ABSTRACT

Title of dissertation: The Impact of Conservation Easements on Habitat Loss in Agricultural Regions

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Natural lands provide irreplaceable ecosystem services, such as wildlife habitat, water filtration and carbon sequestration, but in many regions, they are rapidly being converted to agricultural or urban uses. To counteract this trend, numerous land conservation programs purchase natural land but the impact of these programs is almost entirely unknown. This dissertation develops a framework for evaluating the impact of land conservation programs that incorporates theory from land economics and conservation planning. It posits that private land that enrolls in these programs will have lower economic value and higher ecological value than unenrolled lands. To test the framework, a Propensity Score Analysis is conducted for a federal conservation easement program in the northern plains of the United States. Measures of key economic characteristics (such as a tract's soil productivity, slope and distance to grain markets) and key ecological characteristics (such as a tract's accessibility to nesting pairs of migratory birds and the extent of grassland coverage surrounding a tract) are computed in a Geographic Information System. These measures are used to estimate a logistic regression model that predicts the probability that a tract of land enrolled in the program between 1990 and 2001. Consistent with expectations, tracts with lower economic value and with higher ecological value were more likely to enroll in the program. Using the predicted values from this model, enrolled tracts were matched with control tracts using four specifications of nearest neighbor matching with calipers. Under each of these specifications, the rate of grassland conversion between 2001 and 2006 on enrolled tracts was significantly lower ($p<.0001$) than the rate of conversion on control tracts by between 0.32 percent (for the specification with the lowest estimate) and 0.42 percent (for the specification with the highest estimate). These results indicate that the program did have a statistically significant impact on the rate of grassland conversion during this time period, although the impact was substantively slight.

THE IMPACT OF CONSERVATION EASEMENTS ON RATES OF HABITAT LOSS IN AGRICULTURAL REGIONS

by

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Chapter 1 – Introduction

Natural lands, such as forests, grasslands, and wetlands, provide ecosystem services that are essential to human life and that cannot be replaced by technology (Daily et al. 1997). Such ecosystem services include water filtration, carbon sequestration, and habitat provision, yet these services are seriously threatened by human activity (Daily et al. 1997). The conversion of natural lands to agricultural or urban uses is the primary means by which human activity disrupts ecosystem services (Vitousek, Mooney, Lubchenco, and Melillo 1997). This land conversion can deplete soil resources, alter climate, disrupt hydrologic cycles, and emit atmospheric trace gases (Meyer and Turner 1992) in addition to destroying habitat (Heimlich et al. 1998). Finding the socially optimal use of natural lands requires balancing the short-term consumptive uses of food and fiber grown on these lands and the long-term sustainability of ecosystem services provided by these lands (DeFries, Foley, and Asner 2004 and Foley et al. 2005).

Like other public goods, the benefits of ecosystem services generally accrue to society at large while the costs are borne by private landowners; as a result, the amount of natural lands provided by private landowners often falls below the social optimum (Heimlich et al. 1998). Because of the benefits provided by natural land, and because of the risk of their conversion, many government agencies and private organizations purchase land, or the development rights to that land, to protect it from conversion to more intensive agricultural or urban uses. Private conservation organizations, such as land trusts, had protected over 1.2 million acres in fee-simple and 700,000 acres in conservation easements as of 2001 (Merenlender et al. 2004). Government programs protect additional acreage, including 34 million acres of sensitive cropland under the Conservation Reserve Program and 1.6 million acres under the Wetland Preserve Program protected under short-term leases (Hellerstein 2006). In the United States between 1992 and 2001, federal and state governments spent $32 billion to protect natural lands through fee-simple purchases, short-term rentals, and permanent easements (Lerner, Mackey, and Casey 2007). In spite of the massive investment made to date, the financial cost of protecting a critical mass of land in the major biomes of the United States during the next 30 years would require approximately an additional $428 billion, if purchased in fee-simple, or $257 billion if purchased as conservation easements (Shaffer, Scott, and Casey 2002).

In spite of the importance of the ecosystem services provided by natural lands and the massive amount of money invested in their protection, the impacts of conservation programs on land use are largely unknown. Several authors have called for more rigorous evaluations of land conservation programs, noting that "conservation programs rarely receive comprehensive, in-depth, external, peer-reviewed evaluations" (Kleinman et al. 2000), that conservation decision making is "in the dark ages of trial and error" (Salafsky, Margoluis, Redford, and Robinson 2002), and that "rigorous measurements of the counterfactual are non-existent" (Ferraro and Pattanayak 2006).

In order to understand the impacts of these programs, one must estimate the counterfactual, which is the amount of land conversion that would have occurred in the absence of the program (Ferraro 2009). The naïve approach is to assume that protected land would have been converted (if it were not enrolled in the program) at the same rate as unprotected land. This is incorrect because it does not account for the fact that protected tracts generally self-select into conservation programs, making them unlike tracts that do not enroll. Because conservation programs alone cannot dictate land use patterns, land markets respond in ways that are not always obvious (Bockstael 1996), making it important to fully assess the land use impacts of these programs. If protected land is at low risk of development, it may not have been developed even in the absence of a conservation program (Lynch and Liu 2007 and Ferraro 2009). If landowners with lower quality lands are more likely to enroll, adverse selection may limit program effectiveness (Lynch and Lovell 2003 and Duke 2004). Other policy interventions, such as the construction of roads, may counteract the effects of establishing protected areas (Cropper, Puri, and Griffiths 2001). Protecting some tracts of land may displace development to nearby tracts of land (Wu 2000 and Armsworth, Daily, Kareiva, and Sanchirico 2006), especially if land conservation creates a positive amenity that attracts development (Irwin and Bockstael 2002, Wu and Plantinga 2003, and Towe, Nickerson and Bockstael 2008). Although a small number of studies have addressed each of these three aspects individually, the total number is small relative to the scale of land conservation programs, the diversity of regions in which these programs operate, and the number of research gaps about their effectiveness.

Reliable information about the impacts of land conservation programs is essential to guiding careful policy, planning, and investment decisions. In particular, the results of rigorous impact evaluations could be used to refine the strategies used to target land for conservation (Newburn et al. 2005 and Newburn, Bereck, and Merenlender 2006), assess the role of land conservation in contrast to that of regulation (Daniels and Lapping 2005), predict the amount of funds necessary to meet a conservation target (Larkin, Alavalpati, and Shrestha 2005), make policy decisions to balance the allocation of land to human versus natural uses (DeFries, Foley, and Asner 2004), and estimate the scale of conservation that is optimal in a given landscape (Polasky et al. 2008). In particular, by distinguishing between the impact of exogenous landowner or landscape factors and the impact of targeting decisions of the conservation program, it is possible it design programs so that they are more effective. Many factors that drive land use, such as commodity prices or farming technology, are out of the control of conservation programs, yet programs can adjust the price they offer per acre and the criteria they use to target lands for protection. Information about the effectiveness of a given strategy in a given setting could inform the literature on such targeting strategies (Newburn et al. 2005 and Newburn, Bereck, and Merenlender 2006).

This dissertation aims to assess the effectiveness of land conservation programs though an empirical case study of a U.S. Fish and Wildlife Service (FWS) program operating in the Northern Plains. The program seeks to prevent grassland, which provides critical habitat for numerous species of migratory birds, from being converted to cropland (US GAO 2007). Through this analysis, this dissertation seeks to answer the following research questions. First, what factors drive land to enroll in a conservation program? Second, how much land would have been converted in the absence of the program?

To answer these questions, this dissertation adopts the following methodology. Through a review of literature in land economics and conservation planning, key factors related to program enrollment and land conversion are identified. Data for key land characteristics are linked to tracts in the study area through analysis in a Geographic Information System (GIS). The join count statistic among program enrollment decisions is calculated. It shows a high degree of clustering, and correspondingly, the characteristics of buffers surrounding each tract are also calculated to account for the impact of surroundings on whether a tract enrolls in the program. Using the resulting dataset, the decision to enroll a tract of land in the program between 1990 and 2001 is predicted using a logistic regression model. The regression model shows that tracts are more likely to enroll in the program if they have lower economic value and higher ecological value. The estimated regression model is used to generate propensity scores, which estimate the probability of enrollment for tracts that did not actually enroll in the program. Treatment tracts are matched with control tracts on the basis of the estimated propensity scores. The rate of grassland conversion between 2001 and 2005 for treated and control tracts are compared to estimate the impact of the program. The results show that the rate of grassland conversion on treated tracts was significantly lower than the rate on control tracts. In particular, about 0.38 percent or 0.42 percent of enrolled land, depending on the model, would have converted to cropland between 2001 and 2006 if they had not enrolled in the program between 1990 and 2001. The rate of grassland conversion on control tracts, however, was not significantly different from the rate of grassland conversion in the study area overall.

Chapter 2 – Theory

This chapter describes a review of the literature in the fields of program evaluation, land economics and conservation planning that pertains to the potential impacts of land conservation programs in agricultural regions. First, the concept of the counterfactual is described in the context of land conservation programs. Second, land economics literature regarding the motivations of landowners for either converting or conserving their land is reviewed. Third, the literature on conservation planning, which describes the factors that motivate conservation programs and the ways in which these programs can increase their efficiency, is reviewed.

This review suggests that land conservation programs face two inherent dilemmas meeting their objectives of reducing rates of land conversion. First, because of landowners' incentives to allocate their land to the use that yields the greatest returns, it is likely that land that is least likely to be converted is most likely to enroll in a conservation program. Second, because of conservation agencies' objectives of acquiring contiguous patches of habitat, it is likely that these agencies will focus conservation on more remote areas that are under less development pressure. Optimization studies have shown that programs can be most efficient by selecting properties and pricing easements in proportion to their risk of conversion. However, it is hypothesized that the incentives of landowners and the objectives of conservation programs will constrain the effectiveness of land conservation programs in reducing rates of habitat loss.

Program Evaluation and the Counterfactual

In order to estimate the impact of a land conservation program, it is necessary to estimate the amount of protected land that that would have been converted if it had not enrolled in the program. This is known as estimating the counterfactual (Ferraro 2009). The Neyman-Rubin counterfactual framework, as described in Guo and Fraser (2010), assumes that each observation (e.g., each tract of land) has two potential outcomes (e.g., the number of acres converted during a given time period). If the tract were to enroll in the program, Y_1 would be the number of acres converted; if the tract were not to enroll in the program, Y_0 would be the number of acres converted. For any given tract, only one of these outcomes is realized, and therefore, can be observed.

A standard measure of program impact is the average treatment effect on the treated. In the case of a land conservation program, it measures the amount of *avoided* land conversion as a result of certain tracts enrolling in the program. It is calculated as the expected difference between Y_1 and Y_0 among tracts of land that enroll in the program. It is described in equation (1), in which E is the expectation operator, X is a vector of tract characteristics, and W is an indicator of enrollment status, which equals 1 if a tract of land enrolls in the program and 0 if the tract does not enroll in the program. Thus, TT is the difference between the actual amount of land converted on enrolled tracts, Y_1, and the counterfactual amount of land that would have been converted on these tracts, Y_0. This equation applies only to those that actually enrolled in the program (i.e., for which W=1) and for which Y_1 is observed and Y_0 is unobserved.

$$TT = E[(Y_1 - Y_0)|X, W = 1] \qquad (1)$$

Conservation easements restrict landowners from converting land to a higher intensity use. Assuming that landowners comply with the terms of the easement, the amount of land conversions on protected land (i.e., $Y_1|W=1$) would be zero. Therefore, assuming full compliance, the impact of the program is the amount of land that would have occurred on enrolled tracts if these tracts had not enrolled in the program (i.e., $Y_0|W=1$). Under this assumption, equation (2) represents an alternative expression of TT and is equivalent to equation (1).

$$TT = E[Y_0|X, W = 1] \qquad (2)$$

In experimental data, random assignment of cases to treatment and control groups allows both Y_0 and Y_1 to be measured directly. Non-experimental data, however, suffer from the "fundamental problem of causal inference" (Holland 1986 as cited in Guo and Fraser 2010). In the case of a land conservation program, this dictates that we cannot observe the outcomes of a tract of land in both the enrolled and the unenrolled state. In other words, we can observe $Y_1|W=1$ (the amount of land conversion that actually occurred on enrolled tracts) and we can observe $Y_0|W=0$ (the amount of land conversion that actually occurred on unenrolled tracts) but we cannot observe $Y_1|W=0$ (the amount of land conversion that would have occurred on enrolled tracts if they had not enrolled).

The rate of land conversion on all unenrolled tracts is not a valid measure of the counterfactual. Because cases are not randomly assigned to be treated, treated and untreated cases are generally different from one another in ways that affect the outcome

(Rosenbaum, cited in Guo and Fraser 2010). As described later in this chapter, enrolled tracts may be less likely than other tracts to convert from grassland to cropland regardless of their enrollment in the program. Stated formally, enrolled and unenrolled cases are likely to differ on the conditioning variable, X. As a result, they will have different expected outcomes: the expected amount of land conversion for tracts that actually enroll, $E[Y_0|W=1]$, is unlikely to equal to the expected amount of land conversion for tracts that do not actually enroll, $E[Y_0|W=0]$. This non-random difference between enrolled and unenrolled tracts is referred to as selection bias and it invalidates using observed outcomes on unenrolled tracts as the counterfactual. A naïve estimate of program impacts would be the rate of conversion on unenrolled tracts (i.e., $Y_0|W=0$). In order to estimate program impacts, it is necessary to find a way to estimate $Y_0|W=1$.

The central task of program evaluation, therefore, is to estimate the counterfactual, that is, the outcome of treated cases if they had not been treated. In assessments of land conservation programs, this means modeling the process by which by which landowners and conservation officials jointly determine whether a tract of land will be enrolled in a conservation program. Assuming that the set of tracts that did not enroll in the program contains some tracts that are otherwise similar to those that did enroll in the program, modeling this selection process can be used to identify unenrolled tracts that are similar to enrolled tracts. The land use on the similar tracts can be used as an estimate of the counterfactual.

Prior research has shown that estimating the counterfactual levels of land use can lead to significantly different interpretations of program impacts as compared to naïve estimators that do not adjust for selection bias. Lynch and Liu (2007) use propensity scores to detect the impact of Maryland's Rural Legacy program on the amount of farmland preserved. They find that properties in designated areas, in comparison to a group of properties selected using propensity scores, were more likely to be preserved but no less likely to be converted. Using a similar approach, Andam et al. (2008) estimated that protected areas in Costa Rica prevented approximately 11-12 percent of lands from converting. The estimate would have been about 44 percent using traditional conservation science approaches – a four-fold difference. Both studies demonstrate that relying on inappropriate measures or casual empiricism can lead to false conclusions about program effectiveness. However, the number of studies using quasi-experimental methods to assess the effects of these programs is extremely limited (Ferraro 2009). It has not been determined whether similar results would be obtained for grassland conservation programs operating in rural areas. The following sections describe the background literature for building such a study.

Landowner Decisions

According to land economics, land owners allocate their land to the use that yields the greatest return among all possible uses. In a simple agricultural scenario land use can be divided into two uses: grassland/rangeland, which is the less intensive land use, and cropland, which is the more intensive land use. This scenario has been shown to be empirically valid across much of the Great Plains (Claassen and Tegene 1999). In this scenario, land owners decide whether to maintain the land as grassland, which they can use to raise cattle, or convert the land to cropland. They make this decision based on the returns that they would obtain from each of alternative these land uses. Land that yields greater returns from grazing will be allocated as rangeland and land that yields greater returns from crops will be allocated as cropland. In a plot level model, which is invariant to the scale of the operation, this decision can be expressed in equation (3) (Lichtenberg 1989 and Bockstael 1996).[1] Assume that that a plot begins in use 1, grassland, that the landowner faces a decision to convert to use 2, cropland. The decision to convert will be made if the returns to use 2, R_2, minus the cost to convert the land, C, exceed the returns to use 1, R_1.

$$R_2 - C > R_1 \qquad (3)$$

The returns to each land use for each plot can be expressed as a function of a vector of factors, X. These factors, which are described in detail in the subsequent section, include land quality, the price of inputs and the price of crops produced on the land (Lichtenberg 1989). They also include location (Chomitz and Gray 1996), landowner characteristics (Lynch and Lovell 2003), government payments (Claassen et al. 2011), and attitudes about land conservation (Luzar and Diagne 1999), all of which are described in later in this chapter. A conservation easement program attempts to prevent land conversions by offering a payment, P, if the landowner agrees to keep their

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[1] This simple formulation can be expressed in terms of the optimal timing of conservation (Lynch and Liu 2003) or of conversion (Towe, Nickerson and Bockstael 2008). It can also be expressed as a function of scale of a farming or grazing operation or for larger land units (Lichtenberg 1989). However, the simple plot-level, single-time period formulation is sufficient to motivate the discussion of program impacts.

land in use 1. In the presence of an option to sell an easement, the landowner would convert his or her land from use 1 to use 2 if the returns to use 2, R_2, minus conversion costs, C, exceed the returns to use 1, R_1, plus the easement payment, P. The decision rule for converting from use 1 to 2 in the presence of an easement payment and as a function of the vector of factors that drive returns, X, is shown in equation (4).

$$R_2(X) - C > R_1(X) + P \qquad (4)$$

As a result of this formulation, land owners are assumed to enroll in a conservation program if the easement payment, P, outweighs the opportunity cost of converting the land from use 1 to use 2. This is shown in equation (5), in which the opportunity cost, $R_2(X)$-C- $R_1(X)$, is shown on the right-hand side. Unless the easement payment is calibrated to perfectly offset the opportunity cost, which may be difficult to estimate in practice, the vector of factors X will influence landowners' decisions both to convert their land and to enroll in the program. That is, both decisions will vary as a function of X. In particular, properties that have higher values of X, which are more likely to be converted, will be less likely to enroll in the program. This suggests that the very types of land that are most likely to convert are least likely to enroll.

$$P > R_2(X) - C - R_1(X) \qquad (5)$$

Empirical studies in a variety of locations and a variety of time periods have assessed both program enrollment and grassland conversion. These studies generally find that the set factors, X, that determine returns to higher intensity land use make a tract of land more likely to be converted and less likely to be enrolled in a conservation program. The results of these studies are described below.

Land Quality

The productive value of a tract of land, that is, the amount of a commodity it can produce per unit area, is driven by a vector of characteristics, including the depth of topsoil, the water-holding capacity of the soil and the steepness of terrain (Lichtenberg 1989). Following this logic, the lower intensity land use, ranching, is assumed to be more profitable on lower quality land and the higher intensity land use, cropping, is assumed to be more profitable on higher quality land. All other factors being equal, it is cheaper to grow crops on high quality land - land with fertile soil, plentiful water sources, a longer growing season and level ground for plowing. On low quality land, by contrast, cropping is more expensive, requiring extra fertilizer, additional irrigation, and time-intensive plowing. Ranching, however, may be profitable on such land, since cattle can feed on native vegetation which requires little maintenance, can utilize wetlands in natural depressions for watering holes, are more resilient than crops to fluctuations in weather and are relatively indifferent to steep terrain. Thus, on lower quality land, ranching will generate higher returns than cropping, whereas on higher quality land, cropping will generate higher returns than ranching. Correspondingly, lower quality land will also be best suited for a conservation easement, which generally restricts the higher intensity land use (cropping) but permits the lower intensity land use (grazing).

The relationship between land quality and agricultural land use is demonstrated at the county level by Lichtenberg (1989) and at the plot level by numerous subsequent studies. Empirical studies generally find that higher quality land is more likely to convert from grassland to cropland. Claassen and Tegene (1999) found that tracts of land with a higher value on a land quality index were more likely to convert to cropland between 1980 and 1987 in the Corn Belt. Claassen et al. (2011) found that land with higher values on the National Commodity Crop Productivity Index (NCCPI) were more likely to be converted to cropland and less likely to be hay/pasture, rangeland, or enrolled in the Conservation Reserve Program (CRP). Rashford, Walker, and Bastian (2010) find that tracts of land in the Prairie Pothole portions of Iowa, Minnesota, North Dakota, South Dakota and Montana with the highest quality soil were about five times more likely to convert to cropland than land with the lowest quality soil between 1982 and 1997. Stephens et al. (2008) find that native grassland in the Missouri Coteau of North and South Dakota was more likely to be converted to cropland if it was steeply sloped, had lower density of wetlands, experienced higher precipitation, and if there were more (sic) frost-free days. These findings are consistent with studies conducted in tropical areas showing that forested tracts with higher potential for cropland are more likely to be cleared (e.g., Chomitz and Gray 1996 and Cropper, Puri and Griffiths 2001).

Conversely, empirical studies also generally find that higher quality land is less likely to enroll in land conservation programs. Goodwin and Smith (2003) find that the decision to enroll in CRP was positively associated with soil erosion but not with land tolerance for erosion. Tanaka and Wu (2004) found that land was more likely to enroll in

CRP if it is on medium, as opposed to high, land capability class and if it had a high erodibility index but found no effect of precipitation. Shultz (2005) finds that tracts of land with deep, difficult-to-drain wetlands were more likely to enroll in the Wetlands Reserve Program (WRP). Lambert, Sullivan and Claassen (2007) find that highly erodible land and land that is distant from water are more likely to enroll in CRP. While a few studies show no effect of land quality (e.g., Cooper and Osborn 1998 and Johnson, Misra and Ervin 1997), the general conclusion of this body of literature suggests that land with high quality soil is more likely to be converted and less likely to be enrolled in a conservation easement program. This finding holds up with various measures of land quality in different locations and at different times.

Location

The classic von Thunen model predicts that the distance imposes a transportation cost, and therefore, that less intensive land use will occur further from central markets (Chomitz and Gray 1996). This finding is well-supported in studies of land conversion in developing economies, in which transportation may be more difficult and agriculture is more common. Chomitz and Gray (1996) find that distance to market makes land less likely to be converted from forest into agriculture between 1989 and 1992 in Belize. Nelson and Hellerstein (1997) find that accessibility to village centers is positively associated with irrigated cropland and negatively associated with forest in rural Mexico. Cropper, Puri and Griffiths (2001) find that the log of the distance to the nearest market is positively correlated and that population density is negatively correlated with clearing forested plots in Thailand.

The monocentric urban model extends von Thunen's theory to urban areas. The impact of distance to urban centers on residential land values is well-established for regions a monocetric city (Brueckner 1987) and empirical studies of regions dominated by a single, large city generally find that conversions are more likely at closer distances. Irwin, Bell, and Geoghegan (2003) find that the log of distance to DC and to the nearest small town are negatively associated with residential land conversion in Calvert County, Maryland. Helmer (2004) finds that distance to urban areas is negatively associated with land development in Puerto Rico. Wear and Bolstad (1998) find that distance to the nearest road and distance to the nearest market center were negatively associated with building density in Southern Appalachia. Cho and Newman (2005) find that distance to the city center is negatively associated with residential development in Macon County, North Carolina. A few studies find the opposite results. Newburn, Berck and Merenlender (2006) find that travel time to San Francisco is positively correlated with the development of both vineyards and residential structures in Sonoma County, California, though they note that this is contrary to expectations. Overall, however, literature indicates that distance to population centers is correlated with less-intensive land use.

Similar results are reflected in studies of programs of farmland preservation programs, which are designed to prevent farmland from being converted to urban land uses, and therefore, are consistent with the monocentric urban model. Studies of farmland preservation programs, in which farming is the lower intensity land use relative to urban development, show that distance to urban centers is positively associated with enrollment. Lynch and Lovell (2003) find that distance to the nearest city is likewise correlated with enrollment in a purchase of development rights program to protect farmland in Maryland. Similarly, Duke (2004) finds that distance to an urban center is positively correlated with enrollment in a farmland preservation program in Delaware.

Studies of the impact of location on decisions to enroll in programs designed to protect natural lands, however, have shown mixed results. Lambert, Sullivan and Claassen (2007) find that enrollment in CRP is not associated with being located in a metropolitan county. Likewise, Albers, Albo and Chen (2008) find no relationship between the distance to urban areas and the location of protected areas in California, Illnois or Massachusetts. Other studies have suggested the opposite effect. For example, Luzar and Diagne (1999) found that property owners who lived in a city of more than 10,000 people in Louisiana were more likely to enroll land in the WRP. In other studies, distance to a central market is often not studied, either because the data lack sufficient spatial resolution or because study areas are perceived to be homogenous with respect to this characteristic (Stephens et al 2008). Assessing the impact of location on land use and program enrollment decisions may encounter two problems. First, if the study area lacks a single market center but instead has polycentric markets, the proper form of the accessibility function has not been established either empirically or theoretically (Anas, Arnott and Small 1998). Second, protected lands can be left idle, used as working land for a lower intensity land use, or used as recreational areas. If they are left idle or used as lower intensity productive land, it is possible remote land would be more likely to enroll.

If they are used as recreational lands, however, it is possible that more accessible land would enroll in the program. This is because protected land has greater amenity value when located near population centers where such lands are rarer.

Returns to Land Use

Returns to land use are often proxied by land rental rates. Johnson, Misra and Ervin (1997) find that land is more likely to be re-cropped upon expiration of a CRP contract if the commodity base has a high value. Claassen and Tegene (1999) found that land is more likely to be converted from pasture to cropland with a higher difference in cropland versus pasture rental rates. Claassen et al. (2011) found that the allocation of land to cultivated cropland, hay/pasture, range or CRP is positively associated with the returns to the respective land use. Rashford, Walker and Bastian (2010) found that grassland in the PPR was more likely to convert to cropland where county-level returns per hectare are greater. Stephens et al. (2008) in a similar study area find conflicting results, with high county cropland value in one portion of the region being positively associated with grassland conversion and being negatively associated in another portion. Cooper and Osborn (1998) find that landowners' stated preference to re-enroll in CRP is negative associated with the market value of similar but unenrolled land.

In a residential setting, studies have drawn similar conclusions. Land is more likely to be developed if it has a high residential value (Bockstael 1996) in the Patuxent River Watershed in Maryland. Land is more likely to be developed with high land values in Macon County, North Carolina (Cho and Newman 2005). Land in Western Washington and Western Oregon is more likely to be developed if there is high forest rent (based on stumpage prices) (Kline and Alig 1999).

Government Payments

Government payments – either to protect land, in the form of an easement, or to convert land, in the form of crop subsidies – are associated with land use decisions. Easement payments can be thought of as returns to enrollment in an easement program. Not surprisingly, studies consistently show that enrollment is positively correlated with easement price. Cooper and Osborn (1998), Goodwin and Smith (2003), and Tanaka and Wu (2004) found that enrollment in CRP was positively associated with CRP rental rates while Claassen and Tegene (1999) found that CRP rental rates are negatively associated with conversion of pasture to cropland. Schultz (2005) finds that the offer price for a U.S. Fish and Wildlife Service (FWS) wetland easement in the Prairie Pothole Region is positively associated with the likelihood of enrollment. Government payments for agriculture, which generally support cropland, can be thought of as additional returns to cropping versus other land uses. Rashford, Walker and Bastian (2010) found that estimated county-level government payments were positively associated with land conversion to cropland. Claassen et al. (2011) found that federal crop insurance, marketing loans, and disaster assistance payments increased returns to cropping and incentivized conversion of land to cropland. Lambert, Sullivan and Claassen (2007), however, found that government payments are not associated with enrollment in CRP. Goodwin and Smith (2003) found that the decision to enroll in CRP was positively correlated with government payments, though they acknowledge that this was opposite to what they expected.

