones. The positive effect of size on conservation ROI can be broken into two effects: positive effects of size on conservation benefit and acquisition cost. While the literature has confirmed these two positive effects separately, the relative ratio of the two effects had remained largely unexplored. This research filled the gap in the literature by finding that the proportion of the increase in conservation benefit due to the increase of parcel size is greater than the proportion of the increase in cost due to the same increase of parcel size.

The comparison of the elasticities of conservation ROI with respect to size between the protected and unprotected areas shows that a conservation organization's scale effects with protected area size on conservation benefit and cost are not shown in non-conservation acquisitions in the wider land market. This finding implies that having different preferences potentially tied to protected area size leads to scale effects with protected area size on conservation benefit and cost, while the general market behavior of the non-conservation buyers do not result in the same scale effects for unprotected matching sites.

Although this research provides useful information about parcel size effects on ecological and economic effectiveness of conservation parcel acquisitions, it is worth mentioning a caveat to be explored in further research. While the change in effective mesh size was used to represent the conservation benefit measure in this research, the literature raises a question about what ecological indicator should be used in pursuing similar research objectives. The question is important in conservation planning because efforts to prioritize locations for future protection are found to be hindered by differences over what ecological indicator should be used (Dale and Beyeler, 2001; Wiens et al., 2008). Thus, a need exists for analogous analysis to be developed using different ecological indicators that cover various aspects: metrics associated with species-based conservation (e.g., tree species richness on-site) and metrics associated with the ecological condition and structure of the forest ecosystems on sites being protected (e.g., canopy cover and tree size).

References

- Adams, V. M., R. L. Pressey, and R. Naidoo. 2010. "Opportunity costs: Who really pays for conservation?" *Biological Conservation* 143(2):439– 448
- Andam, K., Ferraro, P., Pfaff, A., Sancho-Azofeifa, G., & Robalino, J., 2008. Measuring the effectiveness of protected area networks in reducing deforestation. *PNAS*. 105, 16089-16094.
- Andam K., Ferraro P., Sims K., Healy A., & M Holland. 2010 Protected areas reduced poverty in Costa Rica and Thailand. *Proc. Natl Acad. Sci. USA* 107, 9996 – 10 001.
- Ando A., J. Camm, S. Polasky, and A. Solow. 1998. "Species distributions, land values, and efficient conservation." *Science*. 279(5359):2126-2128.
- Armsworth, P.R., L. Cantu-Salazar, M. Parnell, Z.G. Davies, and R. Stoneman. 2011. "Management costs for small protected areas and economies of scale in habitat conservation." *Biological Conservation* 144(1): 423-429.
- Balmford, A, K.J. Gaston, S. Blyth, A. James, and V. Kapos. 2003. "Global variation in terrestrial conservation costs, conservation benefits, and unmet conservation needs." *Proceedings of the National Academies of Sciences of the United States of America* 100(3):1046-1050.
- Beasley, J.C., Z. Olson, G. Dharmarajan, T. Eagan II, and O. Rhodes Jr. 2011. "Spatio-temporal variation in the demographic attributes of a generalist mesopredator." *Landscape Ecology* 26, 937-950.
- Braden, J., Won, D., Taylor, L., Mays, N., Cangelosi, A., Patunru, A., 2008. Economic Benefits of remediating the Sheboygan River, Wisconsin area of concern. *Journal of Great Lakes Research*, 34, 649-660.
- Brownstone, D. De Vany, A., 1991. Zoning, returns to scale, and the value of undeveloped land.

The Review of Economics and Statistics, 73, 699–704

Burkey T. 1995. “Extinction rates in archipelagos: implications for populations in fragmented habitats.” *Conservation Biology*, 9:527–541

Carwardine, J., K.A. Wilson, M. Watts, A. Etter, C.J. Klein, and H.P. Possingham. 2008.

“Avoiding costly conservation mistakes: the importance of defining actions and costs in spatial priority setting.” *PLoS One* 3(7): 2586.

Chape, S., Spalding, M., Jenkins, M. (Eds.). 2008. *The World's Protected Areas—Status, Values and Prospect in the 21st Century*. University of California Press, Los Angeles, California, USA.

Cheshire, P., S. Sheppard S. 1995. “On the price of land and the value of amenities.” *Economica* 62(246):247–267

Cho, S., N. Poudyal, R. Roberts. 2008. “Spatial analysis of the amenity value of green open space.” *Ecological Economics* 66(2–3): 403–416

Cho, S., C. Clark, W. Park, S. Kim. 2009. “Spatial and temporal variation in the housing market values of lot size and open space.” *Land Economics* 85: 51–73.

Colwell, P., Munneke, H. 1997. The Structure of Urban Land Prices. *Journal of Urban Economics*, 41, 321-336.

Dale, V. and S. Beyeler. 2001. “Challenges in the development and use of ecological indicators.” *Ecological Indicators* 1:3-10

Diamond, D. 1975. “The island dilemma: lessons of modern biogeographic studies for the design of Natural reserves.” *Biological Conservation* 7(2): 129-136.

ESRI. Data Maps For ArcGIS (2011), p. 10

ESRI. ArcGIS Help 10.1: Spatial Analyst Toolsets, ArcGIS Resources Internet site:

- <http://www.esri.com/> (Accessed April 12, 2013)
- Ferraro P., Pattanayak S. 2006. Money for Nothing? A Call for Empirical Evaluation of Biodiversity Conservation Investments. *PLoS Biology* 4(4): e105.
- Frazee, S.R., R.M. Cowling, R.L. Pressey, J.K. Turpie, and N. Lindenbergh. 2003. "Estimating the costs of conserving a biodiversity hotspot: a case study of the Cape Floristic Region, South Africa." *Biological Conservation* 112(2): 275–290.
- Fuhlendorf, S., W. Harrell, D. Engle, R. Hamilton, C. Davis, and D. Leslie, Jr. 2006. "Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing." *Ecological Applications* 16:1706–1716
- Fuller R., McDonald-Madden, E., Wilson, K., Carwardine J., Grantham H., et al. 2010. Replacing underperforming protected areas achieves better conservation outcomes. *Nature*. 466,365–367
- Garrett, T. 2001. Economies of scale and inefficiency in county extension councils: A case for consolidation? *American Journal of Agricultural Economics*, 83(4): 811-825.
- Game, E. 2013. "Identifying Conservation Priorities using a Return on Investment Analysis." *Encyclopedia of Biodiversity*, second edition, Volume 4, S. Levin, ed., Waltham, MA: Academic Press.
- Gaston K., Jackson S., Cantú-Salazar L., Cruz-Piñín G. 2008. The ecological performance of protected areas. *Annual Review of Ecology, Evolution and Systematics*, 39, 93–113.
- Grigsby, W., M. Baratz, G. Galster, and D. MacLennan. 1987. "The Dynamics of Neighborhood Change and Decline." *Progress in Planning* 28:1–76.
- Gwamna, E., W. Yusoff, and M. Ismail. 2015. "Determinants of Land Use and Property Value." *Advanced Science Letters* (4): 400 – 407