Non-Monetary Returns

In addition to monetary returns, landowners may decide to enroll land in a conservation program for non-monetary reasons. The Theory of Planned Behavior (Luzar and Diagne 1999) suggests landowners also value protecting land because doing so conforms with their values or perceived social norms. Having a positive attitude about land conservation, belonging to an environmental organization has a positive effect, and being informed about the program have a positive effect on enrollment in the WRP (Luzar and Diagne 1999). Based on a survey of landowners with conservation easements in the Midwestern United States, Farmer et al. (2011) identified several non-monetary motivations for enrolling land in a conservation easement, including personal connection to the land, concern for preserving nature, witnessing land development, loss of open space, cultural significance of the property, land provides resources for the community. However, this study did not obtain data from landowners without conservation easements and did not correlate these factors with enrollment decisions. Consistent with the predictions of the Theory of Planned Behavior that social norms influence landowner decisions, Lynch and Lovell (2003) find that hearing about a land conservation program through word-of-mouth or from a neighbor has a positive influence on enrollment in a purchase of development rights (PDR) farmland preservation program.

Landowner Characteristics

Demographic factors can influence the potential returns to land, and therefore, can influence land conversion and program enrollment decisions. These factors include the whether or not a landowner is engaged in off-farm employment, education level, and the age of the landowner. The literature produces contradictory findings, however, with regard to these factors. Studies have found mixed results of the impact of off-farm employment and landowner income. Skaggs, Kirksey and Harper (1994) suggest that those with off-farm employment are more likely to graze land and less likely to crop it because grazing has lower labor requirements and the work is more constant, both of which are conducive to having off-farm employment. They find that landowners with CRP contracts who are employed part-time are more likely to state that they will graze the land upon the expiration of their contract, which is consistent with maintaining the land in a lower intensity land use. Similarly, Luzar and Diagne (1999) find that landowners with an income greater than $55,000 are more likely to enroll in WRP. Other studies, however, find that income is positively correlated with enrollment in a land conservation program. For example, Cooper and Osborn (1998) find that landowners with higher incomes are less likely to re-enroll in CRP. The impact of landowner education on landowner decisions also leads to mixed results. College education is found to have a negative effect on enrollment in WRP (Luzar and Diagne 1999) and a positive correlation with planting crops (Johnson, Misra and Ervin 1997). Lambert, Sullivan and Claassen (2007), however, found that having some college education was not associated with enrollment in CRP. The impact of age on landowner decisions has also shown mixed results. Skaggs, Kirksey and Harper (1994) suggest that age is associated with a decreased willingness to convert land, and therefore, that older land owners are more likely to crop land upon the expiration of a CRP contract (since cropping was the base case). Similarly, Cooper and Osborn (1998) find that retired land owners are less likely to re-enroll in CRP, but Lambert, Sullivan and Claassen (2007) find the opposite, that landowners with more years of farming experience are more likely to enroll in CRP. Household size has also been shown to have mixed effects on program enrollment. Luzar and Diagne (1999) found that household size has a negative effect on WRP enrollment. By contrast, Lambert, Sullivan and Claassen (2007) the number of children under age 18 in the household is positively associated with CRP enrollment. In summary, there are no consistent findings regarding the impact of demographic factors on landowner decisions.

Scale and Conversion Costs

Land conversion and enrollment in land conservation programs is associated with the scale/focus of farming operations. Cooper and Osborn (1998) find that landowners' stated preference to re-enroll in CRP is positively associated with the number of acres in livestock in a nationwide sample. Tanaka and Wu (2004) find that the decision to enroll in CRP is negatively associated with the amount of land in cultivated cropland during the prior year. Johnson, Misra and Ervin (1997) find that landowners' stated preference to re-crop land after the expiration of a CRP contract is negatively associated with having a livestock operation, which is compatible with maintaining the land as rangeland rather than cropland. Lambert, Sullivan and Claassen (2007) find that enrollment in CRP (the land retirement portion) is positively associated with farm size and the proportion of owned land that is operated. By contrast, for the FWS wetland easement program, which operates at a small scale, Shultz (2005) found enrollment was not associated with the percentage of land in pasture, hay, or CRP. Other studies are based on NRI data which does not have spatial resolution that allows for the testing of these effects.

Probabilistic Models

The preceding discussion assumes that land use decisions are deterministic, yet in practical applications, returns are not known with certainty and decisions are stochastic. Actual decisions can be affected by unanticipated events, misjudgments, and incomplete information. As a result, the decision to convert a tract of land can be expressed as the probability that the returns from one land use exceed the returns from an alternative land use (Bockstael 1996). The probabilistic form of the landowner’s decision to convert a tract of land is shown in equation (6). Consider the matrix **X** to contain values for k attributes described in the preceding section as influencing landowner decisions for each of n tracts of land. Calculating the probability of conversion requires transforming the n×k attribute matrix, **X,** into a probability that ranges from 0 to 1 for each tract of land, often using either the logit or the probit framework. Using the probit model by way of illustration, the probability that a tract of land is converted, π_i, is determined by **X**, a k×1 vector of coefficients, $\boldsymbol{\beta}$, the cumulative probability density of the normal (Gaussian) distribution, Φ, and the random error term, ε. The equation for the normal probability (cumulative) density function is obtained in standard statistics textbooks. Tracts with higher values of $\boldsymbol{X\beta}$ are more likely to convert. The probability of conversion, π_i, represents the likelihood that a tract of land i would convert from a lower intensity land use to a higher intensity land use, given its characteristics. Conversely, π_i is the probability that conversion would be avoided on this tract of land if it were to enroll in a conservation program. In that sense, π_i it can be thought of a probabilistic version of the counterfactual.

$$\pi_i = pr(y_i = 1 \,|\, \boldsymbol{X_i}) = \Phi(\boldsymbol{X}_i\boldsymbol{\beta} + \boldsymbol{\varepsilon}_i) \qquad (6)$$

Land Conversion with the Option to Sell a Conservation Easement

The option to purchase a conservation easement makes it more profitable to refrain from converting land at all levels of $\boldsymbol{X\beta}$. This is expressed in equation (7), in which π_i', the probability of conversion is estimated in the presence of an easement, **P**, which is an n×1 vector of the per-acre price offered for an easement and in which $\boldsymbol{\gamma}$ is an indicator that equals 1 if the easement is sold and zero otherwise. Note that at all levels of $\boldsymbol{X\beta}$ this curve is lower than the curve for π_i, the probability of conversion without the option to sell an easement. This difference is greatest in the center, however, and smallest at the extremes. Intuitively, this is because tracts of land at the extremes have their minds made up. Tracts with very high value land will almost certainly convert and an easement will do little to change that decision. Conversely, tracts with very low value land will almost certainly not convert, and an easement can only slightly decrease their (already low) likelihood of converting. Tracts in the middle of the distribution are more easily influenced by changes in the relative returns from competing land uses. Mathematically, this occurs because the probabilities, π_i and π_i', are estimated via the normal distribution, which is dense in the center of the distribution and sparse in the tails.

$$\pi_i' = pr(y_i = 1|\boldsymbol{X_i}, \boldsymbol{P}) = \Phi(\boldsymbol{X_i\beta} - \boldsymbol{P\gamma_i} + \boldsymbol{\varepsilon}_i) \qquad (7)$$

The probability of land conversion in the presence of an option to sell a conservation easement, π_i', can be used to derive the probability that a tract of land enrolls in the program. Assume that a landowner can chose to either convert to a higher intensity land use, to enroll in the program or neither. If the landowner chooses neither, they might wait until future time period to convert (Town, Nickerson and Bockstael 2008) or they might wait for future time period to enroll (Lynch and Lovell 2003). However, considering an instantaneous decision made for a single time period, landowners who chose not to convert their land, and thereby to maintain their land in a less intensive use, can receive additional revenue by enrolling in the conservation easement program. That is, those who do not find it more profitable to convert with the option to sell an easement will find it optimal to enroll. Thus, the probability that a tract of land enrolls in the program is 1-π_i'.

Conservation Planning

The quality of habitat – in terms of its capacity to minimize species extinction and support viable populations – can be expressed as a function of its size. Assuming that the habitat objective is to protect a certain level of biodiversity, or to protect habitat that supports a given number of species, the minimum habitat requirements entail protecting sufficiently large patches of habitat (Bender, Contreras and Fahrig 1998). One of the earliest formalizations of the species-area relationship was Gleason (1922) who noted that the plant species observed in a sampling unit, referred to as a quadrat, increases logarithmically with the size of the quadrat. The concept was applied by Diamond (1975) to the study of island biogeography and who applied the concept to the optimal design of nature reserves. He observed that the number of species supported by a patch of habitat is correlated with its size and its proximity to other patches. Based on these findings, he concludes that larger nature preserves and nature preserves that are more connected to each other will be most effective at minimizing extinction rates. Relatedly, the size of a nature reserve has also been shown to increase the likelihood that species populations will survive. Larger nature reserves are more resilient to random shocks, such as the destruction of habitat by extreme weather or decimation of populations by disease (Soule 1985).

If the objective of a conservation program is to protect a certain number of species, the area required to support that number of species can be derived from the species-area curve. Species-area curves can assume several possible functional forms (Fanliang and Legendre 1996 and Tjorve 2003). Regardless of the functional form, however, the number of species increases with area (Tjorve 2003). To illustrate the role of the species-area curve in land conservation, the logarithmic form is given in equation (8), which attributed to Gleason (1922). The same results can be derived with the other functional forms. This equation shows that the number of species support by patch j, Sj, is determined by c and z, which are parameters to be empirically estimated, and the log of Aj, which is the size of the patch.

$$S_j = c + z \cdot log(A_j) \qquad (8)$$

Assuming that the conservation group desires to protect S* species, the required patch size, A_{min}, that will support that number of species can be derived from the species-area curve. This is shown in equation (9). With this framework, the objective of the conservation group would be to obtain and protect habitat patches of size A_{min}.

$$A_{min} = exp\left(\frac{S^* - c}{z}\right) \qquad (9)$$

Numerous algorithms have been developed to guide the design conservation of conservation reserves to meet various conservation objectives. The fundamental approach in the conservation planning literature is known as the “maximal coverage location problem” (Church and Revelle 1974). Its objective is to protect the smallest number of sites that meet a conservation objective, given that conservation budgets are limited. Recent extensions (Church, Stoms and Davis 1996) allow the algorithm to consider the fact that some potential sites may be irreplaceable, flexibility with regard to other factors, and complementarity among protected sites.

In order to protect a patch of habitat of a given size, A_{min}, a conservation group must identify a set of tracts that are unconverted, that collectively meet the minimum size threshold for a patch of habitat, and that are willing to enroll in the program. The probability that the tracts in a given patch of habitat, j, would enroll in a land conservation program is given by equation (10). The number of tracts in patch j is defined, according to the objectives of the conservation program, to be of size A_{min}. Assuming that each tract is of unit size (i.e., its area is equal to 1), the probability that the tracts in patch j can be enrolled is the sum of the probability of all tracts from i to A_{min} in patch j.

$$pr(A_j > A_{min}) = \sum_i^{A_{min}} (1 - \pi'_{ij}) \qquad \forall i \in j \qquad (10)$$

Traditional conservation planning approaches as described above, however, have not accounted for the probability that a tract of land would otherwise be converted or the cost to acquire the tract. While they focus on obtaining the highest quality habitat, they do not compensate for the tendency of landowners to enroll tracts of land with low probabilities of conversion. Newburn et al. (2005) describe several strategies for cost-effective targeting of protected land. To compensate for the tendency of tracts of land with the lowest probability of conversion being most likely to enroll in a land conservation program, the strategy proposed by Newburn et al. (2005) is for the land conservation program to target land based on its risk of conversion, its cost to acquire, and the expected ecological benefit it would provide. The objective function for the optimization problem faced by the conservation program, as expressed in equation 11, is to maximize the expected ecological benefit of protected land within a budget constraint. In this equation, B_i refers to the estimated ecological benefit (often expressed as species richness or biodiversity that a tract would contribute to a protected area); P_i refers to the cost of acquiring the tract; X_i indicates whether or the program decides to acquire tract i; E is the expectation function indicating that the equation yields the expected ecological value per dollar of the tract; and M is the budget constraint. The problem requires selecting the set of tracts, X_i, that produce the greatest expected ecological benefits within the budget constraint.

$$Max. E(B) = \sum_i \pi_i \left(\frac{B_i}{P_i}\right) X_i \qquad s.t. \sum_i X_i P_i < M \qquad (11)$$

An approximate solution to this problem can be obtained through a greedy algorithm, in which all tracts of land are sorted in order of their expected ecological benefit per dollar, $E(B_i)$, and tracts are acquired until the budget constraint is reached. This solution can expressed as a decision rule in which a tract is acquired if its expected ecological benefit per dollar exceeds the expected ecological benefit per dollar established by a threshold. The threshold incorporates the budget constraint and is established as the expected ecological benefit per dollar of the tract that would exhaust the budget if properties are ranked from highest to lowest. If a program has extensive data on the costs, benefits and risks, it can establish this threshold through a formal process. Otherwise, the program may use a combination of data, field evaluations, local knowledge, and experience to establish the threshold implicitly.

Empirical applications of this simple decision rule have shown that conservation programs can prevent more habitat loss for a given budget than other approaches (e.g., Babcock, Lakshminarayan, Zilberman 1996 and 1997, Ando et al. 1998, Polasky, Camm and Garber-Yonts 2001, Messer 2006, and Newburn, Berck and Merendlender 2006). The literature points out, however, that in practice, conservation agencies seldom adopt this decision rule. The fact that studies have only recently pointed out the potential efficiency gains, and the potential complexity in these methods, point out one reason why land programs may not be using them. Without using them, based on the summary of the literature in this chapter, conservation programs may be subject to adverse selection in program enrollment. This would lead to the properties that are at the lowest risk of conversion being most likely to enroll unless the program attempts to target properties with a greater conservation-benefit-per-dollar using the methods described above.

Chapter 3 – Methodology

This dissertation uses data on a federal grassland conservation program, operated by the U.S. Fish and Wildlife Service (FWS) in the Northern Plains of the United States, as a case study to test general hypotheses about the impact of land conservation programs. This dissertation seeks to answer the following research questions: (1) What factors influence the enrollment of tracts in a grassland conservation easement program? (2) How much grassland conversion was avoided because of the program? To answer these questions, data from the FWS grassland easement program in north central South Dakota is used to estimate propensity scores, that is, the probability that a tract of land enrolled in the program between 1990 and 2001. Treated tracts are matched to control tracts and the treatment effect is estimated by comparing rates of land conversion for these groups between 2001 and 2006.

Research Design

The research design entails using Propensity Score Analysis (PSA), which corrects for the non-random assignment of tracts into the conservation program and allows for an estimation of counterfactual rates of land conversion. This entails the following steps: calculating the economic and ecological characteristics of tracts using a Geographic Information System (GIS); assessing the spatial clustering of program enrollment decisions; estimating the propensity of a tract to enroll in the program using a logistic regression model; matching treated (i.e., enrolled) tracts to otherwise similar control tracts using the estimated propensity scores; and estimating treatment effects by comparing subsequent rates of land conversion between treated and control tracts. This chapter describes each of these steps in detail.

Study Area

The study area is a portion of the Prairie Pothole Region of the Northern Plains of the United States where the U.S. Fish and Wildlife Service (FWS) has operated a grassland easement program since 1990 and a wetland easement program since 1959 (US GAO 2007). See map in figure 1. The region provides critical breeding habitat for grassland birds, such as mallard, gadwall, blue-winged teal, northern shoveler and northern pintail (Reynolds et al. 2006). Grasslands and wetlands complement each other to provide habitat, as these grassland birds use grasslands as nesting areas and wetlands as foraging areas (Reynolds et al. 2006).

Prior to European settlement, the region was covered in prairie grasslands and wetlands, which supported abundant populations of waterfowl. As of 2001, more than half of the land in the study area had been converted to cropland.[2] In recent years, grassland conversion has been slow but significant. Using “new breakings” data from the Farm Services Agency (FSA), Stubbs (2007) reports that 102,571 acres of native

[2] This is based on GIS calculations performed for this dissertation and described in subsequent sections.

grassland were converted to cropland in South Dakota between 2005 and 2006. Using LANDSAT imagery, Stephens et al (2008) estimated that 0.4 percent of native grassland in the western portion of this region was converted to cropland each year between 1989 and 2003. Using data from the National Resources Inventory (NRI), Rashford, Walker and Bastian (2010) estimated 1.3 percent of grassland converted to cropland each year between 1982 and 1997 for the Prairie Pothole Region. During this period, the probability of conversion varied significantly across the study area. In South Dakota, for example, grassland parcels with the highest quality soil were about five times more likely than those with lowest quality soil to convert to cropland (Rashford, Walker and Bastian 2010).

To prevent such habitat loss, the FWS program purchases two types of conservation easements. Grassland easements allow landowners to graze cattle on the land during certain times of the year but restrict them from harvesting hay during the spring nesting season and from planting crops at all (US GAO 2007). Wetland easements restrict landowners from draining, filling, or altering the hydrology of wetlands (US GAO 2007). The program purchased 1,447,000 acres of wetland easements between 1959 and 2006 and 906,000 acres of grassland easements between 1990 and 2006 (US GAO 2007). This dissertation focuses on the grassland easement portion of the program. The agency's goal is to protect an additional 10.4 million acres of grassland, which amounts to approximately 16 percent of the 64-million acre Prairie Pothole Region (US GAO 2007).

The study area is the central western portion of the Prairie Pothole Region. It is defined by the boundaries of the Prairie Pothole Region to the west, the border of

North and South Dakota to the north, and the extent of Public Land Survey System (PLSS) data to the south and the east. (See figure 1). The study area was defined by these boundaries for several reasons. First, the area is defined by the overlap of spatial data that could be obtained for the conservation easement program and the area that is covered by the Public Land Survey System (PLSS), which is described below. Second, the area has a high concentration of tracts enrolled in the FWS program and a comparatively low concentration of tracts enrolled in the Conservation Reserve Program (CRP), which could bias program estimates. Third, the scale of the study area – which encompasses most of 13 counties – is comparable to the scale at which most regional planning models are developed. These reasons make the study area both feasible to develop an analysis and provide an opportunity to address common challenges that might be commonly faced in developing regional models.

Propensity Scores

To estimate the impact of a conservation easement program, one must confront what has been called "the fundamental problem of causal inference" (Holland cited in Guo and Fraser 2010). To estimate the impact of the program, one needs to compare the actual rate of conversion on enrolled tracts to the counterfactual rate of conversion on similar tracts. Since tracts of land with conservation easements are likely to differ from other tracts of land on key covariates, it is not sufficient to assume that rates of conversion on protected tracts would equal rates of conversion on unprotected tracts (Ferraro 2009).

Propensity Score Analysis (PSA) can be used to address this complication, which arises from the non-random assignment of easements to properties. A propensity score is an estimate of the likelihood that a tract of land is conserved, given its characteristics (D'Agostino 1998). If two tracts of land have the same propensity score, yet one tract is placed under a conservation easement and the other one is not, we can treat these two tracts of land as having randomly been assigned to receive an easement; by comparing outcomes (e.g., land use change) between the two tracts we can infer the effect of the program (D'Agostino 1998). The validity of PSA for drawing causal inferences about program effects depends upon the following two assumptions being met. First, the Conditional Independence Assumption (CIA) requires that selection of a property into either the treatment group (those with easements) or into the comparison group (those without easements) is determined only by observable factors (Caliendo and Copeinig 2005). Second, the assumption of Common Support requires that, for a given set of values of the covariates, it is possible for a property to be either in the treatment group or in the comparison group; that is, there must be some untreated tracts of land that are similar to treated tracts (Caliendo and Copeinig 2005).

Oftentimes, propensity scores are used to match treated cases with similar untreated cases in Propensity Score Matching (PSM). For example, Lynch and Liu (2007) use PSM to evaluate Maryland's Rural Legacy program. Similarly, Andam et al. (2008) use PSM to assess the impact of protected areas on deforestation in Costa Rica. If the above conditions are met, the two groups can be considered equivalent on their observable characteristics and their outcomes can be compared in the same way that the outcomes of a treatment and control group in a randomized experiment would be compared. Using data obtained through a spatial analysis, which is described in the next section, this dissertation employs a Propensity Score Analysis, which is in the subsequent section.

Spatial Analysis

The study region is divided into a lattice of square tracts based on the Public Land Survey System (PLSS). The PLSS demarcates land into sections of 640 acres, into quarter sections of 160 acres and into quarter-quarter sections of 40 acres. Based on visual inspection of land cover and enrollment in conservation easement programs generally correspond to the boundaries of quarter-quarter sections. (See figure 2). Therefore, this analysis uses 40-acre tracts as the fundamental unit of analysis. This framework follows Stephens et al. (2008) who used 40-acre tracts in their study of grassland conversion in the region and Reynolds et al. (2006) who used 40-acre tracts as the cell size for their model of the accessibility of grassland tracts to nesting pairs of migratory birds. The study area for this analysis, using quarter-quarter sections as the unit of analysis, contains 221,224 tracts, which is equivalent to 13,800 square miles covering 13 counties.   I used the Model Builder application in ArcInfo 10.3 to process each of the data layers described below and to attribute a value for them to each of the 221,224 tracts on the lattice.

Tract Enrollment

To determine which tracts were enrolled in the program, boundary shapefiles of grassland easements purchased between 1990 and 2006 were obtained from FWS. A spreadsheet of purchase prices and purchase dates, also obtained from the FWS, was merged with the shapefile. Between 1990 and 2006, the FWS purchased 1,729 grassland easements in the study area totaling 466,356 acres. The mean acreage for these grassland easements is 270 acres, but the size varies greatly. The standard deviation is 394 acres and the size ranges from 25 acres, at the fifth percentile, to 733 acres at the 95th percentile. For the most part, 40-acre tracts were either completely contained by grassland easements or were completely not eased. Approximately 10 percent of tracts, however, were partially covered by an easement. Based on visual inspection, this is largely the result of measurement differences between the easement boundary dataset and the PLSS boundary file. Of the tracts that were partially covered by an easement, 1.6 percent were covered by fewer than 10 acres and were considered unenrolled in the program; 10.2 percent were covered by between 10 and 35 acres and were considered to be enrolled in the program; and 88.2 percent were covered by 35 or more acres and were also considered to be enrolled in the program. To compensate for irregularities in easement boundaries, I clipped tracts in the latter two categories by the boundaries of the easements rather than including the entire 40-acre tract. This results in some small amount of heterogeneity of tract size, but ensures that all of the land within each tract that is considered to be enrolled was actually enrolled in the program.

Tract Eligibility

Of the 221,224 40-acre tracts in the study area, only those with sufficient grassland coverage that were under private ownership were eligible. The 2001 National Land Cover Database (NLCD) is used to determine whether each tract had sufficient grassland coverage to be eligible for the program. The dataset was downloaded from http://www.mrlc.gov/. The 2001 NLCD data are based on satellite imagery at 30-meter resolution that is processed into one of 16 land cover categories for inland portions of the continental United States based, which are based on the Anderson classification system (Homer et al 2004). The major land uses in the study area were as follows: cultivated crops (39.6 percent of the area); grassland/herbaceous (33.6 percent); pasture/hay (18.2 percent); open water (2.3 percent) and emergent herbaceous wetlands (2.3 percent). Figure 3 shows land cover in the study area according the NLCD 2001. The NLCD 2001 database (Homer et al. 2004) defined these land use categories are defined as follows:

- Cultivated crops are “areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled."

- Grassland/Herbaceous areas are "Dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing."
- Pasture/Hay are "Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation."
- Open water is "All areas of open water, generally with less than 25 percent cover of vegetation or soil."
- Emergent herbaceous wetlands are "Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water."

Determining which tracts were eligible for enrollment in the program based on their land cover was not simply a matter of selecting all tracts classified as grassland/herbaceous. In particular, the NLCD is based on satellite observations, while FWS decisions are based on field inspections by biologists (GAO 2007). Therefore, the land cover categories from NLCD do not necessarily correspond to the way in which agency officials would categorize land for conservation purposes. To address this issue, I used NLCD 2001 data to calculate the land cover for tracts that were covered by a grassland easement. Based on this calculation, enrolled tracts contained a total of 62 percent grassland/herbaceous, 32 percent pasture/hay, 2 percent wetland, 2 percent open water, and 1 percent cropland overall. For any given tract, the relative percentages of these land covers varies greatly. Based the scoring sheet used by FWS officials to evaluate potential land for conservation, I determined each tract should have at least 50 percent of grassland/herbaceous and pasture/hay combined and that it should have no more than 40 percent wetland or open water. Because of the potential for measurement error in satellite data, I allowed eligible tracts to contain as much as 10 percent cropland. By applying these criteria to all tracts in the study area, 104,485 40-acre tracts (or 47 percent) would be eligible for enrollment based on their land cover. There was a small number of tracts that were covered by easements but that did not meet these land use criteria. Since the satellite data do not provide perfect measurement, I assumed this was the result of measurement error in the NCLD data and these tracts were removed from the analysis.

The second major eligibility requirement is that enrolled tracts be located on private property that is not covered by a conservation easement. To apply this requirement to the sample data, I removed tracts of land that were either public or that were enrolled in a conservation easement program. Details about the major types of public land and conservation easement programs operating the study area are provided in table 1. For some of these programs, current spatial data were unavailable, and therefore, tracts enrolled in these programs could not be removed from the analysis. These cases are discussed below. Both the South Dakota state government and the federal government own tracts of protected habitat in the study area. The South Dakota School and Public Lands provide grazing, farming, oil, mineral, and gas leases to raise money for public schools; South Dakota Game, Fish, and Parks Lands are managed for recreation; and South Dakota Game Production Areas are maintained as wildlife habitat. Shapefiles of these tracts were obtained from http://arcgis.sd.gov/server/sdgis/Data.aspx. The FWS manages several federal wildlife refuges, wetland management districts and fee-simple lands for habitat protection. Shapefiles of these tracts were obtained from the FWS and are also available from http://arcgis.sd.gov/server/sdgis/Data.aspx.

In addition to protected public land, several conservation easement programs operate on private land in the study area. The National Resource Conservation Service (NRCS) and the Farmland Services Agency (FSA) of the U.S. Department of Agriculture (USDA) administer several conservation easement programs that restrict cropping on potential migratory bird habitat. The Wetland Reserve Program (WRP) and the Emergency Wetland Reserve Program (EWRP), which were created in 1985, entail both temporary and permanent easements that restrict cropping on both wetlands and the surrounding uplands. The Grassland Reserve Program (GRP), which was created in 1996, offers both permanent and temporary easements that protect and restore grasslands while allowing grazing. The Emergency Watershed Protection Program (EWPP), established in 1996, offers permanent easements on wildlife habitat in floodplains. GIS data for the NRCS programs were downloaded for the most recent year. Because these data were not current for the study period, and because a visual inspection indicated they had a very small presence in the study area, these data were not used in the analysis.

Among private conservation easement programs, the major one is Ducks Unlimited. A shapefile of the centroids of Ducks Unlimited easements was obtained from Ducks Unlimited at www.ducks.org. Table 1 contains a summary of each of these programs.

Shapefiles of these tracts were overlaid upon the lattice of 40-acre tracts in the study area. For the most part, the boundaries of these public and protected lands correspond to the boundaries of the 40-acre tracts defined by the lattice. In some cases, however, the protected areas have irregular boundaries. In such cases, I defined as tract as protected areas as follows. If more than 20 percent of a tract overlaps with one of these easements, I considered the entire tract to be protected. If less than 20 percent overlaps, I considered the entire tract to be unprotected. Because Ducks Unlimited collaborates with FWS on the purchase of many conservation easements in the study area, many of the centroids fell within the boundaries of FWS grassland easements. Those that fell outside of these boundaries were assumed to have the same average size as FWS easements. Thus, all tracts that contained the centroid for a Ducks Unlimited and the surrounding eight tracts were considered to be enrolled in a Ducks Unlimited easement program. Ducks Unlimited operates several types of land conservation programs, some of which relate to restoration and conservation practices as opposed to land preservation per se. Thus, only those points classified land preservation programs in the Ducks Unlimited data were considered to be enrolled as conservation easements. Based on this classification system, 4,324 of the 221,224 tracts in the study area (2 percent of the total area or 4 percent of the tracts with eligible land cover) are either public land or are enrolled by one of the above easement programs.