- Jaeger, J. 2000. "Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation." *Landscape Ecology* 15(2):115-130
- James, A.N, K.J. Gaston, and A. Balmford. 2000. "Integrating costs of conservation into international Priority setting." *Conservation Biology* 14(3):597-605.
- Jones, K. and D. Lewis. 2015. "Estimating the Counterfactual Impact of Conservation Programs on Land Cover Outcomes: The Role of Matching and Panel Regression Techniques." *PLoS ONE* 10(10): e0141380.
- Joppa L., Pfaff A. 2009. High and far: biases in the location of protected areas. *PLoS ONE* 4.
- Joppa, L., Pfaff, A., 2011. Global protected area impacts. *Proceedings of the Royal Society of Biological Sciences*, 278, 1633–1638
- Kapos, V., Balmford, A., Aveling, R., Bubb, P. Carey, P., Entwistle, A., Hopkins, J., Mulliken, T., Safford, R., Stattersfield, A., Walpole, M., Manica, A. 2008. Calibrating conservation: new tools for measuring success, *Conservation Letters*, 1, 155–164
- Kim, T, Cho, S.H., Larson, E.R., and P.R. Armsworth. 2014. "Protected area acquisition costs show economies of scale with area." *Ecological Economics* 107(1):122-132.
- Kopits, E., McConnell, V., Walls, M. 2007. The Trade-off Between Private Lots and Public Open Space in Subdivisions at the Urban-Rural Fringe. RFF Discussion Paper No. 07-33.
- Krug, W. 2001. "Private supply of protected land in Southern Africa: A review of markets approaches, barriers, and issues." Paper prepared for the OECD International Workshop on Market Creation for Biodiversity Products and Services; 25–26 January 2001; London, United Kingdom.
- Kruse, S.A. and J. Ahmann. 2009. "The value of lake adjacency: a hedonic pricing analysis on

- the Klamath river, California.” Working Paper Series No. 5. Ecotrust.
- Langholz, J. and W. Krug. 2005. “New forms of biodiversity governance: non-state actors and the private protected area action plan.” *Journal of International Wildlife Law and Policy* 7:9–29
- Lansford N., and L. Jones. 1995. “Recreational and Aesthetic Value of Water using Hedonic Price Analysis.” *Journal of Agricultural and Resource Economics* 20(2):341-355.
- Latzko, D.A., 1998. Economies of Scale in Mutual Fund Administration. Pennsylvania State University, York Campus.
- Lesage, J. and R. Pace. 2009. Introduction to Spatial Econometrics. CRC Press.
- MacArthur, R., E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton, NJ: Princeton University Press.
- Maddala, G. 1992. Introduction to Econometrics, 2nd ed. New York: Macmillan.
- Mahan B., S. Polasky, and R. Adams. 2000. “Valuing Urban Wetlands: A Property Price Approach.” *Land Economics* 76(1):100-113.
- Margules, C.R., and R.L. Pressey. 2000. “Systematic conservation planning.” *Nature* 405: 243–53.
- Mascia M., Pailler S. 2011. Protected area downgrading, downsizing, and degazettement (PADDD) and its conservation implications. *Conservation Letters*. 4, 9–20
- McConnell, V. and M. Walls. 2005. “The Value of Open Space: Evidence from Studies of Nonmarket Benefits.” Resources for the Future, Washington D.C.
- McGarigal, K., SA Cushman, and E Ene. 2012. FRAGSTATS v4: Spatial Pattern Analysis

- Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Internet site:
<http://www.umass.edu/landeco/research/fragstats/fragstats.html> (Accessed May 25, 2016)
- Moore, J., A. Balmford, T. Allnut, and N. Burgess. 2004. "Integrating costs into conservation planning across Africa." *Biological Conservation* 117(3):343-350.
- Murdoch, W., S. Polasky, K.A. Wilson, H.P. Possingham, P. Karieva, and R. Shaw. 2007. "Maximizing return on investment in conservation." *Biological Conservation* 39(3-4):375-388.
- Murdoch W., J. Ranganathan, S. Polasky, and J. Regetz. 2010. "Using return on investment to Maximize conservation effectiveness in Argentine grasslands." *Proceedings of the National Academy of Sciences* 107(49):855-862.
- National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA JPL). 2011. "ASTER Global Digital Elevation Map Announcement."
<http://asterweb.jpl.nasa.gov/gdem.asp>
- Nelson, A. Chomitz, K. 2011. Effectiveness of Strict vs. Multiple Use Protected Areas in Reducing Tropical Forest Fires: A Global Analysis Using Matching Methods. *PLoS ONE*, 6, 1-13.
- Newbold, et al., 2015. "Global effects of land use on local terrestrial biodiversity." *Nature*, 520, 45–50.
- Norton-Griffiths, M. and C. Southey. 1995. "The opportunity costs of biodiversity conservation in Kenya." *Ecological Economics*, 12:125-139.
- Ovaskainen, O. 2002. "Long-term persistence of species and the SLOSS problem." *Journal of Theoretical Biology*, 218:419–433.

- Peiser, R. 1987. "The determinants of nonresidential urban land values." *Journal of Urban Economics*, 22(3), 340-360
- Polasky S., J.D. Camm, and B. Garber-Yonts. 2001. "Selecting biological reserve cost-effectively: an application to terrestrial vertebrate conservation in Oregon." *Land Economics* 77(1):68-78.
- Polasky, S. et al., 2008. "Where to put things? Spatial land management to sustain biodiversity and economic returns" *Biological Conservation* 141: 1505 – 1524
- Poveda, K., E. Martinez, M. Kersh-Becker, M. Bonilla, T. Tschardtke. 2012. "Landscape simplification and altitude affect biodiversity, herbivory and Andean potato yield." *Journal of Applied Ecology* 49(2): 513-522.
- Rosenzweig, M. 1995. *Species diversity in space and time*. Cambridge University Press, Cambridge, UK.
- Sander, H. and S. Polasky. 2009. "The value of views and open space: Estimates from a hedonic pricing model for Ramsey County, Minnesota, USA." *Land Use Policy* (26):837-845
- Silva, J., M. R. Fariñas, J. M. Felfili, C. A. Klink. 2006. "Spatial heterogeneity, land use and conservation in the cerrado region of Brazil." *Journal of Biogeography* 33(3): 536–548.
- Simberloff, D. S. and L. G. Abele. 1982. "Refuge design and island biogeographic theory - effects of fragmentation." *American Naturalist* 120(1):41-56.
- Sims, K. 2010. "Conservation and development: Evidence from Thai protected areas." *Journal of Environmental Economics and Management* 62(1):94-114.
- Snyder, S, M. Kilgore, R. Hudson, J. Donnay. 2007. "Determinants of forest land prices in Northern Minnesota: a hedonic pricing approach." *Forest Science* 53(1): 25–36.
- Soule, M., D. Simberloff. 1986. "What do genetics and ecology tell us about the design of nature

- reserves?" *Biological Conservation* 35(1): 19-40.
- Strange, N., Rahbek, C., Jepsen, J., Lund, M., 2006. Using farmland prices to evaluate cost-efficiency of national versus regional reserve selection in Denmark. *Biological Conservation*. 128, 455-466.
- Sutherland, W.J., Pullin, A.S., Dolman, P.M., Knight, T.M., 2004. The need for evidence-based conservation. *Trends in Ecological Evolution*, 19, 305-308
- Sutton, N. and P. Armsworth. 2014. "The Grain of Spatially Referenced Economic Cost and Biodiversity Benefit Data and the Effectiveness of a Cost Targeting Strategy. *Conservation Biology* 28(6):1451-1461.
- Tear, T., B.N. Stratton, E.T. Game, M.A. Brown, C.D. Apse and R.R. Shirer. 2014. "A return-on-investment framework to identify conservation priorities in Africa." *Biological Conservation* 173(1):42-52.
- The Nature Conservancy. 2000. Southern blue ridge ecoregional conservation plan. Technical report, The Nature Conservancy and the Southern Appalachian Forest Coalition.
- The Nature Conservancy. 2001. Central Appalachian forest ecoregional plan. Technical report. The Nature Conservancy.
- The Nature Conservancy. 2003. The Cumberlands and Southern Ridge and Valley ecoregion: A plan for biodiversity conservation. Technical report. The Nature Conservancy.
- US Census Bureau. Census 2000 Summary File 3 (SF 3). Generated by Dr. Tae-young Kim. using American FactFinder. Internet site: <http://factfinder2.census.gov>. (accessed February 15, 2013).
- US Census Bureau. TIGER/Line Shapefile. American Community Survey 5-year estimates. 2007-2011. Internet site: <http://census.gov/geo/maps-data/tiger-data.html> (accessed