After selecting tracts based on land cover and conservation status, 100,161 (45 percent) of the 221,224 tracts in the study area were selected as eligible for enrollment in the program in 2001. Of the eligible tracts, 9,296 (9 percent) enrolled in the program between 1990 and 2001 and the remaining 90,865 (91 percent) did not enroll. This distinction forms the dependent variable for the subsequent regression models, in which Y=1 if enrolled and Y=0 if eligible but unenrolled. A close-up map illustrating a typical spatial distribution of ineligible, enrolled, and unenrolled tracts is shown in figure 4.

Data for one conservation program, the Conservation Reserve Program (CRP) and the Conservation Reserve Enhancement Program (CREP), are not publicly available at the disaggregate level. As a result, it was not possible to eliminate these tracts from the set of eligible tracts.

Tract Characteristics

Based on the results of the literature review described in the previous chapter, I identified factors related to the probability that a tract of land would enroll in the program, and correspondingly, the probability that a tract of land would convert from grassland to cropland. In general, factors related to cropland value are hypothesized to be negatively related to enrollment while factors related to the habitat value of land are hypothesized to be positively related. The factors measured for this analysis include soil productivity, slope, wetland density, accessibility to nesting pairs of migratory birds, grassland coverage, distance to the nearest grain buyer and distance to the nearest town and the extent of enrolled tracts in surrounding tracts. A complete list of the variables calculated for each tract is show in table 2.

Soil productivity is hypothesized to make tracts of land more likely to convert to cropland and less likely to enroll in a conservation program. The National Commodity Crop Productivity Index (NCCPI) is used to measure the value of a tract of land for growing commodity crops, such as corn, soybeans, or wheat (NRCS 2008). The NCCPI is based on a computational model that estimates cropland productivity based on inputs such as number of growing days, level of precipitation, and soil type. The index ranges from 0.0 to 1.0, with values of 1.0 being the highest quality cropland and values of 0.0 being the lowest quality. It produces an estimate for each soil unit delineated in the Soil Survey Geographic (SSURGO) database. The SSURGO database is populated by data from field soil samples methods and catalogues the soil type for mapping units, which are defined as areas with a homogenous soil type. The typical 40-acre plot in the study area contains multiple mapping units. A text file of the NCCPI values for each soil unit in the study area was obtained directly from the developer of the NCCPI model[3] and the GIS shapefiles for the corresponding soil mapping units were obtained from the NRCS website at http://soils.usda.gov/survey/geography/ssurgo/. For each 40-acre tract, I calculated the average NCCPI value weighted by the area of each SSURGO soil unit covering each 40-acre tract. A close-up of NCCPI values overlaid with the tract boundaries appears in figure 5. NCCPI is hypothesized to be negatively correlated with enrollment decisions, as the owners of more agriculturally valuable land are less likely to

[3] Robert Dobos, NRCS, personal communication, December 10, 2010.

restrict their land from conversion, and to be positively correlated with conversion for the same reason. It is presumed that fertile soil has little additional value for grazing cattle, which is allowed with a conservation easement, but considerable additional value for growing crops, which is not allowed with an easement.

Steeply sloped land is hypothesized to be less likely to be converted to cropland and more likely to enroll in a conservation program. The National Elevation Dataset (NED) is a raster file that indicates elevation at 200-meter resolution. The NED is produced by the U.S. Geological Survey (USGS) and was downloaded from the agency's data warehouse site at http://seamless.usgs.gov. I converted the elevation data to percentage slope using the Slope tool in the Spatial Analyst Toolbox of ArcInfo version 10.3. The map of the entire study area with the average slope associated with each tract appears in figure 6. I then calculated the average slope for each 40-acre tract in the study area. Steeply sloped land is harder to farm, because of the difficulty in operating farm equipment yet it is suitable for grazing cattle since they would be relative indifferent to steep slopes. Furthermore, rates of soil erosion are generally higher on steeper slopes, making the soil less viable for cropping in the long term. For these reasons, it is hypothesized that slope will be positively correlated with decisions to enroll in the program and negatively correlated with decisions to convert land from rangeland to cropland.

Tracts of land with greater wetland density are hypothesized to be less likely to be converted to cropland and more likely to be enrolled in a conservation easement program. The National Wetlands Inventory (NWI) is used to measure the density of wetland basins. NWI is based on a national survey of the United States in which all wetland basins were identified, classified and their boundaries delineated. The process entailed visual inspection of aerial photographs according to a set of classification rules developed by Cowardian (Wilen and Bates 1995). I downloaded NWI data from http://www.fws.gov/wetlands/data/. I tallied the perimeter of all wetland basins within each 40-acre tract in the study area. Wetland density, particularly as measured by the total length of wetland perimeters, has been shown to be a nuisance for farmers and an amenity for grassland birds. For example, Gelso, Fox and Peterson (2008) showed that farmers find that it is easier to maneuver farm equipment around one large wetland than it is among numerous small wetlands that collectively sum to the same area. Therefore, this measure is hypothesized to be positively correlated with enrollment in the conservation easement program and negatively correlated with conversions to cropland. A close-up of this measure, along with both wetland basin and tract boundaries, appears in figure 7.

Accessibility between grasslands, where grassland birds maintain their nests, to wetlands, where grassland birds feed, is hypothesized to make a tract of land more likely to enroll in the conservation easement program. Breeding Pair Accessibility Maps measure the accessibility of each tract of grassland to nearby wetlands (Reynolds et al. 2006). The maps are based on field data collected by observing the density of mallard ducks, blue-winged teal, gadwall, northern pintail, and northern shovelers at 2,800 wetlands each spring between 1987 and 1998 (Reynolds et al. 2006). These data were fitted to regression models and the parameter estimates combined with the known distance that hens will fly from wetlands to their nests. The resulting map estimates the maximum number of nesting pairs that would be able to access a given 40-acre tract from neighboring wetlands. The map was obtained as a shapefile from FWS and appears in figure 8. Because these accessibility maps are a primary means by which the FWS targets land for protection (GAO 2007), it is hypothesized that tracts with higher breeding pair accessibility will be more likely to enroll in the conservation program, but that this measure will not influence land conversion decisions.

Distance to agricultural markets is assumed to make a tract of land more likely to enroll in a conservation program and less likely to convert from grassland to cropland. Distance to market was measured in two ways. The first measure is the Euclidean distance between each 40-acre tract and the nearest state-certified grain buyer. Grain buyers can include grain elevators, warehouses, ethanol processing plants and other facilities that are licensed to purchase grain. The list of state-certified grain buyers in South Dakota was obtained from the South Dakota Public Utilities Commission, which regulates these facilities, at http://puc.sd.gov/. The locations of these facilities were determined by matching the cities and towns in which these facilities are located with the locations of cities and towns of the same name in the U.S. Census. There were 80 facilities in the study area and the adjacent counties. A second measure was the distance to cities and towns of more than 2,500 people in the study area using data from the 2000 Census. There were 5 such cities and towns in the study area and the adjacent counties. The study area has a rectilinear road network with no urban areas that would create congestion, so Euclidean distance is presumed to be a valid measure of accessibility. It is assumed that transportation costs would be minimal for land that is not under production, which might be the case for tracts enrolled in the conservation program and that it would be higher for cropland than rangeland, since planting crops requires greater capital investment and labor costs. A map of the locations of grain buyers, cities and towns appears in figure 9.

Omitted Variables

While omitted variable bias is always a concern in specifying regression, models it is a particular concern when estimating the impacts of land conservation programs. As described earlier, Propensity Score Analysis is only valid for causal inferences if the selection process, by which some tracts of land enroll in the program and others do not, is based on observable factors (Guo and Fraser 2010). As described later, the estimates from spatial regression models can be biased if observed variables that are included in the model are correlated with unobserved by spatially correlated variables (LeSage and Pace 2010). Therefore, it is important to fully account for conceptually important predictors in studies of the impact of land conservation programs, and if not, to employ methods to account for potential biases that might be introduced by the omission of these variables.

In spite of the importance of accounting for all conceptually important factors, very few studies of land use and land cover change actually do so. This is likely because of the practical obstacles to compiling the multiplicity of data sources required. In particular, studies that include data on landowner characteristics, such as values, skills, and resources, often lack data on geographic factors, such as soil, slope and location, and vice versa. If data on land characteristics are obtained for a sufficiently long enough time period to observe land cover change, it is often impossible to reconstruct comparable landowner data, given difficulties in identifying, contacting and surveying landowners. In other instances, privacy restrictions prevent data from being used to obtain the full range of relevant variables to assess land cover change. Other studies have both land and landowner data but lack data on surrounding land. In most studies of grassland conversion or cropland use in the United States, these studies use data from the National Resource Inventory (NRI) (Claassen and Tegene 1999, Lewis and Plantinga 2007, Lubowski, Plantinga and Stavins 2008, Rashford, Walker and Bastian 2010, and Claassen et al. 2011) or the Forest Inventory and Analysis (FIA) (Kline and Alig 1999), which are publically available dataset that contains tract-specific data on land use and landowner characteristics for a representative sample of the 48 contiguous United States. For privacy reasons, however, the exact locations of NRI data points are not revealed. This precludes their use to understand interaction effects, spillover effects, or neighborhood effects more generally. A small number of studies include both spatial and survey data, such as Lynch and Lovell (2003) who estimated the probability of enrollment in a farmland preservation program using data obtained from both a survey of landowners and a GIS analysis of properties, though studies that combine landowner and land characteristics are rare.

Similar to this general body of literature, this dissertation employs data on some important characteristics but not all. In particular, this study omits data on the returns to various land uses and on landowner characteristics. To estimate the returns to various land uses, most studies use county-level averages, although these studies generally deal with larger studies areas that provide a sufficiently large number of counties. For example, Lubowski et al. (2006) uses county-level returns to study land conversion for the contiguous 48 states and Rashford et al. (2010) and Claassen et al. (2011) use county-level returns in their studies that cover much of the Northern Plains. The study area for this dissertation is substantially smaller, however, as it only includes 13 counties. Because of the small number of counties in the study area, because the study area is relatively homogenous in terms of these values, and because these indicators would be fairly crude measures of most of the variables of concern, it was determined that county-level data would not be sufficiently precise or informative in this study.

Most studies that obtain data on landowner characteristics do so through surveys administered directly to landowners. For example, Luzar and Diagne (1999) surveyed landowners in Louisiana about their decisions regarding enrollment in the Wetland Reserve Program (WRP). Surveying landowners was not feasible in this dissertation, however, for two reasons. First, the names of landowners were not available in this dataset and public land records, which might be used to link properties to landowners, are generally only available through personal visits to county courthouses in the study area. More importantly, many of the program enrollment decisions in this study occurred as early as 1990 and the most recent decisions were made in 2001. Even if the owners of sample tracts from that time period could be identified, being able to contact them and obtain valid responses to survey questions would be practically difficult if not impossible. For the reasons described above, this dissertation primarily employs data about the physical characteristics of tracts and their surroundings. Therefore, the relationships modeled with this analysis are based on the stable, underlying land characteristics.

The Join Count Statistic

The join count statistic (Cliff and Ord 1973) is used to measure spatial autocorrelation of categorical variables. Several authors have used this statistic to assess spatial autocorrelation of land use decisions and as a preface to constructing discrete choice models of urban development (Ding 2001) and rural development (Cho and Newman 2005). The units of analysis for the join count statistic are the pairs of locations that are spatially connected. Each pair of locations is referred to as a 'join.' In the simplest and most common case, cells are determined to be spatially joined based on their relationship with their immediate neighbors. This is referred to as a first-order join. A first-order join can be defined as cells that share a common edge, cells that share a common vertex, or cells that share either a common edge or a common vertex (Cliff and Ord 1973). In the first case, known as the rook's connectivity, a cell would have four joins corresponding to its neighbors directly to the north, south, east and west. In the second case, known as the bishop's connectivity, a cell would have four joins corresponding to its neighbors immediately to the northwest, northeast, southeast, and southwest. In the third case, known as the queen's connectivity a cell would have eight joins, which would include all of the joins in the rook's connectivity and all of the joins in the bishop's connectivity. Under any of these definitions of connectivity, a join between two cells i and j is indicated by the variable wij, which equals 1 if cells i and j are joined and equals zero otherwise. The complete NxN matrix of weights, which indicates whether each pair of cells i and j are connected, is known as the spatial weight matrix W.

For a dichotomous variable, such as whether or not a property enrolls in a conservation program, three join count statistics can be produced. These statistics correspond to the three possible combinations of categories: (1) the number of joins in which both tracts are enrolled; (2) the number of joins in which both tracts are unenrolled; and (3) the number of joins in which one tract is enrolled and the other tract is not enrolled. I will refer to these three possible statistics as EE joins, UU joins, and EU joins, respectively. Below, equation 12 specifies the join count statistic for EE and UU joins and equation 13 specifies the equation for EU joins. The terms xi and xj, respectively, equal 1 if tract I or tract j is developed and equal zero otherwise. Equation 14 sums the total number of joins in which both tracts in the join fall into the same category. It is specified below as EE, referring to both tracts being enrolled in the program, but the same equation would apply to the case in which both tracts are unenrolled (UU). Equation 16 sums the total number of joins in which the two tracts in a join fall into different categories. In the present study, this would be the case in which one tract is enrolled in the program and the other is unenrolled (EU).

$$EE = \frac{1}{2}\sum_{i}\sum_{j} w_{ij}\, x_i x_j \qquad (12)$$

$$EU = \frac{1}{2}\sum_{i}\sum_{j} w_{ij}\left(x_i - x_j\right)^2 \quad (13)$$

The join count statistics presented in equations 15 and 16 can be used to gauge whether a dichotomous variable exhibits positive spatial autocorrelation, negative spatial autocorrelation or spatial randomness. Positive autocorrelation is measured by both equation 12 and equation 13. Equation 12 increments for each join in which both cell i and cell j are in the category. If either of the cells is not in the category, or if both of the cells are not in the category, it is not incremented. Thus, a high value of equation 12 indicates positive autocorrelation. Conversely, equation 13 increments for each join in which cell I and cell j are in *different* categories. Thus, a low value of equation 13 indicates positive autocorrelation. Negative spatial autocorrelation would be measured by a low value for equation 12, which would indicate that the same type of tracts are unlikely to occur together, and by a high value for equation 13, which would indicate that different types of land are likely to neighbors.

The measures on these join count statistics can be compared to that which would occur under complete spatial randomness, in which a tract is neither more likely nor less likely to be enrolled if its neighbor is enrolled – in other words, if knowing the enrollment decision of a tract tells you nothing about the enrollment decision of its neighbor; the two decisions are complete independent of each other; and, it would occur if a farmer's decision about how to use one section of land is uninfluenced by his decision to use another section of land. This might occur if there were no economy of scale in farming decisions and no desire on the part of conservation groups to protect uninterrupted patches of habitat. Economic theory and ecological theory suggest the exact opposite, to complete spatial randomness serves as the null hypothesis. Complete spatial randomness would be suggested if the observed number of joins, as calculated by the join count statistics in equation 12 and 13, is not significantly different from the expected number of joins. The expected number of joins for any given combinations of values is based on the total number of joins at a given distance, the total number of cells of a given value in the lattice, and the assumption that, if they were distributed with complete spatial randomness, the probability of any given cell being E would be independent of the probability of any other cell being B. Thus, the expected number of EE joins at a given distance class is the total number of joins at that distance class time the probability that one of the cells in the join would be E (pr(B)) times the probability that the other cell in the join would be B. This is given in equation 14. The equations to calculate the expected number of EE joins is given in equation 14 and to calculate the expected number of EU joins is given in equation 15.

Generally speaking, these equations assume that, if E cells and U cells were distributed completely at random, the number of joins of any given type would be proportional to the overall number of cells of a given value in the lattice. More specifically, the first term of the equation, which is one half of the double summation of the matrix weights i and j, represents the total number of joins between cells of any given type in the lattice. nE represents the total number of E cells in the lattice and N represents the total number of cells in the lattice. The ratio between them expresses the proportion of E cells in the lattice. That represents the probability that any given cell in the lattice is B. Under complete spatial randomness, the probability that its neighbor would be E is one minus n_E (removing the first cell) divided by one minus N (removing the first cell from the denominator). The product of these two represents the probability that two cells would be the same color if value were distributed randomly. Multiplied by the total number of joins it produces the expected number of EE joins under the assumption of complete spatial randomness. If the observed number of EE joins exceeds this number, it indicates that EE joins are more common than expected, and therefore, that the data/obs are clustered. The equations for the variances of these statistics are lengthy; they are omitted here for simplicity, but can be found in Cliff and Ord (1973, pp. 14-15).

$$\mu_{EE} = \frac{1}{2}\sum_{i}\sum_{j} w_{ij} \left(\frac{n_E}{N}\right)\left(\frac{n_E - 1}{N - 1}\right) \tag{14}$$

$$\mu_{EU} = \sum_{i}\sum_{j} w_{ij} \left(\frac{n_E}{N}\right)\left(\frac{n_U}{N - 1}\right) \tag{15}$$

To detect spatial autocorrelation, the observed numbers of joins in equations 15 and 16 are compared to the expected number in equations 14 and 15. Combining the variance with the observed and expected number of joins of a given type, the join count statistic can be transformed into a standard normal deviate and tested for statistical significance. As an example, the equation for a standard normal deviate for joins of the same type is shown in equation 16 for EE, in which σ_{EE} is the variance of the join count statistic in equation 12.

$$z_{EE} = \frac{(EE - \mu_{EE})}{\sigma_{EE}} \qquad (16)$$

The discussion above describes join count statistics for first-order neighbors. While the statistic is usually limited to first-order neighbors, Cliff and Ord (1973) wrote that "there is nothing in the structure of the tests" to prevent it from being used "to determine how the autocorrelation function decays over space." Such an analysis has been conducted in a few instances, such as McDonald and Urban (2006) who use the join count statistic to develop a correlogram, which examines spatial autocorrelation as a function of distance. Although the standard method is to have binary weights of first-order, neighbors, the method can be generalized to non-binary weights and multiple distance classes. To accommodate distance, equations 12 and 13 can be rewritten as equations 17 and 18 in which the spatial weight matrix, and therefore the join count statistic, is a function of the distance (d) separating two locations in a join (Fortin and Dale 2005). Equations 14 and 15 can likewise be modified to be expressed as a function of distance, with a different set of spatial weights for each distance interval.

$$EE(d) = \tfrac{1}{2}\sum_{i}\sum_{j} w_{ij}\,(d) x_i x_j \qquad (17)$$

$$EU(d) = \tfrac{1}{2}\sum_{i}\sum_{j} w_{ij}(d)\left(x_i - x_j\right)^2 \qquad (18)$$

By plotting the observed versus expected join count statistics for various distance classes, one can examine the extent to which spatial autocorrelation varies with distance. In the formulation described above, each successive distance weight matrix would appear as a series of concentric rings in which each target cell is compared to the ring of cells located at a specified distance from it. The join count statistic for various distance classes continues this calculation for successively larger and larger rings of cells.

In order to accurately test whether the observed autocorrelation is statistically significant, it is necessary to adjust the significance levels for conducting a statistical test at each distance class. Because each statistical test is associated with some random probability that a relationship could be detected, the more tests that are conducted means that there is a higher chance that a relationship could be detected when, in fact, such a relationship occurred by the mere chance of testing multiple times. For this reason, the standard is to Bonferroni correct the critical values for multiple tests. According to Legendre and Legendre (1998), the progressive Bonferroni correction can be used, in which the probability of a type I error, alpha, is adjusted for the number of distance classes. The formula just to adjust the critical values for tests of significance is given below in equation 19. At a given distance class, the significance level for a two-sided z-test at the 95 percent confidence level is computed by taking the critical alpha level and dividing by the number of distance classes up until that point. The critical value for the z score can be determined by evaluating the inverse normal probability density distribution at α'. As a result of this correction factor, the critical value for the z score is higher for each consecutive distance class. Thus, a higher z score is needed to obtain a statistically significant autocorrelation when the two points in a join are separated by a distance of 10 miles as compared to a distance of 1 mile.

$$\alpha'(d) = \frac{\alpha}{d} \qquad (19)$$

Spatial Buffers

While program enrollment decisions for a given tract of land will be influenced by the characteristics of that tract, such as its soil quality or wetland density, they will also be affected by the characteristics of surrounding tracts. As mentioned above, the consideration of surrounding land characteristics can be driven by spatial spillovers, in which the decisions made about one tract reflect the decisions made about nearby tracts, or resource flows, in which all of the tracts in a given area are affected by the same underlying cause, such as considerations about the scale of an particular use by either a conservation program or a landowner. Buffer characteristics are likely to influence program enrollment decisions for both ecological and economic reasons.

With regard to ecological reasons, conservation programs are presumed to be motivated to acquire patches of habitat that meet a certain size threshold, and thus, will seek evaluate land for conservation at spatial scales that are larger than individual tracts. In protecting grasslands in the Prairie Pothole region, this size threshold is driven by the habitat requirements of waterfowl. Key species of ducks, for example, will travel between 1.2 and 4.0 kilometers between wetlands, where they forage, to grasslands, where they nest (Reynolds et al. 2006). Understanding of this process has led the FWS to develop core areas of contiguous habitat on the scale of one mile wide and greater surrounded by additional outlying habitat, which may be more fragmented (Johnson et al.

2010). The conservation program, therefore, evaluate the land surrounding a target tract when considering whether a given tract will provide suitable habitat. All things being equal, a tract of grassland that is surrounded by grassland provides better habitat than one that is surrounded by cropland. Land immediately surrounding a target tract, for example, within a half-mile radius, will be examined for the potential to create a contiguous patch of grassland. As such, the typical easement in the study area comprises about 8 contiguous 40-acre tracts. Outlying land, such as land within a one-mile radius, has importance as supporting habitat. In terms of spatial spillover, a decision made to protect a tract of land in one year may increase the attractiveness of protecting nearby tracts in subsequent years. This is because the conservation group will tend to safeguard its original investments by protecting nearby land in subsequent years to provide assurance that the protected tracts, collectively, will provide sufficient habitat.

With regard to economic factors, landowner decisions also are assumed to be affected by spatial processes that operate at multiple scales. Landowners are assumed to make decisions about broader scales of farming operations, such as whether to operate a ranch or to cultivate crops, based on the characteristics of one or more sections of land. (As noted earlier, a section is one square mile and contains 16 40-acre tracts). For example, the average farm in South Dakota in 2002 was 1,380 acres, according to the U.S. Census of Agriculture, which corresponds to slightly more than two sections. Therefore, land use decisions about a particular tract of land will be affected by the context of surrounding land, which may be owner by the same person. For example, if a section of land is steeply sloped, it may lead the landowner to operate a ranch, and therefore, to devote the entire section to grazing even if some of the tracts on the section are flat enough to crop. Similarly, the characteristics of surrounding land may affect the cost of farming land on the target tract. For example, if a tract of land within is flat itself but is surrounded by steep slopes, it may be harder to for farm equipment to access it, and therefore, would be less likely to be cropped. Spatial spillovers may occur at a broader scale, such as among a landowner and immediate neighbors. For example, landowners may influence each other's behavior, such by providing information about the option to enroll land in a conservation easement program. In the study area, for example, the program does not advertise and relies entirely on word-of-mouth. Thus, land use on one property may be affected by the land use on surrounding properties.

Based on these considerations, I projected spatial buffers around each tract in the study area and calculated the characteristics of the land in those buffers as additional predictors of a tract's program enrollment decision. The inner buffer is defined by all of the tracts that intersect a half-mile radius around each tract and the outer buffer is defined by all of the tracts that intersect a one-mile radius. A complete list of the variables calculated for each buffer is show in table 2. These variables are generally calculated in the same manner as their corresponding tract-level variables, which are described above. There are two variables that are unique to the buffers, however: namely, the extent of grassland coverage and the number of tracts already enrolled in the program.

The extent of grasslands in surrounding tracts is measured used the 2001 National Land Cover Database (NLCD). Based on the definitions described above to categorize tracts as either eligible or ineligible based on their land cover, the total amount of tracts with eligible grassland in buffers was calculated. It is hypothesized that tracts embedded in larger areas of grassland are more likely to enroll. This is because the conservation program attempts to protect larger patches of habitat (Johnson et al. 2011).

In addition, I calculated the total number of tracts that enrolled in the conservation easement program in each of the buffers but that are not part of the easement, if one exists, associated with the target tract. For each buffer, I calculated the total number of tracts that enrolled in the conservation easement program between 1990 and 2001. If the target tract also enrolled in the program, I calculated the total number of tracts in the buffer that were enrolled as part of the same easement as the target tract. I then subtracted those tracts from the total to result in the net number of grassland easements within each buffer. This variable, in particular, helps to counteract the omitted variable problem, such that it allows for unmeasured but spatially correlated factors to be included when predicting program enrollment.

Propensity Score Analysis

Propensity Score Analysis commonly entails matching treated cases to control cases and follows three steps (Guo and Fraser 2010). First, propensity scores, which is the conditional probability of enrolling in the land conservation program given the covariates, are estimated using logistic or probit regression. Second, treated cases are matched to untreated cases based on similarity of their propensity scores in order to obtain a matched dataset of treated and control cases. Third, the matched dataset is analyzed to estimate the impact of group membership on the outcome of interest, which in this case, is the conversion of grassland to cropland. The impact can be measured in different ways, typically as the Average Treatment Effect on the Treated (TT) or the Average Treatment Effect (ATE). In this analysis, the TT, which is defined in equation 1, is estimated.

Estimating Propensity Scores with Logistic Regression

Propensity scores are typically estimated with a logistic regression model in which the dependent variable, whether or not a case enrolls in a program, is predicted based on a set of covariates that are associated with both program enrollment and with the outcome of interest (Guo and Fraser 2010). In this dissertation, a logistic regression model is estimated to predict the enrollment of a tract in the conservation easement program based on the factors that are hypothesized above to influence land use decisions. The full set of 19 main effects, which include ecological and economic characteristics of tracts and the buffers surrounding them, appears in table 2. Guo and Fraser (2010) summarize the key criteria by which propensity score models should be evaluated: (1) like all logistic regression models, it should have a high goodness-of-fit; (2) it should minimize the overall prediction error within the sample; (3) it should result in the treatment and control groups being balanced on the covariates.

Based on this framework, I estimated a logistic regression model using all of the tracts of land that either enrolled in the program or were eligible to enroll in the program between 1990 and 2001. The model contained each of the 19 main effects as specified in table 2. In addition, I examined bi-variate plots between each variable and the logit of program enrollment to detect any non-linear effects. When threshold effects were detected, dummy variables were created and included in the model with their interactions with the main effects. Through this process, a total of 8 dummy variables and 8 interaction variables were included in the model, bringing the total number of covariates to 35. I estimated the model using PROC LOGISITIC in SAS. Model goodness-of-fit was examined using Likelihood Ratio chi-square test, which evaluates the null hypothesis that all coefficients are equal to zero. I used the Receiver-Operator Characteristic (ROC) curve to examine the predictive accuracy of the model. The ROC curve illustrates the tradeoff between the sensitivity of a model, which is the percentage of enrolled properties that the model correctly predicts as being enroll, and the specificity of the model, which is the percentage of unenrolled tracts that the model correctly predicts as being unenrolled. The area under the ROC curve is the c-statistic and it measures the overall accuracy of the model.