- February 15, 2013).
- Underwood, E.C., M.R. Shaw, K.A. Wilson, P. Kareiva, K.R. Klausmeyer, M.F. McBride, M. Bode, S.A. Morrison, J.M. Hoekstra, and H.P. Possingham. 2008. Protecting biodiversity when money matters: maximizing return on investment. *PLoS One* 3(1): e1515.
- United States Geological Survey (USGS). Biodiversity information serving our nation database. (BISON). Washington, D.C. Internet site: <http://www.bison.ornl.gov> (accessed August 20, 2013).
- United States Geological Survey (USGS). Gap Analysis Program (GAP). 2014. Protected Areas Database of the United States (PADUS), version 1.3. (accessed November 10, 2012).
- Wiens, J., G., Hayward, R. Holthausen, and M. Wisdom. 2008. "Using Surrogate Species and Groups for Conservation Planning and Management." *Bioscience* 58(3): 241-252.
- Wiens, J. 2009. "Landscape ecology as a foundation for sustainable conservation." *Landscape Ecology* (2009) 24:1053–1065
- Wilson, K., M. McBride, M., Bode, and H. Possingham. 2006. "Prioritizing global conservation efforts." *Nature* 440, 337–340
- Wilson, K., J. Carwardine, and H. Possingham. 2009. "Setting conservation priorities." *Annals of the New York Academy of Sciences* 1162, 237–64.

Appendix

Table 3.1. Variable Definitions and Descriptive Statistics for Protected and Unprotected Matching Sites (n=82, n = 75)

Variables	Definition	Protected Mean (Std Dev)	Unprotected Mean (Std Dev)
<i>Dependent variables</i>			
ROI	Return on Investment, change in effective mesh size divided by acquisition cost	0.00019 (0.00095)	0.00017 (0.00078)
Acquisition cost	Acquisition cost of protected area (2000 US dollar)	424,414.00 (849,427.00)	450,618.00 (1,106,457.00)
Change in effective mesh size	Difference in effective mesh size within an equal area 5 km buffer around the centroid of each protected parcel before the acquisition from the same estimate after the acquisition (kilometer ²)	24.20 (68.21)	16.80 (66.05)
<i>Geophysical variables</i>			
Protected area Size	Size of protected area (kilometer ²)	108.82 (233.08)	71.07 (251.78)
Average slope	Average slope (degree)	12.53 (7.08)	12.06 (6.84)
Average elevation	Average elevation (meter)	519.87 (287.25)	531.53 (340.36)
<i>Distance-related variables</i>			
Proximity to hospital	Distance to the nearest hospital	11.82 (5.82)	14.60 (6.40)
Proximity to water body	Distance to the nearest water body (kilometer)	17.51 (11.00)	16.46 (9.78)
Proximity to golf course	Distance to the nearest golf course (kilometer)	19.92 (19.25)	28.64 (16.33)
Proximity to major highway	Distance to the nearest interstate or state highway (kilometer)	2.79 (2.11)	2.33 (2.32)
<i>Socioeconomic variables</i>			
Population density of city	Population density per hectare of major city in census block-group	2.05 (0.67)	1.85 (0.80)
Median household Income	Median household income within census block-group (2000 US dollar)	35,570.76 (9,258.60)	37,583.92 (12,201.18)

Table 3.1. Continued

Variables	Definition	Protected Mean (Std Dev)	Unprotected Mean (Std Dev)
<i>Initial stock of conservation benefit</i>			
Weighted species richness	Target species richness multiplied by the quotient of the protected area size and the total area of the 5 km radius buffer	0.007 (5.311)	0.001 (3.82)
Effective mesh size before acquisition	Effective mesh size before the acquisition of the protected area (kilometer ²)	225.41 (532.38)	3.84 (277.24)