Matching Treated to Control Cases

The MatchIt package, which was developed for the R statistical programming language, provides a full range of matching algorithms for Propensity Score Analysis (Ho, Imai, King and Stuart 20007 and Ho, Imai, King and Stuart 2011). I downloaded the packed from http://gking.harvard.edu/matchit/ and used it to conduct Propensity Score Matching.

I used conventional nearest neighbor matching within a caliper and conducting matching both with and without replacement. The nearest neighbor method, as described in Guo and Fraser (2010) is shown in equation 20, in which $C(P_i)$ is the neighborhood of control participants selected to most closely match treated tract i; P_i is the estimated propensity score for treated case i; and P_j is the estimated propensity score for untreated case j, which is a member of all untreated tracts I_0. For each treated tract, one or more untreated tracts, specifically those with the closest propensity score to the target tract, are selected to be control tracts. Once matched, control tracts are discarded without replacement, such that each control tract is only matched to a single treatment tract.

$$C(P_i) = \min_j \|P_i - P_j\|, \qquad j \in I_o \qquad (20)$$

To enhance the validity of matching using a greedy algorithm, calipers can be used that restrict matches to fall within a specified range. Untreated tracts will not be matched to a treated tract, even if they are the closest match, if the match does not fall within the specified caliper. This is shown in equation 21 as a constraint to equation 20, in which ε is the pre-determined caliper level.

$$s.t. \quad \|P_i - P_j\| < \varepsilon, \qquad j \in I_o \qquad (21)$$

In this dissertation, I started by using a caliper equivalent to 0.25 of a standard deviation of the propensity score, as specified by Rosenbaum and Rubin (1985) as cited in Guo and Fraser (2010), such that an untreated tract will only be matched to a treated tract if the distance between the two estimated propensity scores is less than 0.25 of a standard deviation. I experimented with other caliper widths to obtain a sample of control tracts that balanced with the treated tracts on the covariates. If the area of common support is sufficient, greedy matching has the advantage of allowing the matched data to be used in subsequent multivariate analysis. In this analysis, the area of common support was determined by be sufficiently large, and therefore, greedy matching was selected. Given sufficient common support, more reliable estimates of program impacts can be obtained by matching multiple control cases to each treated case. In particular, Haviland et al. (2007), as cited in Guo and Fraser (2010), recommend matching two control cases to each treated case. However, it may not always be possible to match at such a high ratio. I experimented with various matching ratios to obtain the largest sample of control tracts while still obtaining sufficient balance on the covariates.

The quality of matching is based on the balance of the covariates between treated and control groups and based on the percentage of treated cases that are successfully matched with a control. Balance is assessed by comparing the means of the distributions for all covariates between treatment and control groups and testing for statistically significant differences with the d statistic, which measures the standardized distance between treated and control cases for a particular covariate (Ho, Imai, King and Stuart 2011). The d statistic, which is shown in equation 22, measures the difference between treated and control cases in standard deviation units. In this equation, M_{Xt} is the mean of covariate X for treated cases, M_{Xc} is the mean for control cases, and S_X is the overall standard deviation. The statistic d_X is therefore measured in units of standard deviations and is interpreted as the number of standard deviations between the mean of the treatment group and the mean of the control group for each variable X.

$$d_X = \frac{|M_{Xt} - M_{Xc}|}{S_X} \qquad (22)$$

Covariate balance is further assessed by examining QQ plots, which illustrate the correspondence between two distributions, to note any significant departures across the full range of values of the distribution. The extent of common support is assessed through plots of the distributions of the variables and by the proportion of treated cases that are successfully matched to controls. These procedures are described in Guo and Fraser (2010) and in Ho, Imai, King and Stuart (2011).

Post-Matching Estimation of Treatment Effects

The impact of the conservation program on rates of land conversion is to compare conversion rates between treated and control tracts as would be done in a randomized experiment. Based on equation 1, the average treatment effect on the treated is estimated as the difference in conversion rates between treated and control tracts. In theory, the expectation is that rates of conversion on treated tracts will be zero because the grassland easement program restricts landowners from planting crops on eased land. The satellite data measuring land cover change, however, are imprecise and conversions from grassland to cropland are observed on both treated and control tracts. Conversions on treated tracts are assumed to be the result of random measurement error and the difference in conversion rates between the two groups is taken to be the treatment effect. In order to test whether any observed difference in conversion rates between these two groups is statistically significant, standard errors of the conversion rate for each group are estimated through bootstrapping. The estimated standard errors can be used in t-tests to compare the conversion rates between the two groups.

Chapter 4 – Results

This chapter describes the results of the calculations of spatial autocorrelation in program enrollment, an assessment of univariate statistics of key variables characteristics each tract, a comparison of bivariate statistics between enrolled and unenrolled tracts, the results of the logistic regression models developed to estimate propensity scores, the results of matching treated cases to controls and the estimates of program effects based on a negative binomial regression model with the matched data. The join count statistic demonstrates extensive spatial autocorrelation among program enrollment decisions, particularly within a distance of 5 miles. The bivariate analysis shows strong relationships between each of the covariates and enrollment decisions in the expected direction. The logistic regression model is not used to test specific hypotheses about the effects of specific variables on program enrollment decisions, but its results tend to corroborate the relationships identified in the bivariate analysis. Various matching methods are employed and all result in a high percentage of treated tracts being matching with control tracts and qualitatively similar estimates of the impact of the program. In particular, the two most reliable matched samples estimate that approximately either 0.38 percent or 0.42 percent of enrolled tracts would have converted to cropland between 2001 and 2006 if they had not enrolled in the program.

Spatial Autocorrelation

The join count statistic reveals a high level of spatial autocorrelation in program enrollment decisions. The autocorrelation is highest among tracts separately by short distances, decays as the distance between pairs of tracts increases and remains statistically significant for great distances. Figure 10 shows the correlogram of the join count statistic and table 3 shows the corresponding values at one-mile intervals.   The join count statistic exhibits an exponential decline of spatial autocorrelation of enrollment decisions with respect to distance. In figure 10, this is illustrated by the EE line, which shows the ratio of observed to expected joins among enrolled tracts at each distance class. There appears to be a threshold of approximately 5 miles at which the level of autocorrelation levels off. For example, enrolled tracts have 6.2 times as many enrolled tracts located at a distance of 0.50 miles than would be expected under the null hypothesis of complete spatial randomness. At a distance of 5.5 miles, the spatial autocorrelation is substantially and begins to become statistically insignificant. Substantively similar results are obtained from and analysis of the number of EU joins, which compare the observed to the expected number of pairs of tracts in which one tract is enrolled and the other tract is unenrolled. This pattern is illustrated by the EU line in figure 11.

The pattern of spatial autocorrelation can be interpreted with regard to the scale of economic, social and ecological processes that dictate land use decisions. Tracts separated by a distance of 0.50 miles or less are likely part of the same property, as the average farm in South Dakota in 2002 was 1,380, according to the U.S. Census of

Agriculture. If tracts are enrolled in the program, they are likely part of the same easement, as the typical easement in the study area is comprised of 320 acres or 8 tracts. Thus, spatial autocorrelation at this level is expected and represents an obvious outcome of the fact that landowner decisions about whether to enroll one tract are correlated with their decision to enroll another tract. Tracts separated by distances of 1-2 miles would correspond both to landowners and their immediate neighbors, based on the average farm size, and to the scale habitat patches that the program seeks to acquire (Johnson et al. 2011). It is sensible that autocorrelation would be lower at this distance than at closer distances, since land use would be affected by multiple landowners who may differ in their decision making and because the land itself will be more heterogeneous. However, it is also expected that the autocorrelation would be significant at this level, since landowners may influence each other's decisions and since the program may view this as the scale for its enrollment decisions. At a distance of 5 miles, land becomes more heterogeneous, the influences of neighbors presumably diminishes and the ecological importance of habitat contiguity becomes less important. It is sensible, therefore, that the strong level of spatial autocorrelation would diminish. To help to account for the unmeasured but spatially correlated factors in the subsequent analysis, eligible tracts were selected from within a five-mile radius of enrolled tracts. This results in a sample of 78,716 tracts for analysis. Of these tracts, 8,736 (11 percent) enrolled in the program between 1990 and 2001.

Univariate Statistics

The results of this dissertation are only generalizable to the study area, which comprises 1/8th of the Prairie Pothole Region. Therefore, it is important to understand the characteristics of land in the study area as compared to those of land in the larger region. Univariate statistics of the initial sample (n=78,716) of eligible tracts show that land in the study area, on average, has relatively low cropland value and relatively high habitat value. The complete univariate statistics are shown in table 4. In particular, these statistics show the following:

- There is a much higher concentration of FWS grassland easements in the study area than in the Prairie Pothole Region overall. Across the entire 64-million acre Region, FWS purchased grassland easements on 906,000 acres of land between 1990 and 2006 (GAO 2007). These easements amount to about 1.4 percent of total land area. In the study area, by contrast, FWS purchased grassland easement on 5.2 percent of the land area during the same time period. Thus, the study area is the focus of particularly intensive land conservation efforts by this program.
- The soil quality of sample tracts is roughly comparable to that of the broader region, but is substantially lower than soil quality in other parts of the country. The average NCCPI value of 26 for sample tracts in the study area is comparable to the average value of 27 calculated by Claasen et al. (2011) in their study of grassland conversions in a multi-state portion of the Northern Plains. Compared to soil quality nationally, however, soil quality in the study area falls at the lower

end of the spectrum, since the NCCPI scale ranges between 0, which indicates the least productive soil, to 100, which indicates the most productive soil.

- The study area is dominated by agriculture, with the average tract being located far from population centers but relatively close to grain buyers. The study area is located far from the urban centers of South Dakota and North Dakota, with only 5 cities and towns in the study area, or immediately adjacent to it, with populations of more than 2,500 people. The largest of these, Aberdeen, had a population of 24,658 in 2000. Correspondingly, the average tract is remote – an average of 30.19 kilometers from the nearest city or town of more than 2,500 people. Conversely, the average tract is much closer to the nearest grain buyer – only 14.15 kilometers, on average.
- The average tract in the study area has a very high wetland density. The Prairie Pothole Region has among the highest wetland densities of any region in the country (Kantrud, Krapu and Swanson 1989). This is reflected in the average length of wetland basins perimeters among tracts the study tracts of 756 meters. This can be compared to the length of the perimeter of study tracts themselves, which is 1,600 meters for regularly-shaped tracts. This means that the perimeter of wetland basins on the average tract equal about 42 percent of the perimeter of the tract itself. The density of wetlands in the half-mile and one-mile buffers are similarly large.
- Study tracts have a considerably higher accessibility to nesting waterfowl than other portions of the Prairie Pothole Region, which itself is the most critical nesting area for waterfowl in the country. Reynolds et al. (2006) show that the

study area has the highest density of nesting waterfowl in the Prairie Pothole Region. Across the Region, as reflected in the FWS map of nesting pair accessibility (Reynolds et al. 2006), accessibility can range from zero nesting pairs per square mile to over 100 with the agency targeting tracts that support more than 40 (GAO 2007). Thus, the average tract in the study area, which is accessible to 77.85 pairs per square mile, is close to the top of the range and well above the minimum number considered to provide viable habitat.

Comparison of Bi-Variate Means

Enrolled tracts were compared to unenrolled tracts with respect to the means of the independent variables. Although statistically significant differences are not surprising with such a large sample, the bivariate statistics show that enrolled tracts differ from unenrolled tracts in the expected direction. The mean values for enrolled and unenrolled tracts are significantly different on each of the variables considered in this analysis, with enrolled tracts tending to have a higher ecological value and a lower economic value. The differences are evident at the level of tract, half-mile buffer and one-mile buffer. The complete bivariate statistics are shown in table 5. In particular, the bivariate comparisons show the following with regard to economic factors:

- Enrolled tracts have significantly lower soil productivity than unenrolled tracts and are located within buffers that also have lower soil productivity. In particular, the NCCPI value on enrolled tracts is 7% lower, on average, than on enrolled tracts than on unenrolled tracts is similarly lower in the half-mile and one-mile buffers (p<0001).

- Enrolled tracts are significantly more steeply sloped than unenrolled tracts. In particular, the average slope is 12% greater on enrolled tracts than on unenrolled tracts and is similarly steeper in the half-mile and the one-mile buffers (p<.0001).
- Enrolled tracts have significantly greater wetland density than unenrolled tracts. In particular, enrolled tracts have 18% more wetland perimeters than unenrolled tracts and the differences are similarly large in the half-mile and the one-mile buffers (p<.0001).
- Enrolled tracts are slightly further from grain buyers than unenrolled tracts – about 3% further – and are significantly further from cities and towns, by about 12%, on average (p<.0001).

Enrolled tracts have significantly greater ecological value than unenrolled tracts. In particular, the bivariate statistics show the following:

- Enrolled tracts are significantly more accessible to nesting pairs of grassland birds than unenrolled tracts. Specifically, enrolled tracts are accessible to 16% more nesting pairs than unenrolled tracts with the same difference observed in the half-mile and the one-mile buffers (p<0.0001).
- Enrolled tracts are surrounded by more grassland than unenrolled tracts. In particular, both the half-mile and the one-mile buffers contain 15% more grassland for enrolled tracts than for unenrolled tracts (p<0.0001).

- The greatest difference between enrolled an unenrolled tracts is the proximity to other enrolled tracts. In particular, the half-mile buffers around enrolled tracts have 75% more enrolled tracts than the half-mile buffers surrounding unenrolled tracts ($p<0.0001$). Note that for this particular calculation, enrolled tracts in the buffer are excluded if they were enrolled as part of the same easement as the target tract.

Analysis of Bi-Variate Plots

To further explore bivariate relationships, scatterplots between each of the independent variables and the log odds of enrollment were examined for subgroups of cases. The purposes of this analysis were to identify any non-linear relationships and to gauge the strength of any linear relationships. One of the assumptions of logistic regression is that each predictor has a linear relationship with the log odds of the outcome (Agresti 2007). The log odds of the outcome, also known as the logit, is the logarithm of the probability that the outcome occurs divided by the probability that the outcome does not occur. Since the outcome is binary, the logit needs to be estimated using subgroups of cases in which the proportion of cases in which the dependent variable equals 1 are calculated. Scatterplots can be created with respect to each of the independent variables in which these subgroups are the units of analysis. This procedure is not a formal statistical test for non-linearity, and therefore is only suggestive of the presence of non-linearity; however it yields important insights into the specification of the model.

The relationships in these scatterplots are generally consistent with expectations. The economic variables relating to the suitability of a tract for cropland generally show a positive relationship with enrollment along with a threshold effect. This suggests that land has lower quality for cropland is less likely to enroll in the program, but that land quality only exerts an effect after a certain threshold. In particular:

- Soil quality exhibits negative relationship and a threshold effect with the logit of enrollment. See the scatterplots of this relationship in figures 11-13. For tracts with a value lower than 26 on the NCCPI scale, there appears to be a slight positive relationship between soil quality and the logit of enrollment (figure 11). For tracts with a value greater than 26 on the NCCPI scale, by contrast, there is a strong negative relationship. The behavioral interpretation of this threshold is that soil quality matters little in program enrollment decisions if it is below average quality because land below a certain threshold is unlikely to be viable as cropland below that threshold. A similar pattern is evident in the relationships between the logit of enrollment and soil productivity in the half-mile buffer (figure 12) and in the one-mile buffer (figure 13).

- Slope exhibits a positive relationship and a threshold effect with the logit of enrollment. See figure 14. For tracts with an average slope of less than 15 percent, there is a strong positive relationship between the average slope and the logit of enrollment. For tracts with higher values of slope, this relationship appears to reverse. A possible behavioral interpretation is that planting crops is possible but increasingly less viable as terrain goes from perfectly flat land to slopes of less that 15 percent. At that grade, using the land to plant crops becomes no longer viable, so additional increases in slope do not affect the possibility of farming or the decision to enroll. A similar positive relationship is evident in the half-mile buffer (figure 15) and the one-mile buffer (figure 16) though a threshold effect is not evident in the one-mile buffer.

- The length of wetland basin perimeters also exhibits positive relationship and a threshold effect with the logit of enrollment. There is a strong positive relationship between the sum of wetland basin perimeters on a tract and the logit of enrollment below approximately 875 meters of perimeter. For the typical 40-acre tract, which itself has a 1,608-meter perimeter, this would correspond to the sum total of wetland basin perimeters consisting of twice the perimeter of the tract itself. See figure 22. The behavioral interpretation of this is that below 875 meters of wetland perimeter, cropping becomes increasingly more difficult and that beyond this level, it wetland density has already made growing crops sufficiently prohibitive that additional wetland density does not affect the probability of enrollment. A similar relationship is evident in the half-mile buffer (figure 23) and the one-mile buffer (figure 24).
- The distance of a tract with respect to economic centers appears to have a positive relationship with program enrollment, although the pattern as not as strong as it is for the land characteristic variables described above. In particular, there is a moderate positive relationship between the logit of enrollment and both the number of kilometers to the nearest grain buyer (figure 17) and the number of kilometers to the nearest city or town (figure 18).

The variables representing habitat quality show strong positive linear relationships with enrollment. Of note, the extent to which a tract of land is surrounded by other tracts or grassland or by other protected tracts appears to predict program enrollment decisions. It is not clear whether this reflects a spatial spillover effect, in which landowners influence each other, or a reaction function, in which both the tract and its neighbors are influenced by the same underlying factors. Either way, these variables appear to be excellent predictors. In particular:

- The accessibility to nesting pairs of grassland birds is strongly associated with the logit of enrollment. The number of nesting pairs that can access a tract has an almost perfect linear relationship with the logit of enrollment (figure 19). The number of nesting pairs that can access the half-mile (figure 20) and the one-mile (figure 21) buffers also have strong relationships, although the patterns are more variable. This is consistent with the fact that the conservation program uses accessibility as one of its primary measures in evaluating tracts for enrollment.
- Grassland coverage in surrounding land exhibits a strong positive relationship with program enrollment, though grassland coverage on the target tract has an unclear or even a negative relationship. Grassland coverage on both the half-mile buffer (figure 26) and the one-mile buffer (figure 27) is strongly associated with the logit of program enrollment. This is consistent with the conservation program's emphasis on protecting larger patches of habitat which can support greater biodiversity. At the tract level, the relationship is less clear, likely because only tracts with a high proportion of grassland are eligible for enrollment; given

that this proportion is satisfied, it may be other land cover – such as wetlands – that make a tract more likely to enroll.

- The proximity of a tract to other tracts enrolled in the program is strongly associated with program enrollment of the target tract. In particular, the numbers of enrolled tracts in the half-mile buffer (figure 28) and in the one-mile buffer (figure 29) have strong relationships with the logit of program enrollment. This is consistent with the program's objective of protecting contiguous tracts of land in order to establish larger patches of habitat.

Logistic Regression Model

Using logistic regression, the probability of program enrollment is predicted based on a set of covariates hypothesized to predict both program enrollment and land conversion. Each of the19 main effects covariates are described in previous sections and are shown in table 2. In light of the threshold effects observed in the scatterplots as described above, dummy variables and their interactions with the corresponding main effects were created. In particular, dummy variables were created for values of soil productivity more than 0.26 on the NCCPI scale, wetland perimeter more than 875 meters and slope less than 15 percent. This was done at the tract level and at the buffer level for these three variables, except for slope in the one-mile buffer, which did not exhibit such an effect, thereby creating 8 additional variables. Each of these dummy variables was interacted with the corresponding main effect to create another 8 variables. In total, the 19 main effect variables and the 16 dummy and interaction variables led to 35 variables for inclusion in the logistic regression model used to estimate propensity scores. The full model results are shown in table 6. The model has an excellent fit to the data, with the Likelihood Ratio Chi-Square tests significant at $p<.001$. It is highly predictive and explains 80% of the area under the Receiver Operator Characteristic (ROC) curve.

The parameter estimates from the regression model are interpreted to make sure that covariates in the propensity score model correspond to the relationships predicted by theory and to corroborate the fundamental soundness of the Propensity Score Analysis. Since the purpose of the regression model is to obtain a set of control cases that best balances with treated cases, this model is not used to test hypotheses about the influences of various factors on enrollment decisions. However, it is noted that the parameter estimates in this model nearly always correspond with expectations. In general, the model indicates that tracts with a higher economic value were less likely to enroll in the program and that tracts with a higher ecological value were more likely to enroll in the program. Because of most of the variables are measured at both the tract, half-mile buffer and one-mile buffer, and because many of the main effects have corresponding dummy variables and interaction variables, the results are described by way of illustration below by comparing the estimated probability of enrollment for a tract at the 20^{th} percentile of the given covariate with that of a tract at the 80^{th} percentile of the given covariate holding other factors constant. In particular:

- Tracts with higher soil quality are less likely to enroll in the program. Beyond a threshold of 0.26, which is the average soil quality in the study area and which is generally low soil quality compared to farmland nationally, each an increase in a tract's NCCPI rating decreases the odds of enrollment. For example, if the NCCPI rating of for a tract, its half-mile buffer and its one-mile buffer are at the 20th percentile, which is 0.22, 0.24 and 0.24, respectively, that tract has a 0.148 probability of enrollment, holding all other factors constant. By contrast, a tract with NCCPI ratings in the 80th percentile, which are 0.31, 0.30 and 0.30, respectively, has a only a 0.078 probability of enrollment. That soil quality has a predominantly negative effect on the probability of enrollment is predicted by theory because landowners with higher quality soil face a higher opportunity cost of enrolling the program and has been shown to influence land use in the Northern Plains (Lichtenberg 1989 and Claassen et al. 2011).

- Tracts with greater wetland density are more likely to enroll in the program. For example, if the sum of wetland perimeters for a tract, its half-mile buffer and its one-mile buffer are at the 20th percentile, which are 166 meters, 400 meters and 422 meters, respectively, that tract has only a 0.083 probability of enrollment, holding other factors constant. By contrast, if the sum of wetland perimeters for a tract of land are at the 80th percentile, which are 1,252 meters, 977 meters and 931 meters, respectively, a tract of land has a 0.162 probability of enrollment. That tracts with greater wetland density are more likely to enroll in the program is predicted by the costs that wetlands impose on when cultivating land (Shultz 2005 and Gelso, Fox and Peterson 2008).

- Tracts that are located closer to grain buyers are more likely to enroll in the program. Each kilometer from a grain buyer decreases the odds of enrollment by 1.4 percent. For example, a tract located relatively close to a grain buyer, at 8.0 km away, which is the 20th percentile, has a 0.152 probability of enrollment. By contrast, a tract that is located relatively far from a grain buyer, such as one that is 19.4 km away, which is the 80th percentile, has a 0.132 probability. This is contrary to expectations; however, the distance to the nearest city or town has already been accounted for, and that is consistent with expectations.
- Tracts that are located further from cities and towns are more likely to enroll in the program. Each kilometer increases the odds of enrollment by 1.2 percent. For example, a tract that is located relatively near to a city or town, namely, one that is at the 20th percentile of that variable, which is 18.9 km, has a 0.148 probability of enrollment. By contrast, a tract that more distant, namely, one that is at the 80th percentile or 42.2 km away from a city or town, has a 0.125 probability of enrollment, all other factors being equal. The net effect of distance to town is greater than the net effect of distance to grain buyers. This is because the geographic scale of cities and towns is larger, such that each kilometer of distance is less significant that each kilometer of distance to a grain buyer, which are more prevalent.
- Tracts located within surroundings that are accessible to a high concentration of nesting pairs are more likely to enroll in the program. For example, if the accessibility to nesting pairs of grassland birds for a tract, its half-mile buffer

and its one-mile buffer are at the 20th percentile, which are values of 60, 54 and 55 nesting pairs per square mile, respectively, the tract has a 0.109 probability of enrollment. By contrast, if the accessibility is at the 80th percentile, which is 100 nesting pairs per square mile at each of these levels, the probability of enrollment in 0.186. This is consistent with expectations, since accessibility to nesting waterfowl is the primary measure by which the agency targets land for conservation and since this measure is considered for broader patches of habitat (GAO 2007).

- Tracts that are surrounded by steeply sloped land are more likely to enroll in the program. For example, if a tract, its half-mile buffer and its one-mile buffer all have slopes at the 20th percentile, which are 3.4, 4.4 and 4.7 percent, respectively, that tract has only a 0.089 probability of enrollment, all other things being equal. By contrast, if these values are at the 80th percentile, which is 13.7, 13.3, and 12.7 percent, respectively, that tract has a 0.157 probability of enrollment. This is consistent with the expectation that steeply sloped land is more difficult to cultivate and with the results of prior literature, most notably with Stephens et al. (2008) who found that steeply sloped land was less likely to be converted to cropland in the Prairie Pothole Region.
- Tracts are more likely to enroll in the program when they are surrounded by extensive grassland. Each one percentage increase in grassland coverage in the half-mile buffer increases the odds of enrollment by 0.94 percent and each such increase in the two-mile buffer increases the probability by 0.51 percent. For example, when grass coverage at the half-mile and the one-mile buffers

are at the 20th percentile, of 42.9 percent and 38.7 percent, respectively, a tract has a 0.110 probability of enrollment. By contrast, when grassland coverage in these buffers is at 80th percentiles of 83.2 percent and 76.7 percent, respectively, a tract has is a 0.179 probability of enrollment. This finding is expected, since larger patches of grassland are considered to have greater habitat value and are targeted by conservation planners in the region (Johnson et al. 2011).

- The number of enrolled tracts surrounding a given tract has a mixed impact on the probability of enrollment, depending upon whether these tracts are in the half-mile buffer or the one-mile buffer. Each additional tract in the half-mile buffer that is enrolled in the program increases the odds of enrollment for the target tract by 20.5 percent. By contrast, a similar increase in the one-mile buffer decreases the odds of enrollment for the target tract by 2.5 percent. Together, the amount of enrolled tracts in these two buffers has a net positive impact on the probability of enrollment. For example, when the number of enrolled tracts in both the half-mile buffer and the one-mile buffer are at the 20th percentile, which is 0 in both cases, the probability of enrollment is 0.110. By contrast, when they are at the 80th percentile, which is 3 and 9, respectively, the probability of enrollment is 0.179.

Matching Results and Estimated Treatment Effect

Using the estimated propensity scores from the model described above, nearest neighbor matching with calipers was used to match treated to control cases. Several matching specifications were attempted in order to assess the sensitivity of the estimated treatment effects to the matching methods. Matching methods varied in terms of the width of the calipers, the ratio of control to treated cases selected and whether control cases were selected with replacement. Guo and Fraser (2010) suggest a rule of thumb of a caliper width of 0.25 standard deviations of the estimated propensity score. Several matching specifications that employed calipers of this width resulted in a large percentage of treatment cases being matched to control cases (approximately 98 percent) even when sampling was conducted without replacement. However, this caliper width also allowed for a significant imbalance between treatment and control cases on many of the covariates. It was determined that more narrow calipers – specifically a caliper width of 0.10 standard deviations – would lead to slightly more treatment cases being excluded from the matched sample when sampling was conducted without replacement but would lead to complete balance between treatment and control groups on all of the covariates. Therefore, a caliper width of 0.10 standard deviations was used for all matched samples reported here.