Table 3.2. Goodness of Fit for the Protected and Unprotected Matching Sites using Different Spatial Weight Matrices

Spatial weight matrices	Protected		Unprotected	
	Adjusted-R ²	Log-likelihood	Adjusted-R ²	Log-likelihood
K nearest neighbor (KNN)				
K=2	0.127	-106.755	0.129	-65.827
K=3	0.113	-105.834	0.136	-65.805
K=4	0.115	-105.543	0.133	-65.704
K=9	0.109	-107.274	0.113	-65.129
KNN X Inverse distance				
K=2	0.106	-106.680	0.134	-65.791
K=3	0.113	-106.558	0.137	-65.750
K=4	0.100	-107.274	0.136	-65.721
K=9	0.124	-107.043	0.132	-65.833
Inverse Distance	0.085	-105.460	0.129	-65.776

Table 3.3. Parameter Estimates from SAC using a Fourth-order KNN Weight Matrix

Variables	Protected	Unprotected
Constant	-35.615 (12.510)	-40.971 (48.508)
Protected area size	0.323* (0.152)	0.271 (0.285)
<i>Geophysical variables</i>		
Average elevation	1.486* (0.372)	1.895 (1.805)
Average slope	0.186 (0.108)	0.376 (1.020)
<i>Distance-related variables</i>		
Proximity to hospital	-0.591 (0.384)	0.079 (1.054)
Proximity to golf course	0.570* (0.251)	0.530 (1.472)
Proximity to highway	-0.105 (0.137)	0.324 (0.527)
Proximity to water body	0.427 (0.224)	-0.169 (0.197)
<i>Socioeconomic variables</i>		
Population density of city	0.103 (0.236)	0.175 (0.815)
Median household income	2.197* (1.057)	2.928 (3.642)
<i>Initial stock of conservation benefit</i>		
Weighted species richness	-0.236 (0.177)	0.111 (0.308)
Effective mesh size before acquisition	0.284* (0.082)	-0.019 (0.103)
Spatial lag	0.399* (0.129)	-0.068 (0.225)
Spatial error	-0.556* (0.240)	0.133 (0.214)
Adjusted R ²	0.115	0.133
AIC	12.765	44.875

Note: Numbers in parentheses are standard errors, and * denotes significance at the 5% level.