Given this caliper width, four matching specifications were tested. The first matched sample entailed a 1:1 ratio of control to treated cases and sampled without replacement; the second, a ratio of 1:1 with replacement; the third, a ratio of 2:1 without replacement, and the fourth, a ratio of 2:1 with replacement. For each of these matched samples, treatment and control cases balanced on each of the covariates. In particular, the d statistic showed that the means of each of the covariates between the two groups differed by only a small fraction of standard deviation, with the greatest difference among the covariates being 3 percent of a standard deviation. The balance scores for the covariates for each of these samples are shown in tables 7, 8, 9 and 10. As expected, the two samples that allow sampling with replacement (samples two and four) allow for a greater percentage of treated tracts to be matched with a control tract, both of which allow for 99.8 percent of treated tracts to be matched. Conversely, these samples utilize fewer control cases in the matching, such that the control group in sample two has only 83.4 percent of the number of control tracts and sample four has only 88.9 percent of the number control tracts that would be present if sampling were conducted without replacement. The estimated propensity scores are starkly different for treated and untreated tracts prior to matching, but nearly identical after matching. Using the results from the fourth matched sample for illustration, the distributions of estimated propensity scores for both treated and control cases, both before and after matching, are in figure 30.

Overall, the level of common support is high, though tracts with the highest probability of enrollment in the program are those that remain unmatched in all cases. The level of common support is illustrated in figure 31, for the third matched sample and in figure 34, for the fourth matched sample. In these figures, the two middle plots show the distribution matched tracts; the uppermost plot shows the distribution of unmatched treated tracts. Note that when sampling is conducted with replacement, as with matching method 4 as shown in figure 34, only a small number of treated tracts are excluded from matching. These tracts are those shown in the far right of the figure and are those with the highest probability of enrollment. When sampling is conducted without replacement, as with matching method 3 as shown in figure 33, a larger number of treated tracts are unmatched than when sampling is conducted with replacements. In both cases, tracts with the highest probabilities of enrollment are the most difficult to match, but the overall level of common support is high.

Each of the four samples produces a qualitatively similar estimate of the treatment effect. Complete results of the matching for each of the four matched samples are shown in table 11. Standard errors of the conversion rate for the treatment and control groups for each of the four matched samples are calculated in the R programming language using 100 bootstrap samples. Using these standard errors in the calculation of independent sample t-tests, each of the four samples shows that the difference in conversion rates between the two groups is highly statistically significant ($p<.001$) based on an independent samples t-test. The estimated treatment effect on the treated, as shown in equation 1, is the difference in the conversion rates on treatment and control tracts. It varies between 0.32 percent for the second matched sample to 0.42 percent for the third matched sample.

The estimated treatment effects for samples 3 and 4 are more reliable, due to the higher ratio of control tracts to treatment tracts, which decreases the standard errors. Based on sample 3, the program reduced land conversions among enrolled tracts by 0.42 percent between 2001 and 2006. Similarly, based on sample 4, the program reduced land conversions among enrolled tracts by 0.38 percent during this same period. Thus, in the absence of the program, the results from sample 3 would estimate that 1 in 240 tracts would have converted from grassland to cropland between 2001 and 2006. Similarly, the results from sample 4 estimate that 1 in 265 tracts would have converted. While this effect is slight, it must be understood in the context that only 0.54 percent of grassland in the study area overall – included treatment, control and unmatched tracts – converted to cropland during the time period. Thus, the results indicate that the program did have a significant impact on preventing land conversions during this time period, albeit slight.

The conversion rate on control tracts was compared to the rate of grassland conversion in the study area overall using a t-test. Contrary to expectations, however, the grassland conversion rate on control tracts (0.62 percent for the third matched sample or 0.58 percent for the fourth matched sample) was not significantly lower than the grassland conversion rate in the study area overall during this time period (0.54 percent). Thus, even though enrolled tracts have a lower economic value than unenrolled tracts as demonstrated by the logistic regression model, there is no evidence that they would have been any less likely to convert to cropland during the study period if they had not enrolled in the program.

Chapter 5 – Discussion

The results obtained from this analysis can be used to provide preliminary answers to the research questions posed at the beginning of this dissertation. The first question asks what factors drive land to enroll in a conservation program. In the study area during the time period examined, land that is of lower economic value and higher ecological value is more likely to enroll in the conservation easement program. The second question asks how much land would have been converted in the absence of the program. This analysis indicates estimates that a small number of tracts – fewer than 1 in 200 – would have been converted to grassland in the absence of the program.

Drivers of Program Enrollment

As discussed earlier, there are difficulties in applying standard regression models to spatial data for the purpose of testing hypotheses about the effects of specific covariates on the probability of program enrollment. Because enrollment decisions are highly spatially correlated, the assumption of independence of observations is violated, standard errors are incorrect and hypothesis tests are not valid. At the same time, it is instructive to summarize estimates of the regression model for their consistency with theory and for insights into the first research question regarding the drivers of program enrollment. Overall, the regression analysis shows that both economic and ecological factors drive enrollment decisions in a land conservation program.

With regard to economic factors, the results of the analysis show that valuable cropland is less likely to enroll in the program. In particular, for most levels of soil quality, more productive land is less likely to be enrolled in the program; land with steep slopes, which is more difficult to farm, is more likely to be enrolled in the program; and land with a high wetland density, which is also more difficult to farm, is more likely to be enrolled in the program. In addition, land that is less accessible to cities and towns is more likely to enroll, though proximity to the nearest grain buyer has a smaller effect in the opposite direction. Taking all of these factors together illustrates the importance of economic factors in program enrollment decisions. For example, land that is at the 20th percentile in terms of quality for all of these characteristics – that is less productive soil, steep slopes, high wetland density and less accessible to markets – had about a 15.1 percent chance of enrolling in the program between 1990 and 2001. By contrast, land that is at the 80th percentile on this variables – that is, higher quality soil, flatter, lower wetland density and more accessible to markets – had only about a 4.1 percent chance of enrollment in the program.

While these estimates are rough, given the difficulties with applying standard regression models to spatial data, they are consistent with theory and suggest that tracts with less potential as cropland are more likely to enroll in the program. The potential for adverse selection may be particularly high on the lowest quality tracts of land. Each of these variables was shown to have a threshold effect such that their relationship with the probability of enrollment became apparent after a certain level. This suggests that when land reaches a certain level of suitability for cropping, the likelihood that it is enrolled in a conservation program is very sensitive to the specific characteristics of the land. For example, when soil productivity is less than 26 on the NCCPI scale, which corresponds to the lowest quartile of cropland in the country, soil productivity has very little impact on program enrollment decisions. Beyond that point, however, soil productivity has a very strong effect, with each additional increase in soil productivity substantially reducing the probability of program enrollment. This suggest that when land is below a certain quality, the conservation program is in a strong bargaining position and can have a high level of confidence that a landowner might be willing to enroll their land in the program.

Habitat value is also a strong predictor of program enrollment. The extent of grassland in the buffer surrounding a tract, the number of nearby tracts that are enrolled in the program and the accessibility of tracts to nesting waterfowl were positively associated with program enrollment decisions. For example, tracts that are at the 20th percentile for these variables – that is, tracts that are located near few enrolled tracts, that have little grassland cover surrounding them and that are accessible to a small number of nesting pairs of migratory birds – have only about a 3.3 percent chance of enrolling in the program. By contrast, tract that are at the 80th percentile for these variables – that is, tracts that are located near many enrolled tracts, that are surrounded by extensive grassland cover and that are accessible to a large number of nesting pairs of migratory birds – have about a 19.8 percent chance of enrolling in the program.

Because biodiversity and habitat quality generally increase as the size of habitat patches increase, these results are fully consistent with theory. They indicate that land conservation programs are directed at areas that have more contiguous patches of habitat, and therefore, areas where land conversions have been less common. This sets up a conflict between the goal of the program to acquire high quality habitat, on one hand, and to reduce rates of land conversion, on the other. This is because there may be an inverse relationship between habitat quality and the pressure for land conversion. This could force conservation programs to make tradeoffs between protecting the highest quality habitat, which may not be under the threat of conversion, and protecting lower quality habitat, which may be under threat of conversion. Solid empirical models could be developed to guide in these decisions.

Program Impact

The Propensity Score Analysis resulted in balancing treated and control groups on all of the covariates and successfully matched nearly all of treated tracts to similar control tracts regardless of the specification of the matching methods. The results show that the program significantly reduced the conversion rate among tracts that would be likely to enroll. Using the two most largest matched samples, approximately 0.38 percent (based on the results of one sample) or 0.42 percent (based on the results of another) of enrolled tracts would have converted to cropland between 2001 and 2005 if they had not enrolled in the program between 1990 and 2001. At first glance, this suggests that the program made a small impact on land use during the period studied. However, the estimates of program impact are relative to the background rate of land conversion in the study area during the study time period.

A different question is whether the impact of the program is significantly different than the observed rate of land conversion in the study area overall. The fact that enrolled tracts had lower economic value, on average, suggests the presence of adverse selection in program enrollment. In particular, the fact that land with lower soil productivity, steeper slopes and greater wetland density was more likely to enroll in the program suggests that enrolled tracts would be less likely than other tracts to otherwise convert to cropland. However, the conversion rate on control tracts, between 0.58 and 0.62 percent, depending on the matched sample, was not significantly different from the conversion rate in the study area overall. Thus, in spite of the fact that enrolled tracts had lower economic value than unenrolled tracts, there is no indication that they would have been any less likely to convert to cropland during this time period. Longer time periods should be studied to determine whether this effect, or lack of an effect, persists.

With regard to planning, a conservation planner ought to be concerned about these findings if they suggest inefficiencies in the program. This establishes the need to conduct studies over longer time periods, and to collect data that makes such analysis possible, in order to better understand the potential implications of land conservation programs. This raises a dilemma in that the longer the time period that data are collected, the more reliable estimates will be about program impact and the better decisions will be made about program investment. At the same time, however, the more time that passes, the more the program is locked into its earlier decisions and the less opportunity it has to refine its program to make it more effective. An important role in land use change models will be developing ways of estimating program impacts over the long term – and identifying opportunities for these programs to improve – while basing the analysis on limited data that are collected in the short term. This dilemma can also be seen as a conflict between research and planning. Namely, research is traditionally conducted under a conservative framework of attempting to falsify hypotheses and erring on the side of caution when interpreting statistical results. By this metric, the findings of this study do not imply large inefficiencies in program operation during the time period studied.

While the results show that the program had a statistically significant impact, the impact in absolute terms is small. One might question, however, whether the tracts that were protected are particularly valuable, and therefore, whether the program's ecological impact is more significant than appears based on the rate of land conversions that it prevented. There are two reasons to think that the ecological impact of the program is not larger than the avoided rate of land conversion, however. First, the dataset only includes tracts that meet the minimum grassland coverage required by the program; so in terms of that aspect of habitat, all of the control tracts have sufficient ecological value to be worth protecting. Second, after the matching, the control tracts have the same distributions of other ecological covariates, such as grassland coverage on surrounding tracts and accessibility to nesting pairs of migratory birds. Therefore, their habitat value would be equal, on average, to the habitat value provided by the treatment tracts.

Methodological Issues

This dissertation illustrates several methodological challenges to conducting research on land conversion and conservation. The two primary challenges are related. The first challenge is the problem of spatial autocorrelation. Program enrollment decisions are spatially autocorrelated, since protecting large patches of contiguous habitat is a central tenant of conservation planning. This implies that spatial autocorrelation is a statistical challenge that must be addressed in evaluating other programs in other regions for other time periods. Regardless of the statistical method employed, developing regression models to predict program enrollment is complicated. Furthermore, when observations are highly correlated spatially, each observation contributes less information than it would if it were completely independent of the other observations. Therefore, estimating statistical models in this context suffers from a lack of statistical power, meaning that effects may not always be detectable.

Reinforcing the reduced statistical power in these settings is the difficulty of using data from short time periods to make decisions about long-term phenomena. During the time period of this study, the rate of land conversions was extremely low, making it difficult to develop stable estimates. In addition, it shows that the impact of a land conservation program is driven by the background rate of land conversion. In areas with extremely high rates of land conversion, the avoided rate of land conversion attributed to the program will be high. In a study area and time period such as the one examined for this dissertation, land conversion rates were low, making the program appear to be less effective in absolute terms. Since the objective of land conservation programs is to protect land in perpetuity, there is a challenge to converting these short-term rates into long-term tendencies.

In addition, there are difficulties with compiling sufficient data to adequately make land conservation and conversion decisions. It would be ideal to have data on both land and landowner characteristics, for example. When a long time series of data can be obtained to examine land use it is likely difficult or impossible to obtain landowner information because too much time has passed to survey landowners. When it is possible to survey landowners, data on land conversions may not be available. When both are available, such as through a large public survey like the National Resources Inventory (NRI), the exact locations of tracts are not reported, thereby preventing detailed spatial analysis, such as assessments of autocorrelation or surrounding land uses. Thus, studies of land conservation and conversion are likely to be challenged with the problem of omitted variables and the resulting difficulty of developing adequate predictive models.

Policy Implications

These methodological challenges described above have policy implications and present a dilemma for conservation planning. On one hand, a substantial body of literature in land economics suggests that land conservation programs are vulnerable to adverse selection in tract enrollment since tracts of land that are most likely to be converted are least likely to enroll. A related body of literature suggests that this tendency can be overcome if program employ optimization techniques to target land that has the greatest ecological benefits per dollar. In the presence of the methodological challenges of spatial autocorrelation and rare land conversions or short time series, it may be difficult to conduct the empirical analyses required to take advantage of these optimization techniques. An important extension to this work would be to develop spatial models of land use change that can be used to parameterize optimization models to identify ways in which program can operate more efficiently.

Table 1 - Primary Grassland Conservation Programs and Public Lands Operating in Study Area

Program	Description	Restrictions	Ownership
Grassland Reserve Program (GRP)	Authorized in the 1996 Farm Bill and administered by the Natural Resource Conservation Service (NRCS) and Farmland Services Agency (FSA) of U.S. Department of Agriculture (USDA).[a]	Both permanent and temporary easements that to protect and restore grasslands while allowing grazing.[a,c]	Easement
Wetland Reserve Program (WRP) and Emergency Wetland Reserve Program (EWRP)	Authorized in 1985 farm bill and administered by Natural Resource Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA).[a]	Both permanent and temporary easements that restrict landowner from planting crops within the boundaries of the easemement, which includes wetland and surrounding uplands.[b]	Easement
Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP)	Authorized in the 1985 Farm Bill and administered by the Farmland Services Agency (FSA) of the U.S. Department of Agriculture (USDA).[a]	Temporary contracts to convert highly erodible cropland to pasture, grass, or other vegetative cover.[d]	Easement
Emergency Watershed Protection Program (EWPP)	Established in 1996. Natural Resource Conservation Service (NRCS) and Farmland Services Agency (FSA) of U.S. Deparment of Agriculture (USDA).[a]	The program offers permanent easements that restrict cropping but allow the land to be grazed under certain conditions. Retires farmland that frequently floods to protect it as wildlife habitat.[e]	Easement
Ducks Unlimited	Private	Program managed to provide habitat for waterfowl.	Easement
School and Public Lands	State of South Dakota	Awards grazing, farming, oil, mineral, and gas leases on public land to raise money for schools.[f]	Public ownership
Game, Fish, and Parks Land	State of South Dakota	Managed for recreation.[g]	Public ownership
Federal wildlife refuges and wetland management districts	U.S. Fish and Wildlife Service (FWS)	Land protected and managed to provide permanent habitat for waterfowl and endangered species.	Public ownership

Table 2 - Covariates Calculated for Tracts and Buffers

Covariate	Description	Scale	Spatial Scale		
			Tract	Half-Mile Buffer around Tract	One-Mile Buffer around Tract
Soil Quality	Estimated soil productivity based on the National Commodity Crop Productivity Index (NCCPI)	Scale from 0 to 100	X	X	X
Slope	Mean slope (percent) based on National Elevation Dataset (NED)	Percentage	X	X	X
Distance to Buyer[a]	Distance to nearest state-certified grain buyer	Kilometers	X		
Distance to Town[a]	Distance to nearest town with population of 2,500 or more in 2000 based on U.S. Census	Kilometers	X		
Nesting Pair Accessibility	Accessibility to tract for nesting waterfowl based on FWS model	Maximum number of nesting pairs per square mile	X	X	X
Wetland Density	Total length of all wetland basins as defined by the National Wetlands Inventory (NWI)	100m	X	X	X
Grassland Coverage	Number of privately-owned tracts eligible for enrollment based on land cover in 2001 based on the National Land Cover Database (NLCD)	Count	X	X	X
Grassland Easement Coverage[c]	Number of surrounding tracts enrolled between 1990 and 2001 excluding any that might have been acquired in the same easement as the target tract	Count		X	X

Notes:
[a] This variable does not differ appreciably from tract- to buffer-level.

[b] Only non-public land is eligible for program enrollment; therefore, this variable has only one permissible value at the tract level.

[c] Measured at the tract level, grassland easement is the dependent variable, and therefore, can only be measured as an independent variable at the buffer level.

Table 3 - Join Count Statistics for Spatial Autocorrelation in Program Enrollment Decisions

Join Count Statistic for Pairs of Enrolled Tracts												
Distance (miles)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
Observed EE Joins	8	11	12	12	18	16	16	29	26	19	23	29
Expected EE Joins	1.29	2.45	4.37	5.79	7.00	8.77	10.16	10.77	12.73	13.55	13.99	15.24
z-score	5.95	5.49	3.65	2.58	4.15	2.43	1.82	5.53	3.71	1.47	2.39	3.46
z-critical	2.24	2.64	2.81	2.91	2.99	3.05	3.10	3.14	3.18	3.21	3.24	3.27
Obsd/Expd EE Joins	6.19	4.50	2.75	2.07	2.57	1.83	1.58	2.69	2.04	1.40	1.64	1.90
Join Count Statistic for Pairs of Enrolled-Unenrolled Tracts												
Distance (miles)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5
Observed EU Joins	7.00	19.00	24.50	39.50	52.50	66.00	72.00	90.00	98.50	119.50	107.00	121.00
Expected EU Joins	20.66	39.14	69.94	92.59	112.06	140.27	162.52	172.26	203.65	216.77	223.92	243.79
z-score	-3.38	-3.55	-5.92	-6.03	-6.11	-6.70	-7.59	-6.73	-7.95	-6.96	-8.31	-8.05
z-critical	-2.24	-2.64	-2.81	-2.91	-2.99	-3.05	-3.10	-3.14	-3.18	-3.21	-3.24	-3.27
Obsd/Expd EU Joins	0.34	0.49	0.35	0.43	0.47	0.47	0.44	0.52	0.48	0.55	0.48	0.50

Table 4 - Univariate Statistics

Covariate	Mean	Std Dev	Minimum	Maximum
Tract Level				
Soil Productivity	0.26	0.06	0.01	0.44
Slope	9.03	7.15	0.00	54.23
Wetland Perimeter	756.11	626.38	0.00	6106.24
Nesting Pairs	77.85	25.72	0.00	100.00
Grassland Coverage	0.90	0.13	0.25	1.00
Distance to Buyer	14.15	6.76	0.00	40.65
Distance to Town	30.19	12.66	0.30	63.47
Half-Mile Buffer				
Soil Productivity	0.27	0.04	0.04	0.44
Slope	8.92	4.97	0.00	33.74
Wetland Perimeter	694.71	341.73	0.00	2734.75
Nesting Pairs	77.70	24.72	1.00	100.00
Grassland Coverage	0.63	0.22	0.01	1.00
Net Number of Eased Tracts	1.71	3.63	0.00	36.00

One-Mile Buffer				
Soil Productivity	0.27	0.03	0.10	0.41
Slope	8.83	4.36	0.03	25.05
Wetland Perimeter	680.46	300.05	14.17	2002.38
Nesting Pairs	77.30	23.87	6.38	100.00
Grassland Coverage	0.57	0.20	0.00	1.00
Net Number of Eased Tracts	5.02	8.75	0.00	77.00

Table 5- Bivariate Statistics Comparing Unmatched Treated and Untreated Tracts

	Untreated (n=69,890)		Treated (n=8,736)		Difference		Statistical Test[a]	
Tract Level	**Mean**	**Std Dev**	**Mean**	**Std Dev**	**Mean**	**Percent**	**Test Statistic**	**p-value**
Soil Productivity	0.27	0.06	0.25	0.06	-0.02	-7.21%	25.46	<.0001
Slope	8.90	7.12	10.11	7.34	1.22	12.02%	-15	<.0001
Wetland Perimeter	737.65	627.41	903.99	597.92	166.34	18.40%	-23.48	<.0001
Nesting Pairs	76.21	26.11	90.99	17.41	14.78	16.24%	-51.49	<.0001
Grassland Coverage	0.90	0.13	0.89	0.14	-0.01	-0.91%	5.55	<.0001
Distance to Buyer	14.11	6.80	14.49	6.34	0.38	2.63%	-4.98	<.0001
Distance to Town	29.76	12.48	33.65	13.49	3.89	11.57%	-27.23	<.0001
Soil Productivity > 0.26 (Dummy)	0.61	0.49	0.47	0.50	-0.14	-28.96%	598.998	<.0001
Slope <15 (Dummy)	0.84	0.37	0.79	0.41	-0.05	-6.73%	156.5467	<.0001
Wetland Perimeter < 875 (Dummy)	0.70	0.46	0.61	0.49	-0.09	-15.55%	322.7132	<.0001
Soil Productivity Main Effect * Dummy (Interaction)	0.19	0.15	0.14	0.15	-0.05	-34%	29.01	<.0001
Slope Main Effect * Dummy (Interaction)	5.35	4.02	5.52	4.36	0.17	3%	-3.57	0.0004
Wetland Perimeter Main Effect * Dummy (Interaction)	283.66	320.04	316.94	342.17	33.28	11%	-8.87	<.0001
Half-Mile Buffer								
Soil Productivity	0.27	0.04	0.25	0.03	-0.02	-6.70%	37.66	<.0001
Slope	8.80	4.94	9.92	5.12	1.12	11.29%	-19.91	<.0001
Wetland Perimeter	678.86	342.94	821.68	303.39	142.81	17.38%	-37.15	<.0001
Nesting Pairs	76.10	25.07	90.53	16.89	14.43	15.94%	-52.34	<.0001
Grassland Coverage	0.61	0.22	0.72	0.18	0.10	14.59%	-43.46	<.0001
Net Number of Eased Tracts	1.27	2.99	5.18	5.78	3.90	75.41%	-100.74	<.0001
Soil Productivity > 0.26 (Dummy)	0.64	0.48	0.45	0.50	-0.19	-43.38%	1248.636	<.0001
Slope <15 (Dummy)	0.87	0.34	0.82	0.39	-0.05	-6.56%	189.872	<.0001
Wetland Perimeter < 875 (Dummy)	0.73	0.44	0.61	0.49	-0.12	-19.07%	522.8	<.0001

Soil Productivity Main Effect * Dummy (Interaction)	0.19	0.14	0.13	0.14	-0.06	-46%	38.88	<.0001
Slope Main Effect * Dummy (Interaction)	6.43	4.05	6.61	4.52	0.18	3%	-3.64	0.0003
Wetland Perimeter Main Effect * Dummy (Interaction)	376.6	295.33	385.54	331.33	8.94	2%	-2.47	0.0134
One-Mile Buffer								
Soil Productivity	0.27	0.03	0.26	0.03	-0.01	-5.23%	35.04	<.0001
Slope	8.71	4.32	9.77	4.55	1.06	10.82%	-21.45	<.0001
Wetland Perimeter	667.43	302.21	784.82	259.53	117.39	14.96%	-34.74	<.0001
Nesting Pairs	75.75	24.18	89.70	16.71	13.95	15.55%	-52.39	<.0001
Grassland Coverage	0.56	0.20	0.66	0.18	0.10	14.69%	-42.38	<.0001
Net Number of Eased Tracts	4.13	7.49	12.23	13.48	8.10	66.26%	-85.28	<.0001
Soil Productivity > 0.26 (Dummy)	0.67	0.47	0.48	0.50	-0.19	-40.25%	1247.825	<.0001
Wetland Perimeter < 875 (Dummy)	0.76	0.43	0.66	0.48	-0.10	-15.63%	432.1476	<.0001
Soil Productivity Main Effect * Dummy (Interaction)	0.19	0.14	0.14	0.14	-0.05	36%	37.39	<.0001
Wetland Perimeter Main Effect * Dummy (Interaction)	408.11	291.99	418.56	328.69	10.45	2%	-2.91	0.0036

Note:

[a] Test statistics are chi-square for all dummy variables and t-values for all other variables.

Table 6 - Logistic Regression Model Predicting Program Enrollment

Covariate	B	exp(B)	Std. Error (B)	z value	Pr(>|z|)
Intercept	-4.011	0.018	0.391	-10.264	0.000
Tract Level					
Soil Productivity	1.464	4.323	0.448	3.266	0.001
Slope	-0.004	0.996	0.005	-0.717	0.473
Wetland Perimeter	0.000	1.000	0.000	0.132	0.895
Nesting Pairs	0.008	1.008	0.003	2.351	0.019
Grassland Coverage	-0.132	0.877	0.106	-1.239	0.215
Distance to Buyer	-0.014	0.986	0.002	-7.330	0.000
Distance to Town	0.012	1.012	0.001	11.777	0.000
Soil Productivity > 0.26 (Dummy)	2.052	7.783	0.258	7.948	0.000
Slope <15 (Dummy)	-0.317	0.728	0.119	-2.674	0.008
Wetland Perimeter < 875 (Dummy)	-0.347	0.707	0.080	-4.356	0.000
Soil Productivity Main Effect * Dummy (Interaction)	-7.739	0.000	0.935	-8.274	0.000
Slope Main Effect * Dummy (Interaction)	0.020	1.020	0.007	2.860	0.004
Wetland Perimeter Main Effect * Dummy (Interaction)	0.000	1.000	0.000	5.504	0.000
Half-Mile Buffer					
Soil Productivity	-3.428	0.032	1.061	-3.232	0.001
Slope	-0.033	0.967	0.014	-2.383	0.017

Wetland Perimeter	0.001	1.001	0.000	3.699	0.000
Nesting Pairs	-0.007	0.993	0.006	-1.019	0.308
Grassland Coverage	0.937	2.552	0.117	7.984	0.000
Net Number of Eased Tracts	0.187	1.205	0.005	34.435	0.000
Soil Productivity > 0.26 (Dummy)	0.900	2.459	0.447	2.011	0.044
Slope <15 (Dummy)	-1.173	0.309	0.245	-4.798	0.000
Wetland Perimeter < 875 (Dummy)	-0.016	0.984	0.176	-0.093	0.926
Soil Productivity Main Effect * Dummy (Interaction)	-3.458	0.031	1.685	-2.053	0.040
Slope Main Effect * Dummy (Interaction)	0.082	1.085	0.014	5.690	0.000
Wetland Perimeter Main Effect * Dummy (Interaction)	0.000	1.000	0.000	0.980	0.327
One-Mile Buffer					
Soil Productivity	4.337	76.478	1.168	3.713	0.000
Slope	0.006	1.006	0.008	0.721	0.471
Wetland Perimeter	0.000	1.000	0.000	-1.657	0.098
Nesting Pairs	0.014	1.014	0.005	2.967	0.003
Grassland Coverage	0.511	1.667	0.122	4.192	0.000
Net Number of Eased Tracts	-0.026	0.975	0.002	-10.846	0.000
Soil Productivity > 0.26 (Dummy)	1.725	5.613	0.469	3.679	0.000
Wetland Perimeter < 875 (Dummy)	-0.664	0.515	0.203	-3.280	0.001
Soil Productivity Main Effect * Dummy (Interaction)	-7.000	0.001	1.774	-3.945	0.000

Wetland Perimeter Main Effect * Dummy (Interaction)	0.001	1.001	0.000	3.126	0.002

Likelihood Ratio Test: Chi-Square=3,670, df=35, p<.0001

Table 7 - Comparison between Treatment and Control Cases on Covariates for Matched Sample 1 (Matching without Replacement at 1:1 Ratio of Control to Treatment)

Covariate	Means Treated	Means Control	SD Control	Mean Diff	Percent Difference	Standardized Difference (d)
Tract Level						
Soil Productivity	0.248	0.2483	0.0563	-0.0003	-0.12%	0.005
Slope	10.0629	10.1741	7.4179	-0.1112	-1.09%	0.015
Wetland Perimeter	901.3053	892.9271	606.3952	8.3782	0.94%	0.014
Nesting Pairs	90.7779	90.9231	17.379	-0.1452	-0.16%	0.008
Grassland Coverage	0.8944	0.8923	0.1394	0.0021	0.24%	0.015
Distance to Buyer	14.4879	14.4237	6.6171	0.0642	0.45%	0.010
Distance to Town	33.4324	33.4425	12.7582	-0.01	-0.03%	0.001
Soil Productivity > 0.26 (Dummy)	0.4746	0.4763	0.4995	-0.0018	-0.38%	0.003
Slope <15 (Dummy)	0.7886	0.7816	0.4132	0.007	0.90%	0.017
Wetland Perimeter < 875 (Dummy)	0.6087	0.6168	0.4862	-0.0081	-1.31%	0.017
Soil Productivity Main Effect * Dummy (Interaction)	0.1384	0.139	0.1467	-0.0006	-0.43%	0.004
Slope Main Effect * Dummy (Interaction)	5.5091	5.4678	4.3725	0.0413	0.76%	0.009
Wetland Perimeter Main Effect * Dummy (Interaction)	316.405	317.8478	343.2164	-1.4428	-0.45%	0.004
Half-Mile Buffer						
Soil Productivity	0.2541	0.2541	0.0354	0.0001	0.04%	0.000
Slope	9.8766	9.8969	5.1752	-0.0204	-0.21%	0.004
Wetland Perimeter	818.0464	813.73	307.8162	4.3163	0.53%	0.014
Nesting Pairs	90.3092	90.3892	16.6579	-0.0799	-0.09%	0.005
Grassland Coverage	0.7151	0.7161	0.1766	-0.001	-0.14%	0.006
Net Number of Eased Tracts	4.7566	4.6735	5.5179	0.0831	1.78%	0.015
Soil Productivity > 0.26 (Dummy)	0.4578	0.4611	0.4985	-0.0033	-0.72%	0.007
Slope <15 (Dummy)	0.8202	0.8149	0.3884	0.0053	0.65%	0.014
Wetland Perimeter < 875 (Dummy)	0.6172	0.6273	0.4835	-0.0102	-1.63%	0.021

Soil Productivity Main Effect * Dummy (Interaction)	0.1295	0.1303	0.1414	-0.0008	-0.61%	0.006
Slope Main Effect * Dummy (Interaction)	6.6447	6.5666	4.5371	0.0781	1.19%	0.017
Wetland Perimeter Main Effect * Dummy (Interaction)	387.1153	392.8852	332.2769	-5.7698	-1.47%	0.017
One-Mile Buffer						
Soil Productivity	0.2583	0.2585	0.0299	-0.0002	-0.08%	0.007
Slope	9.7368	9.7608	4.6591	-0.024	-0.25%	0.005
Wetland Perimeter	781.6243	774.4828	257.5294	7.1415	0.92%	0.028
Nesting Pairs	89.4696	89.515	16.3614	-0.0454	-0.05%	0.003
Grassland Coverage	0.6575	0.6575	0.1715	0	0.00%	0.000
Net Number of Eased Tracts	11.491	11.5485	12.487	-0.0575	-0.50%	0.005
Soil Productivity < 0.26 (Dummy)	0.4858	0.4896	0.4999	-0.0038	-0.78%	0.008
Wetland Perimeter < 875 (Dummy)	0.6603	0.6725	0.4693	-0.0123	-1.83%	0.026
Soil Productivity Main Effect * Dummy (Interaction)	0.1368	0.1378	0.1412	-0.001	-0.73%	0.007
Wetland Perimeter Main Effect * Dummy (Interaction)	420.0234	427.2126	326.7079	-7.1892	-1.68%	0.022

Table 8 - Comparison between Treatment and Control Cases on Covariates for Matched Sample 1 (Matching with Replacement at 1:1 Ratio of Control to Treatment)

Covariate	Means Treated	Means Control	SD Control	Mean Diff	Percent Difference	Standardized Difference (d)
Tract Level						
Soil Productivity	0.248	0.2476	0.057	0.0004	0.70%	0.007
Slope	10.0629	10.0993	7.3102	-0.0363	-0.50%	0.005
Wetland Perimeter	901.3053	892.6099	594.1502	8.6954	1.46%	0.015
Nesting Pairs	90.7779	90.8086	17.4562	-0.0307	-0.18%	0.002
Grassland Coverage	0.8944	0.8904	0.1413	0.004	2.83%	0.028
Distance to Buyer	14.4879	14.4943	6.6236	-0.0064	-0.10%	0.001
Distance to Town	33.4324	33.3572	12.8003	0.0752	0.59%	0.006
Soil Productivity > 0.26 (Dummy)	0.4746	0.4744	0.4994	0.0001	0.02%	0.000
Slope <15 (Dummy)	0.7886	0.7854	0.4106	0.0032	0.78%	0.008
Wetland Perimeter < 875 (Dummy)	0.6087	0.6113	0.4875	-0.0026	-0.53%	0.005
Soil Productivity Main Effect * Dummy (Interaction)	0.1384	0.1384	0.1466	0	0.00%	0.000
Slope Main Effect * Dummy (Interaction)	5.5091	5.5092	4.4019	-0.0002	0.00%	0.000
Wetland Perimeter Main Effect * Dummy (Interaction)	316.405	315.4261	343.7819	0.9788	0.28%	0.003
Half-Mile Buffer						
Soil Productivity	0.2541	0.2536	0.0355	0.0005	1.41%	0.014
Slope	9.8766	9.9222	5.1248	-0.0457	-0.89%	0.009
Wetland Perimeter	818.0464	813.4191	304.9123	4.6272	1.52%	0.015
Nesting Pairs	90.3092	90.3144	16.7345	-0.0052	-0.03%	0.000
Grassland Coverage	0.7151	0.7143	0.1775	0.0008	0.45%	0.005
Net Number of Eased Tracts	4.7566	4.6757	5.5509	0.0809	1.46%	0.015
Soil Productivity > 0.26 (Dummy)	0.4578	0.4524	0.4978	0.0054	1.08%	0.011
Slope <15 (Dummy)	0.8202	0.8166	0.3871	0.0037	0.96%	0.009
Wetland Perimeter < 875 (Dummy)	0.6172	0.6253	0.4841	-0.0081	-1.67%	0.017
Soil Productivity Main Effect * Dummy (Interaction)	0.1295	0.1279	0.1413	0.0015	1.06%	0.011
Slope Main Effect * Dummy (Interaction)	6.6447	6.6417	4.5697	0.003	0.07%	0.001

Wetland Perimeter Main Effect * Dummy (Interaction)	387.1153	392.0295	332.5628	-4.9141	-1.48%	0.015
One-Mile Buffer						
Soil Productivity	0.2583	0.258	0.0302	0.0003	0.99%	0.010
Slope	9.7368	9.7966	4.6615	-0.0598	-1.28%	0.013
Wetland Perimeter	781.6243	775.6801	257.4484	5.9442	2.31%	0.023
Nesting Pairs	89.4696	89.4441	16.4489	0.0255	0.16%	0.002
Grassland Coverage	0.6575	0.6565	0.1716	0.001	0.58%	0.006
Net Number of Eased Tracts	11.491	11.5836	12.5362	-0.0927	-0.74%	0.007
Soil Productivity < 0.26 (Dummy)	0.4858	0.4788	0.4996	0.007	1.40%	0.014
Wetland Perimeter < 875 (Dummy)	0.6603	0.6739	0.4688	-0.0137	-2.92%	0.029
Soil Productivity Main Effect * Dummy (Interaction)	0.1368	0.1349	0.1413	0.0019	1.34%	0.013
Wetland Perimeter Main Effect * Dummy (Interaction)	420.0234	429.1535	326.7389	-9.1301	-2.79%	0.028

Table 9 - Comparison between Treatment and Control Cases on Covariates for Matched Sample 1 (Matching without Replacement at 2:1 Ratio of Control to Treatment)

Covariate	**Means Treated**	**Means Control**	**SD Control**	**Mean Diff**	**Percent Difference**	**Standardized Difference (d)**
Tract Level						
Soil Productivity	0.248	0.2475	0.0563	0.0006	1.07%	0.009
Slope	10.0629	10.0939	7.3078	-0.031	-0.42%	0.004
Wetland Perimeter	901.3053	894.5403	595.8123	6.765	1.14%	0.011
Nesting Pairs	90.7779	90.978	17.2067	-0.2001	-1.16%	0.012
Grassland Coverage	0.8944	0.8917	0.1389	0.0027	1.94%	0.019
Distance to Buyer	14.4879	14.4641	6.5867	0.0238	0.36%	0.004
Distance to Town	33.4324	33.3384	12.7994	0.0941	0.74%	0.007
Soil Productivity > 0.26 (Dummy)	0.4746	0.4724	0.4993	0.0021	0.42%	0.004
Slope <15 (Dummy)	0.7886	0.7847	0.4111	0.0039	0.95%	0.009
Wetland Perimeter < 875 (Dummy)	0.6087	0.6127	0.4871	-0.0041	-0.84%	0.008
Soil Productivity Main Effect * Dummy (Interaction)	0.1384	0.1375	0.1462	0.0009	0.62%	0.006
Slope Main Effect * Dummy (Interaction)	5.5091	5.4816	4.3601	0.0275	0.63%	0.006
Wetland Perimeter Main Effect * Dummy (Interaction)	316.405	318.849	345.891	-2.4441	-0.71%	0.007
Half-Mile Buffer						
Soil Productivity	0.2541	0.2533	0.0354	0.0008	2.26%	0.023
Slope	9.8766	9.9102	5.1376	-0.0337	-0.66%	0.007
Wetland Perimeter	818.0464	815.077	303.746	2.9694	0.98%	0.010
Nesting Pairs	90.3092	90.4823	16.4773	-0.1731	-1.05%	0.011
Grassland Coverage	0.7151	0.7129	0.1788	0.0022	1.23%	0.012
Net Number of Eased Tracts	4.7566	4.6206	5.5252	0.1359	2.46%	0.025
Soil Productivity > 0.26 (Dummy)	0.4578	0.4525	0.4978	0.0053	1.06%	0.011
Slope <15 (Dummy)	0.8202	0.8176	0.3862	0.0026	0.67%	0.007
Wetland Perimeter < 875 (Dummy)	0.6172	0.6251	0.4841	-0.008	-1.65%	0.016
Soil Productivity Main Effect * Dummy (Interaction)	0.1295	0.1278	0.1411	0.0017	1.20%	0.012

Slope Main Effect * Dummy (Interaction)	6.6447	6.6399	4.5603	0.0048	0.11%	0.001
Wetland Perimeter Main Effect * Dummy (Interaction)	387.1153	393.1204	332.8539	-6.005	-1.80%	0.018
One-Mile Buffer						
Soil Productivity	0.2583	0.2577	0.03	0.0006	2.00%	0.020
Slope	9.7368	9.7773	4.6484	-0.0405	-0.87%	0.009
Wetland Perimeter	781.6243	776.6244	256.8965	5	1.95%	0.019
Nesting Pairs	89.4696	89.5946	16.1778	-0.125	-0.77%	0.008
Grassland Coverage	0.6575	0.6552	0.173	0.0023	1.33%	0.013
Net Number of Eased Tracts	11.491	11.4926	12.4978	-0.0016	-0.01%	0.000
Soil Productivity < 0.26 (Dummy)	0.4858	0.4815	0.4997	0.0043	0.86%	0.009
Wetland Perimeter < 875 (Dummy)	0.6603	0.6706	0.47	-0.0104	-2.21%	0.022
Soil Productivity Main Effect * Dummy (Interaction)	0.1368	0.1354	0.141	0.0014	0.99%	0.010
Wetland Perimeter Main Effect * Dummy (Interaction)	420.0234	426.8391	326.9134	-6.8157	-2.08%	0.021

Table 10 - Comparison between Treatment and Control Cases on Covariates for Matched Sample 1 (Matching with Replacement at 2:1 Ratio of Control to Treatment)

Covariate	Means Treated	Means Control	SD Control	Mean Diff	Percent Difference	Standardized Difference (d)
Tract Level						
Soil Productivity	0.2478	0.2479	0.056	-0.0002	-0.36%	0.002
Slope	10.1125	10.1936	7.3306	-0.0811	-1.11%	0.011
Wetland Perimeter	903.6776	896.7426	591.4092	6.935	1.17%	0.012
Nesting Pairs	90.9872	91.3267	16.8726	-0.3396	-2.01%	0.020
Grassland Coverage	0.895	0.8904	0.1385	0.0046	3.32%	0.033
Distance to Buyer	14.4927	14.4267	6.5584	0.0661	1.01%	0.010
Distance to Town	33.6511	33.3801	12.9282	0.271	2.10%	0.021
Soil Productivity > 0.26 (Dummy)	0.4714	0.4737	0.4993	-0.0023	-0.46%	0.005
Slope <15 (Dummy)	0.7862	0.7834	0.412	0.0028	0.68%	0.007
Wetland Perimeter < 875 (Dummy)	0.6064	0.6115	0.4874	-0.0052	-1.07%	0.010
Soil Productivity Main Effect * Dummy (Interaction)	0.1373	0.1379	0.1463	-0.0006	-0.41%	0.004
Slope Main Effect * Dummy (Interaction)	5.5061	5.5519	4.4055	-0.0458	-1.04%	0.010
Wetland Perimeter Main Effect * Dummy (Interaction)	316.3758	319.3934	346.4046	-3.0176	-0.87%	0.009
Half-Mile Buffer						
Soil Productivity	0.2537	0.2532	0.0353	0.0005	1.42%	0.014
Slope	9.9161	9.962	5.1324	-0.0459	-0.89%	0.009
Wetland Perimeter	821.6597	819.1424	300.5124	2.5173	0.84%	0.008
Nesting Pairs	90.5267	90.8461	16.1718	-0.3195	-1.98%	0.020
Grassland Coverage	0.7192	0.7167	0.1762	0.0025	1.42%	0.014
Net Number of Eased Tracts	5.1661	5.1618	6.0964	0.0043	0.07%	0.001
Soil Productivity > 0.26 (Dummy)	0.4486	0.4518	0.4977	-0.0032	-0.64%	0.006
Slope <15 (Dummy)	0.8168	0.8185	0.3854	-0.0018	-0.47%	0.004
Wetland Perimeter < 875 (Dummy)	0.6129	0.6163	0.4863	-0.0034	-0.70%	0.007
Soil Productivity Main Effect * Dummy (Interaction)	0.1268	0.1275	0.141	-0.0007	-0.50%	0.005
Slope Main Effect * Dummy (Interaction)	6.6251	6.6957	4.5669	-0.0707	-1.55%	0.015

Wetland Perimeter Main Effect * Dummy (Interaction)	385.6094	389.2594	334.4892	-3.65	-1.09%	0.011
One-Mile Buffer						
Soil Productivity	0.2579	0.2578	0.0299	0.0001	0.33%	0.003
Slope	9.7693	9.8358	4.6459	-0.0665	-1.43%	0.014
Wetland Perimeter	784.8021	780.8525	254.1063	3.9496	1.55%	0.016
Nesting Pairs	89.6964	89.9698	15.9763	-0.2735	-1.71%	0.017
Grassland Coverage	0.6613	0.6584	0.1698	0.0029	1.71%	0.017
Net Number of Eased Tracts	12.2065	12.5688	13.4652	-0.3623	-2.69%	0.027
Soil Productivity < 0.26 (Dummy)	0.4763	0.4767	0.4995	-0.0004	-0.08%	0.001
Wetland Perimeter < 875 (Dummy)	0.6559	0.6664	0.4715	-0.0105	-2.23%	0.022
Soil Productivity Main Effect * Dummy (Interaction)	0.134	0.1342	0.1411	-0.0001	-0.07%	0.001
Wetland Perimeter Main Effect * Dummy (Interaction)	418.7014	427.3247	328.9568	-8.6233	-2.62%	0.026

Table 11 - Results of Matching and Estimated Treatment Effects

	Matched Sample 1	**Matched Sample 2**	**Matched Sample 3**	**Matched Sample 4**
Method	Nearest Neighbor	Nearest Neighbor	Nearest Neighbor	Nearest Neighbor
Matching Ratio	1:1	1:1	2:1	2:1
Caliper Width[a]	0.1	0.1	0.1	0.1
Sample with Replacement?	No	Yes	No	Yes
Matched Treated Cases	8471	8732	8471	8732
Matched Control Cases	8471	7284	15537	12560
Unmatched Treated Cases	265	4	265	4
Unmatched Control Cases	61509	62696	54443	57420
Mean Conversion Rate - Treated	0.00208	0.00204	0.00204	0.00205
SE Conversion Rate - Treated	0.00028	0.00024	0.00028	0.00027
Mean Conversion Rate - Control	0.00560	0.00523	0.00620	0.00583
SE Conversion Rate - Control	0.00053	0.00061	0.00468	0.00047
Difference (Control - Treated)	0.00352	0.00319	0.00416	0.00378
p-value[b]	<.001	<.001	<.001	<.001

Notes:

[a] Caliper widths are expressed in standard deviations of the estimated propensity score.

[b] The p-values are based on independent samples t-tests, with equal or unequal sample sizes, as appropriate.

Figure 1 - Study Area

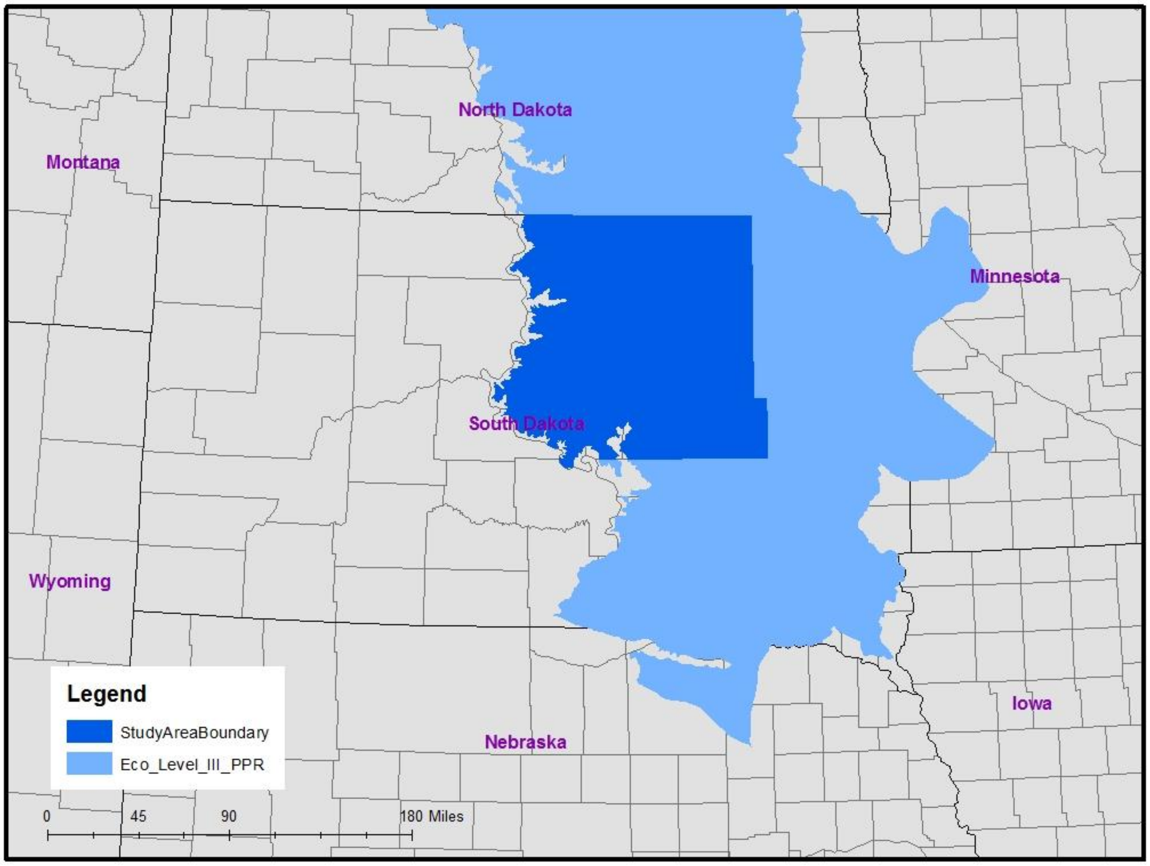


Figure 2 - National Land Cover Data (2001) and Quarter-Quarter Section Boundaries

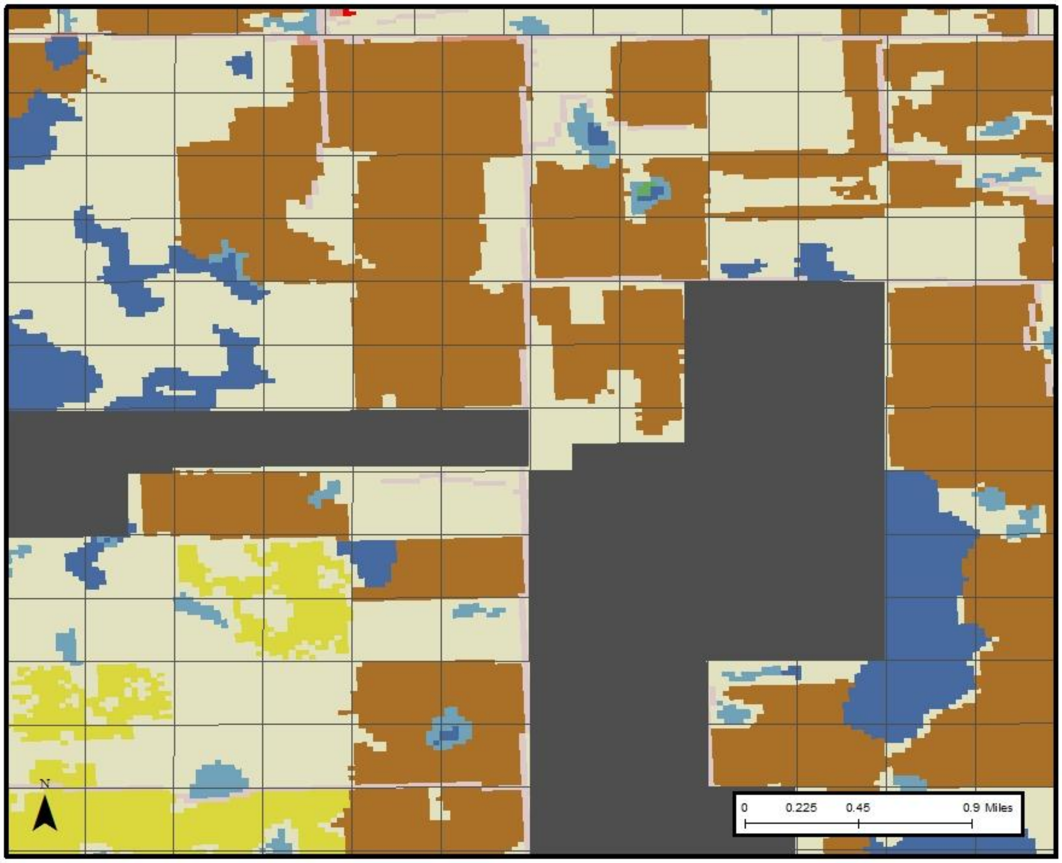


Figure 3 - Land Cover in 2001 in Study Area

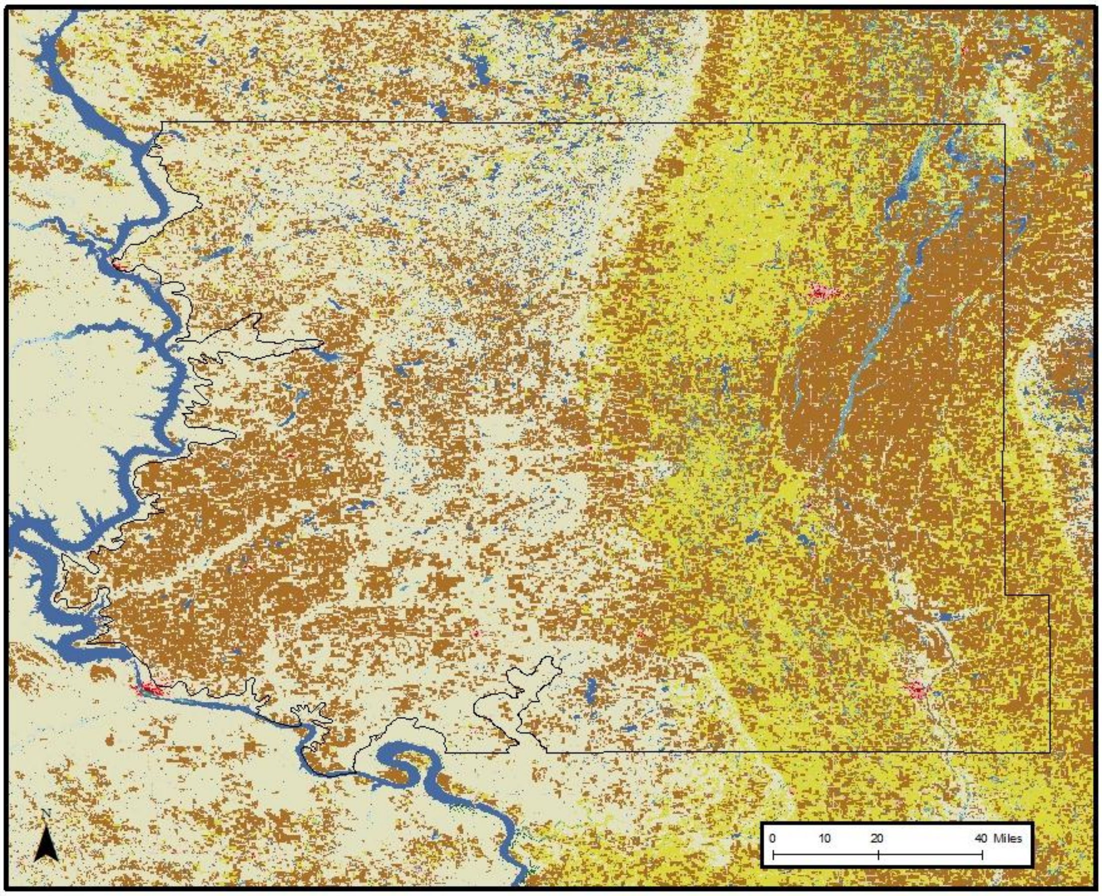


Figure 4 - Spatial Configuration of Enrolled, Unenrolled and Ineligible Tracts

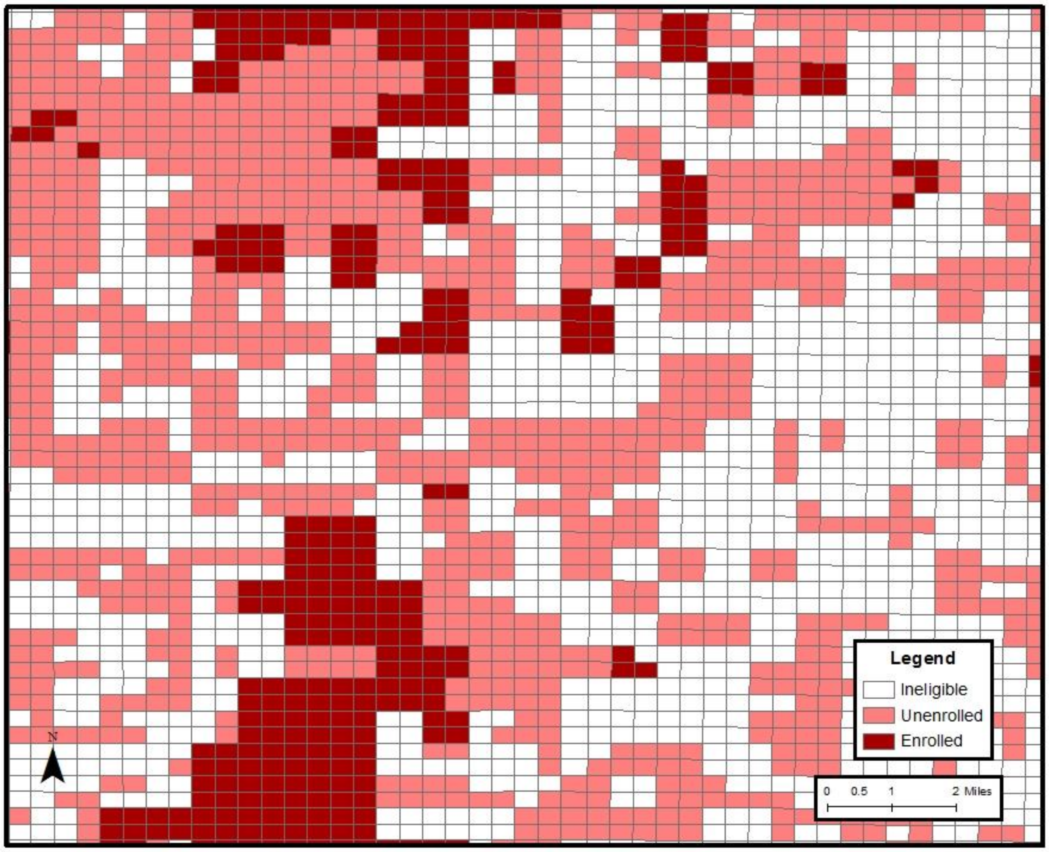


Figure 5 - National Commodity Crop Productivity Index (NCCPI) and Quarter-Quarter Section Boundaries