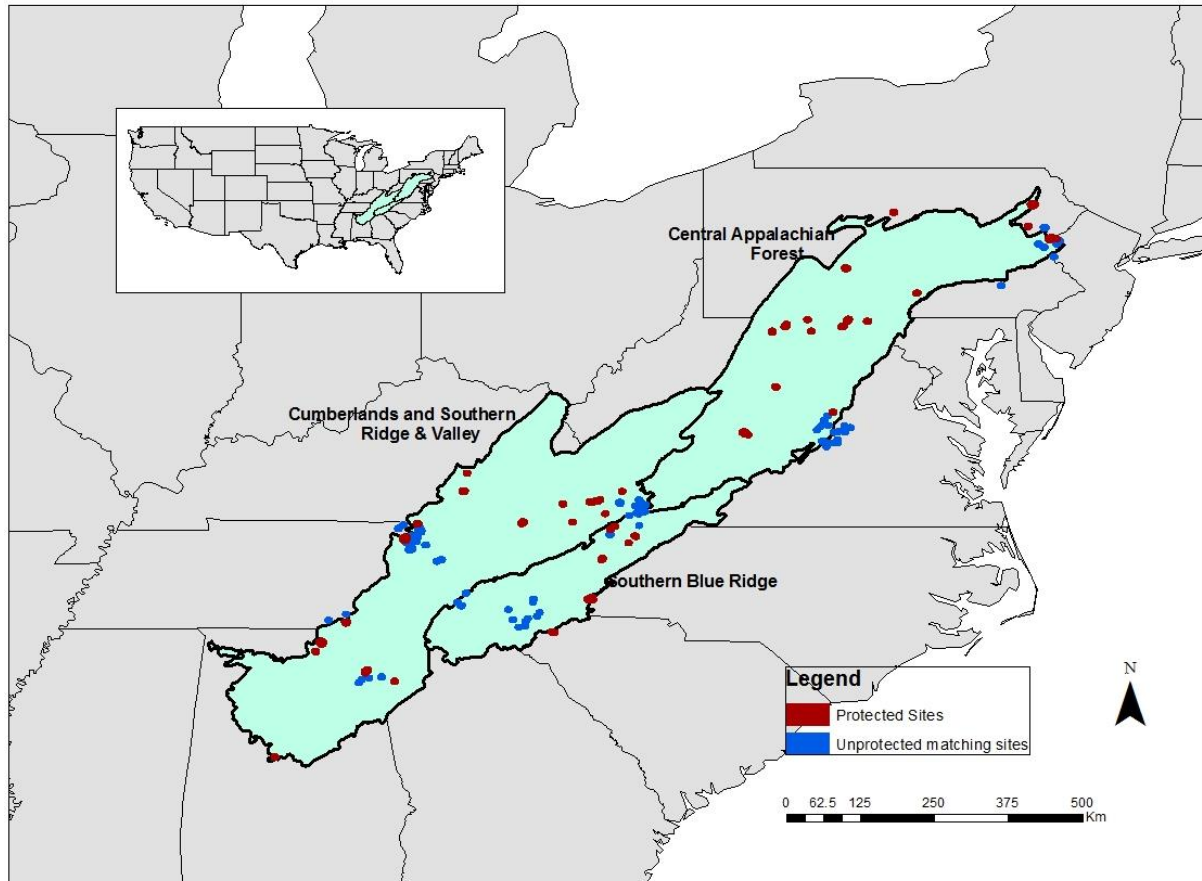


Figure 3.1. 82 Protected Sites Acquired by TNC and 74 Unprotected Matching Sites in Central and Southern Appalachian Forest Ecosystems during 2000-2009

Chapter 4: Summary

The two essays in this thesis analyze the effects of protected area size on conservation ROI using land acquisitions made by TNC to protect the central and southern Appalachian forest ecosystems of the US as a case study. The first essay focused on how the size of protected areas influences ecological and economic effectiveness, and how subsequent changes in ecological and economic effectiveness alter prioritization when making decisions about acquisitions for protected areas. The second essay examined how the size of protected areas influences their ecological and economic effectiveness and how these effects are different from those of unprotected areas.

The results in the first essay suggest that the increase in effective mesh size per dollar invested to acquire a parcel is greater for larger parcels than for smaller parcels and, given the incentive to favor larger parcels over smaller ones, if conservation organizations focus on ecological effectiveness, all else being equal, they tend to favor larger parcels more than if they focus on both ecological and economic effectiveness. Therefore, the conservation prioritization will be biased toward larger parcels if conservation organizations are interested in achieving ecological and economic effectiveness, although their decisions are based on conservation benefit only instead of based on conservation ROI.

The second essay provides the first rigorous test and comparison of the elasticity of size on conservation ROI with area between transactions made by a conservation organization (the treatment group) versus transactions without such involvement (the control group). The comparison of the elasticities of conservation ROI with respect to size between the protected and unprotected areas shows that a conservation organization's scale effects with protected area size on conservation benefit and cost are not shown in non-conservation acquisitions in the wider land market. This finding implies that having different preferences potentially tied to protected

area size leads to scale effects with protected area size on conservation benefit and cost, while the general market behavior of the non-conservation buyers does not result in the same scale effects for unprotected sites.

Vita

Kristen Thiel was born in Crown Point, Indiana. Before joining the Department of Agricultural and Natural Resource Economics, she earned her M.P.A. in Indiana University's SPEA program and her B.S. in environmental science and economics at the University of Maryland. She is currently a survey statistician for the United States Census Bureau and Master's student. She is expected to graduate in the fall of 2016.