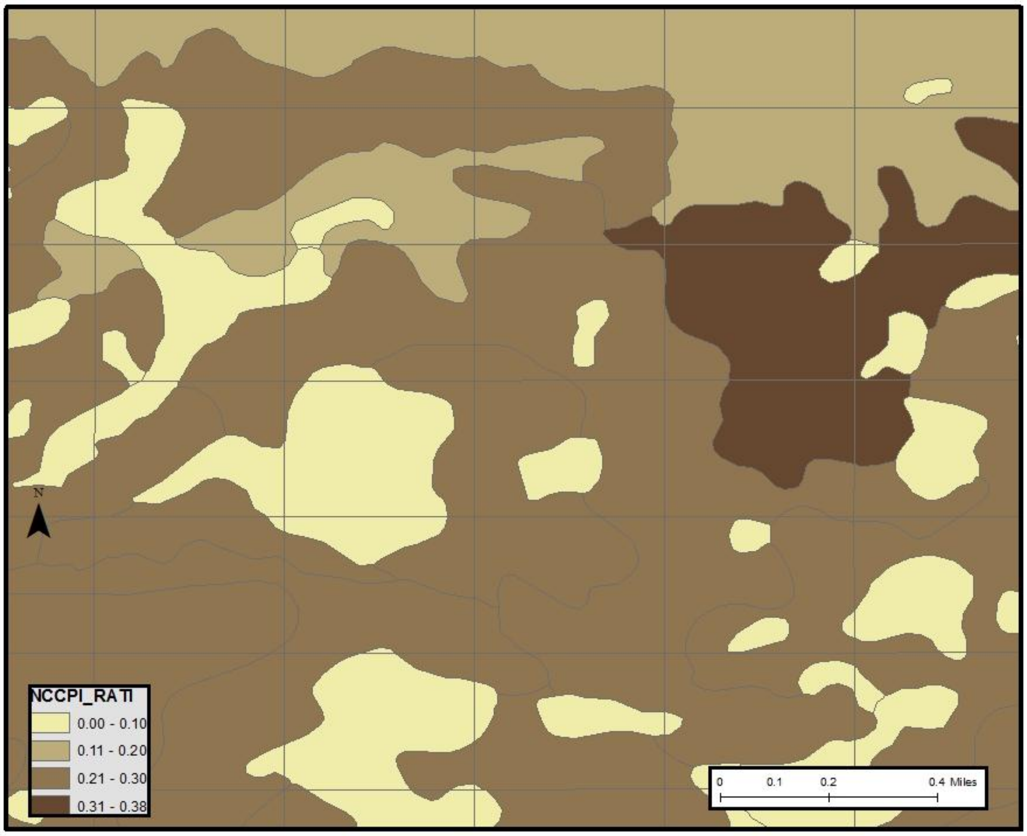


Figure 6 - Slope based on National Elevation Dataset

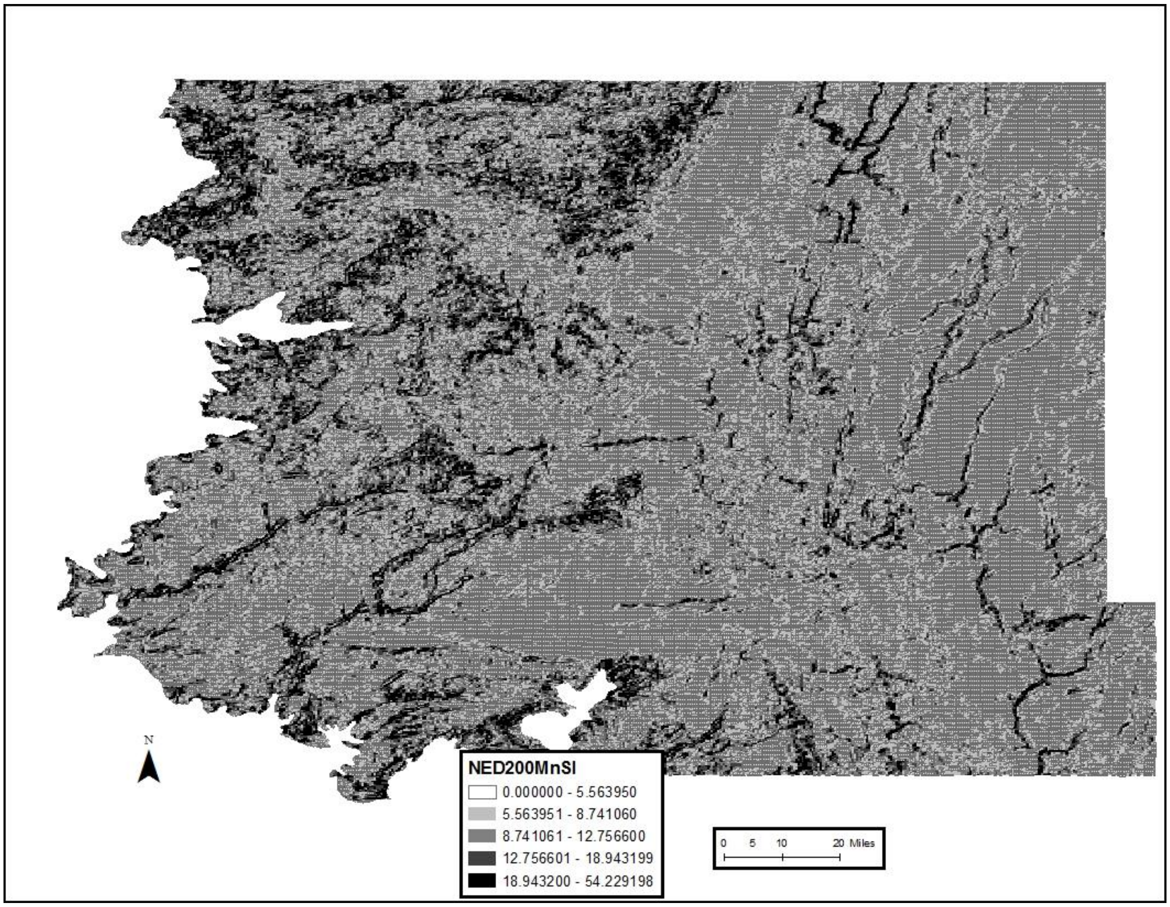


Figure 7 - Wetland Perimeter Length by Quarter-Quarter Section Calculated from National Wetlands Inventory

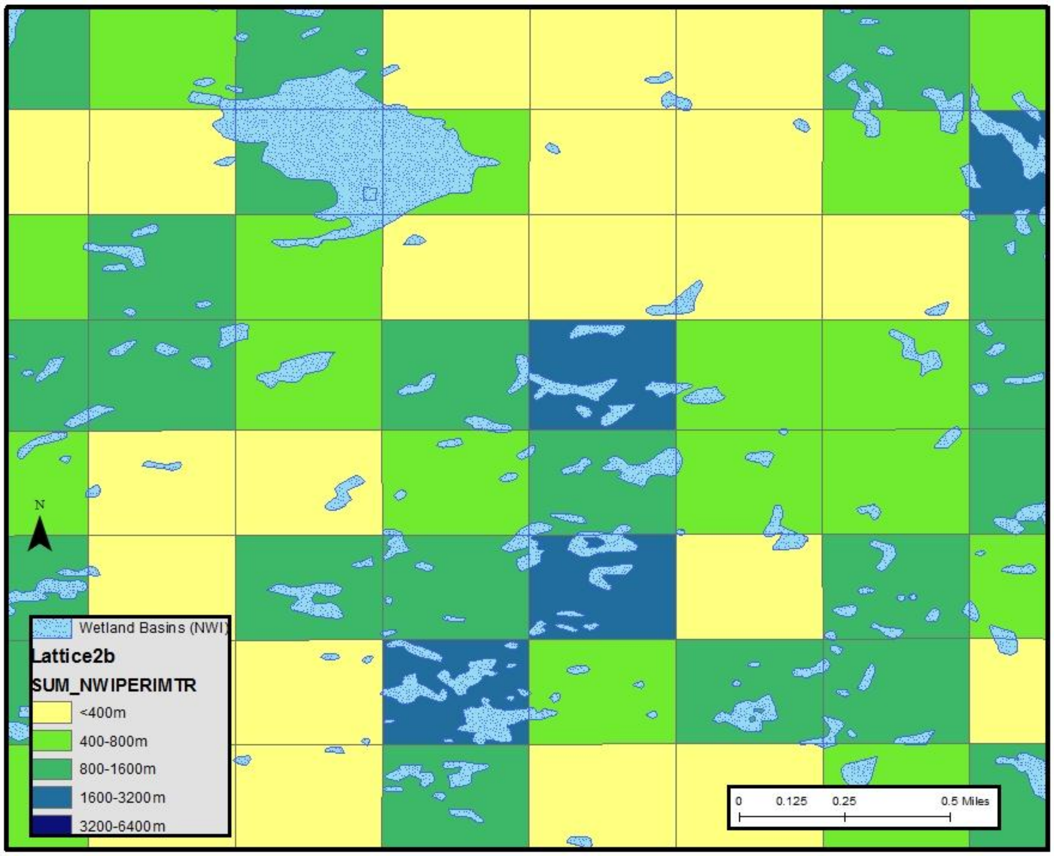


Figure 8 - Tract Accessibility to Nesting Waterfowl

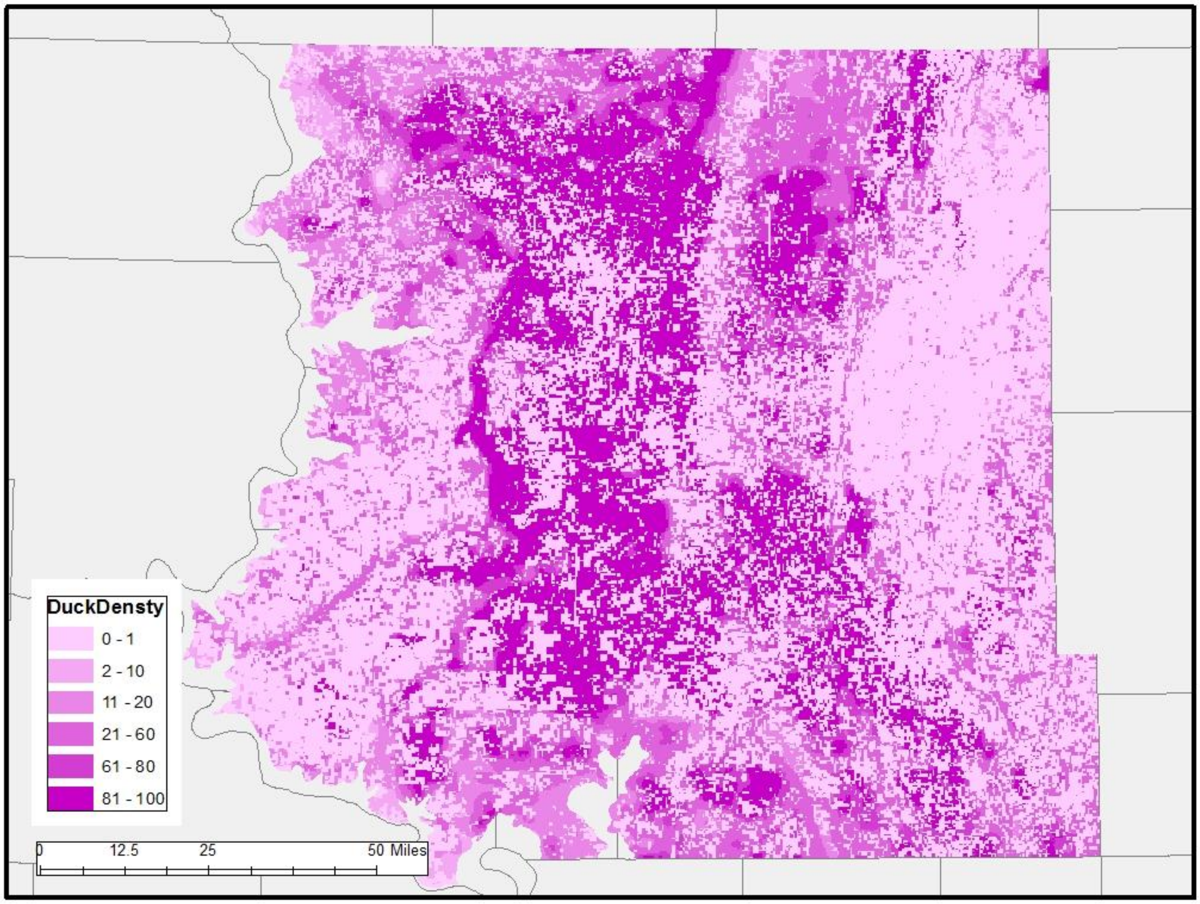


Figure 9 - Locations of Certified Grain Buyers and Cities and Towns

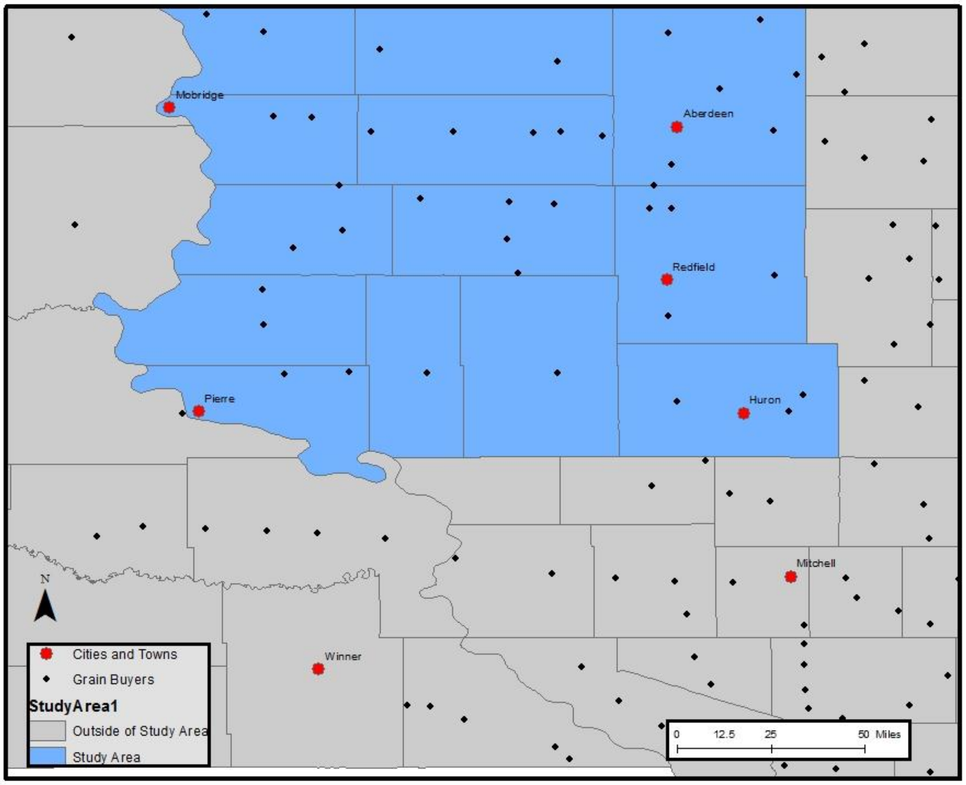


Figure 10 - Correlogram of Join Count Statistic

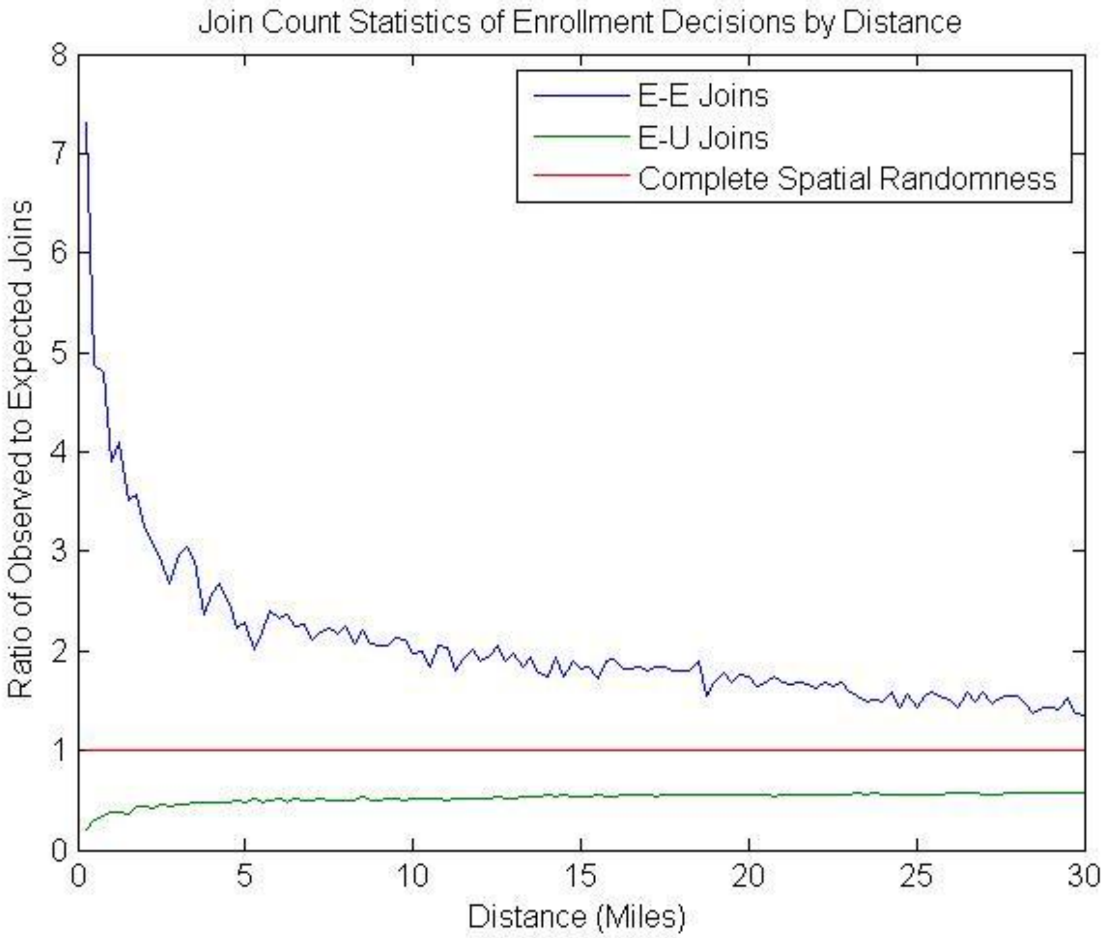


Figure 11 – Logit of Program Enrollment by Mean Soil Productivity (Tract)

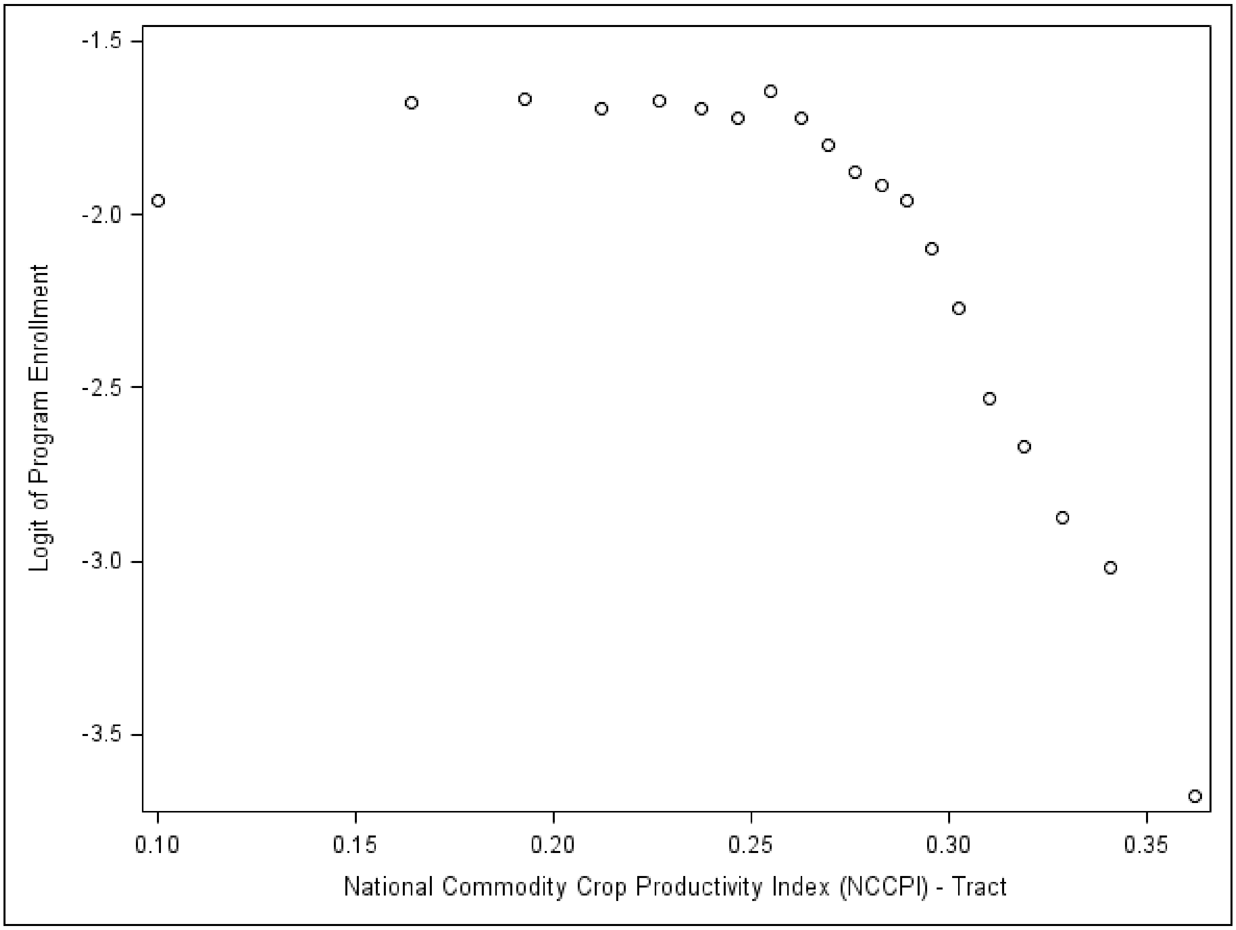


Figure 12 - Logit of Program Enrollment by Mean Soil Productivity (Half-Mile Buffer)

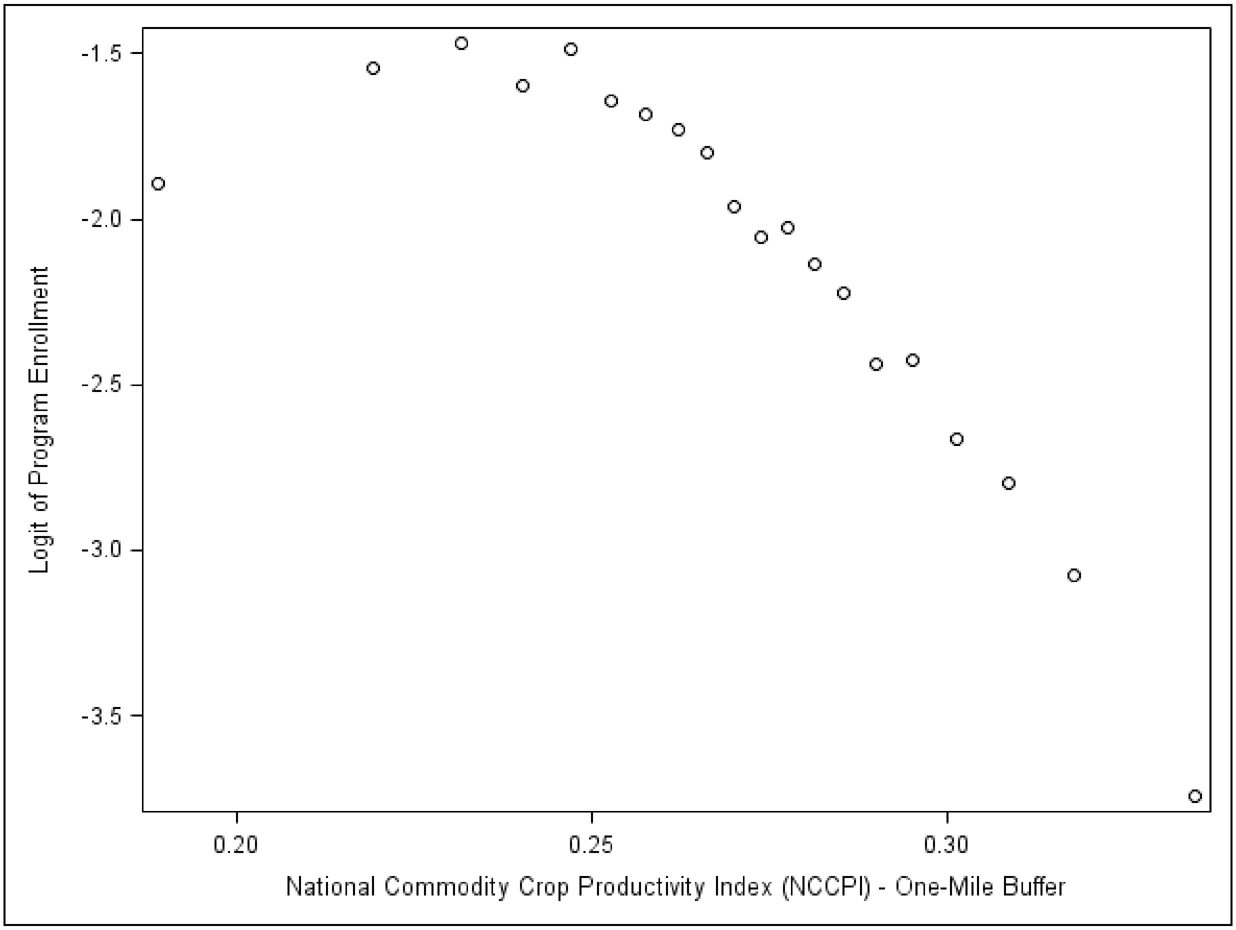


Figure 13 – Logit of Program Enrollment by Mean Soil Productivity (One-Mile Buffer)

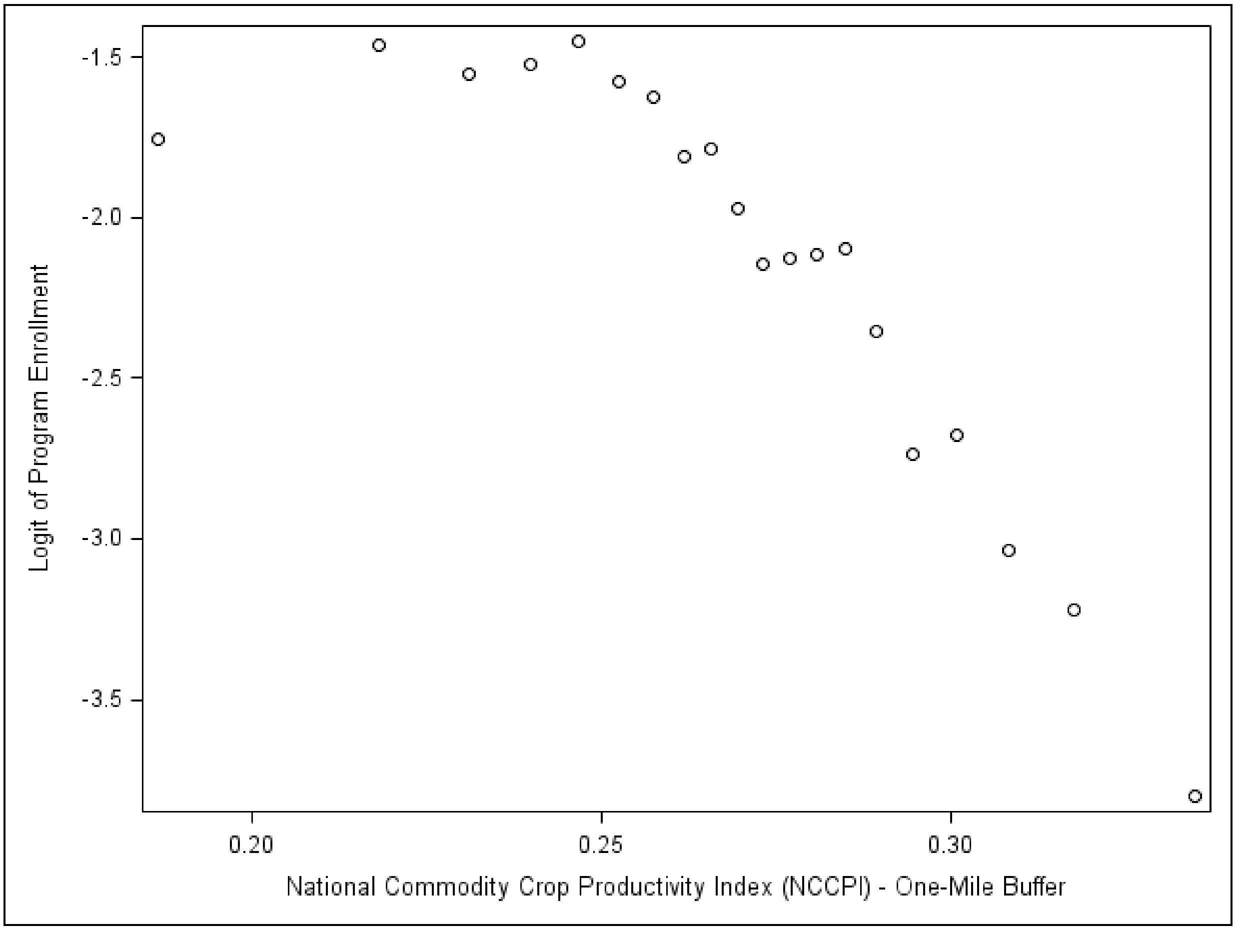


Figure 14 - Logit of Program Enrollment by Mean Slope (Tract)

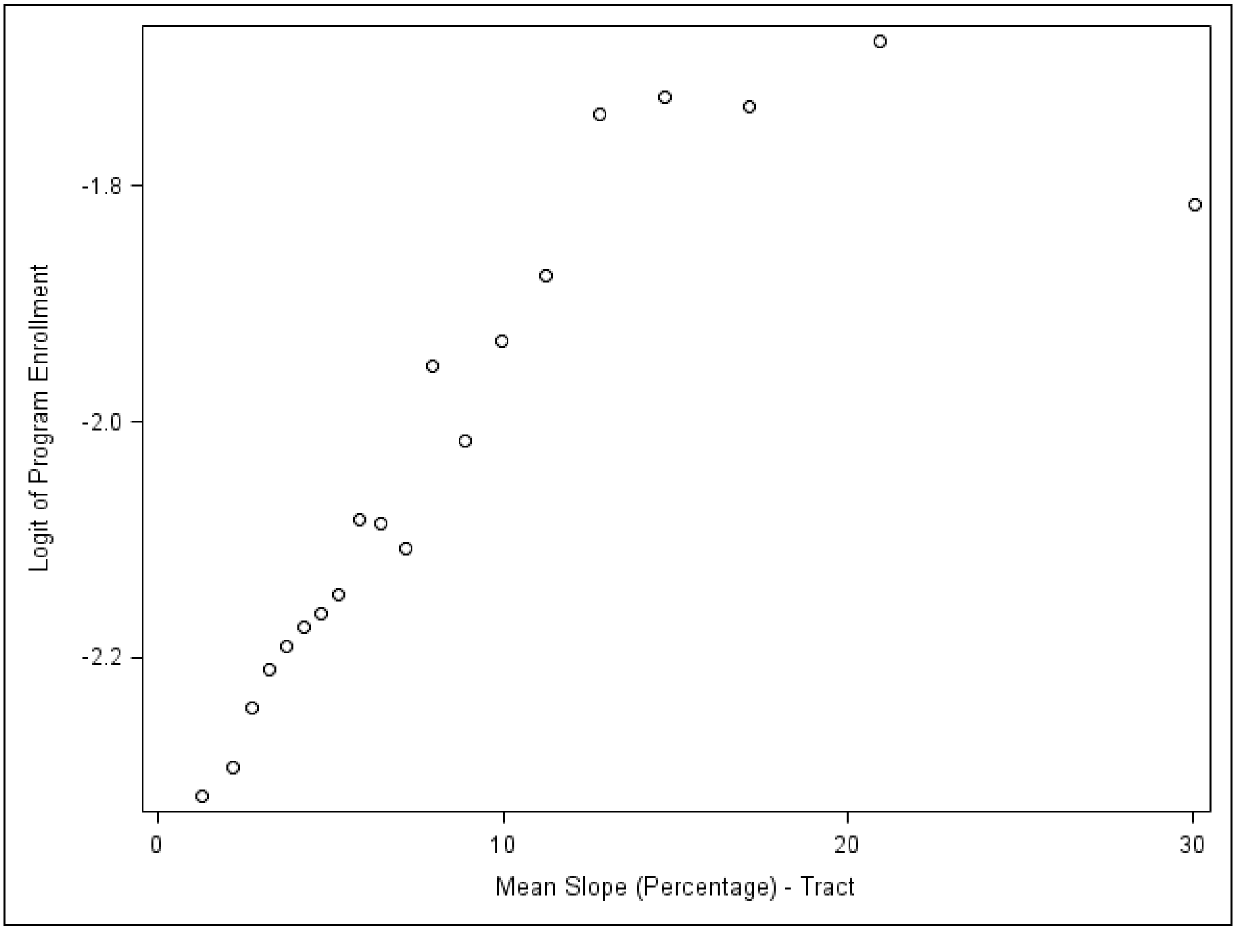


Figure 15 – Logit of Program Enrollment by Mean Slope (Half-Mile Buffer)

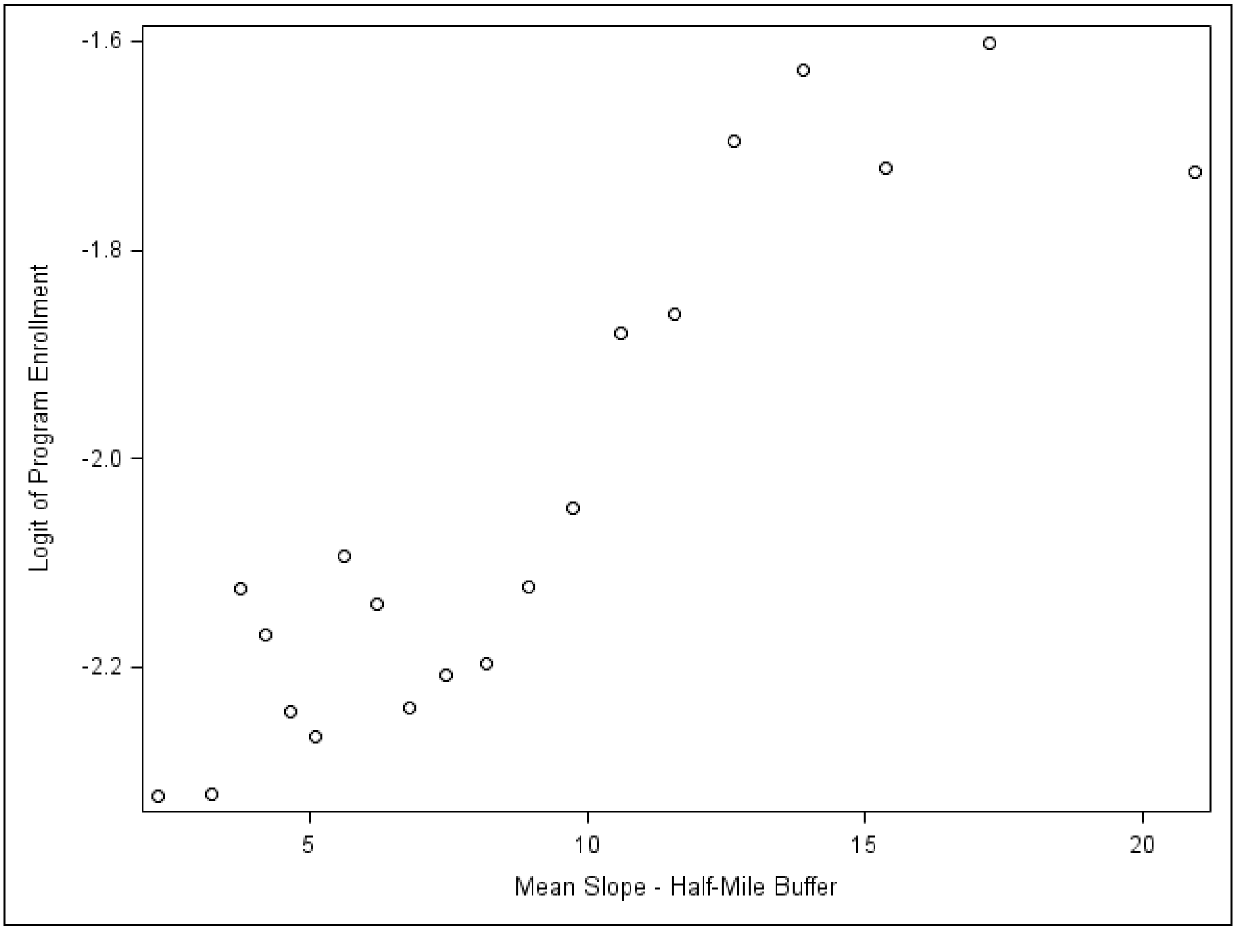


Figure 16 – Logit of Program Enrollment by Mean Slope (One-Mile Buffer)

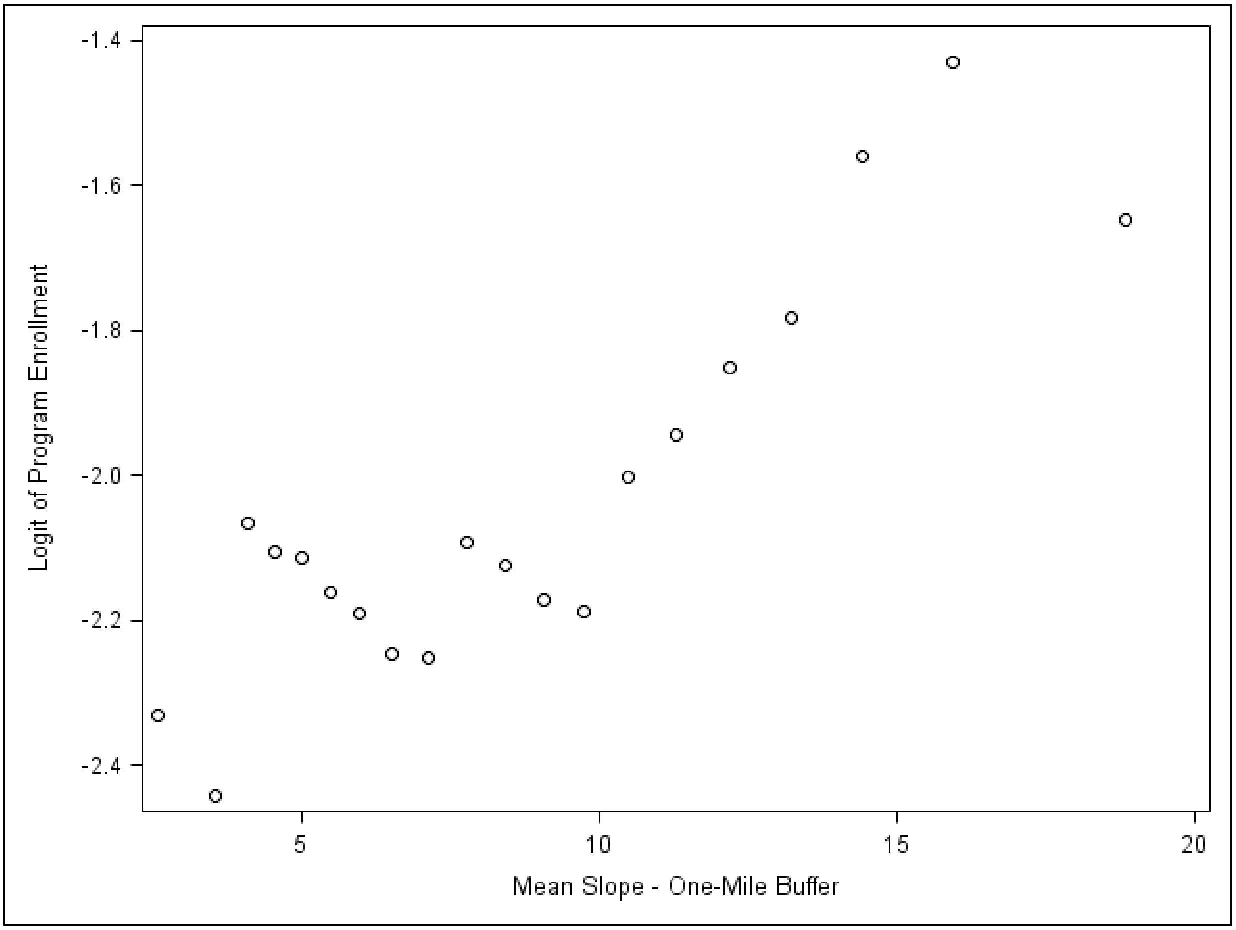


Figure 17 – Logit of Program Enrollment by Distance to Nearest Town

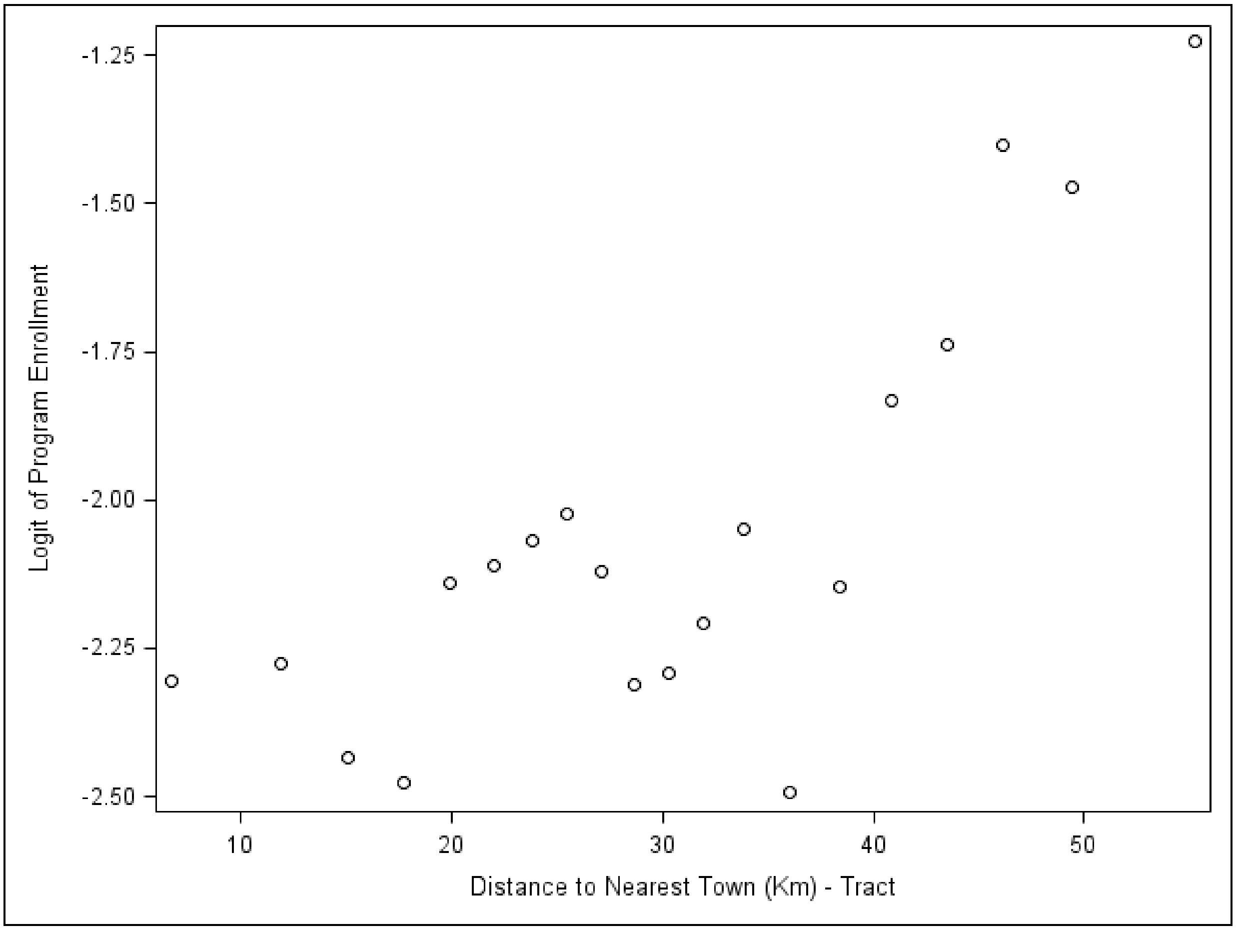


Figure 18 - Logit of Program Enrollment by Distance to Nearest Grain Buyer

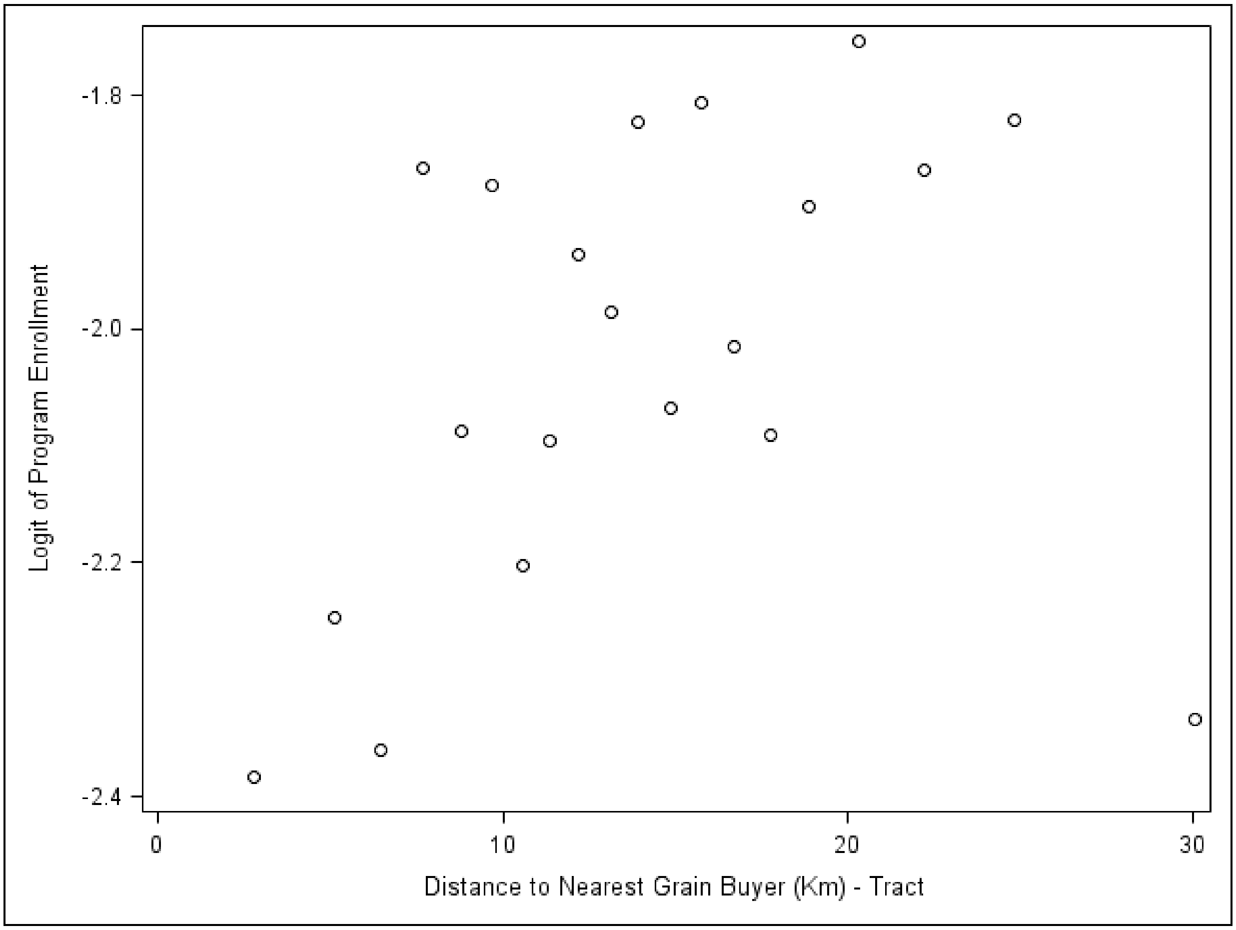


Figure 19 - Logit of Program Enrollment by Accessibility to Nesting Pairs of Grassland Birds (Tract)

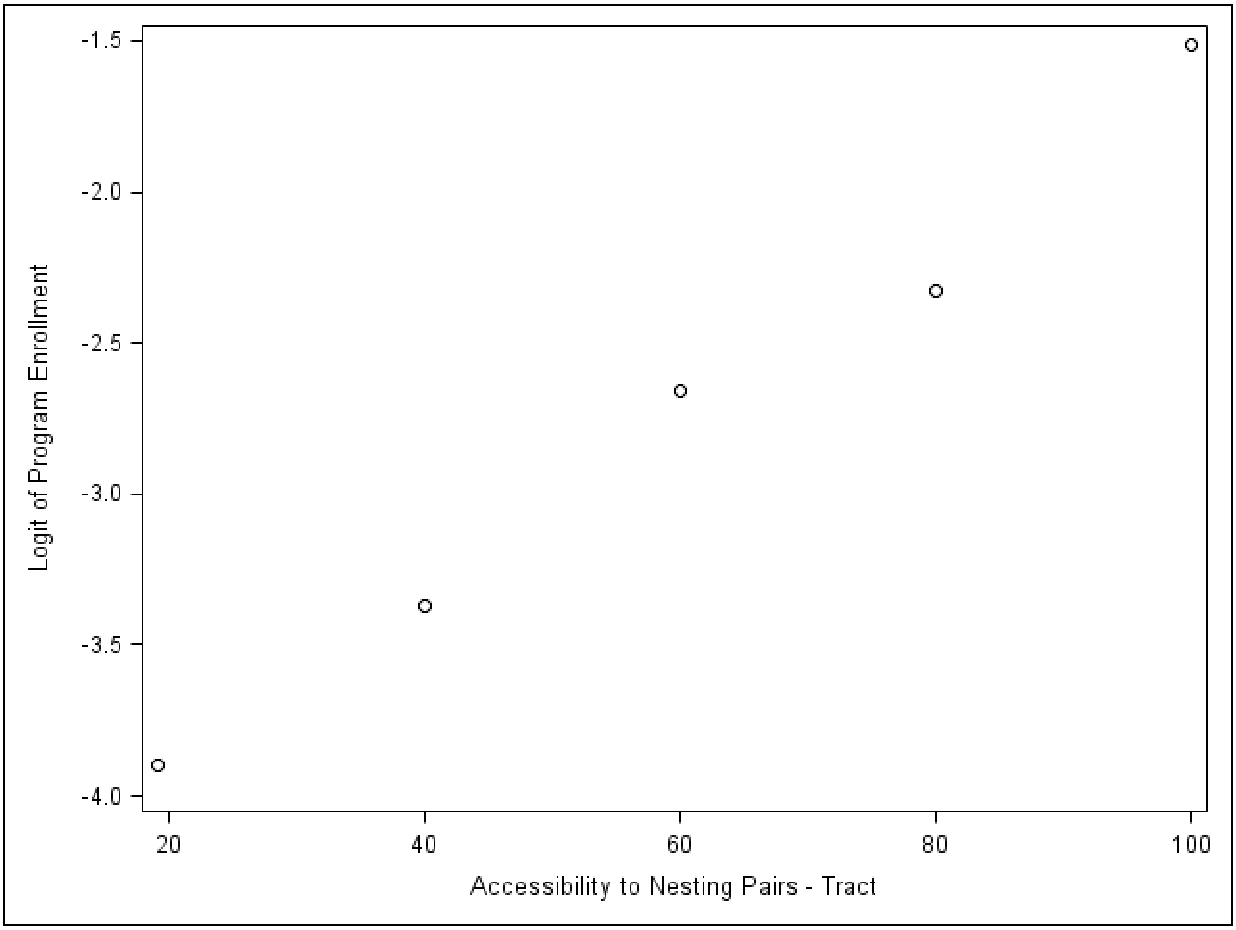


Figure 20 – Logit of Program Enrollment by Mean Accessibility to Nesting Pairs of Grassland Birds (Half-Mile Buffer)

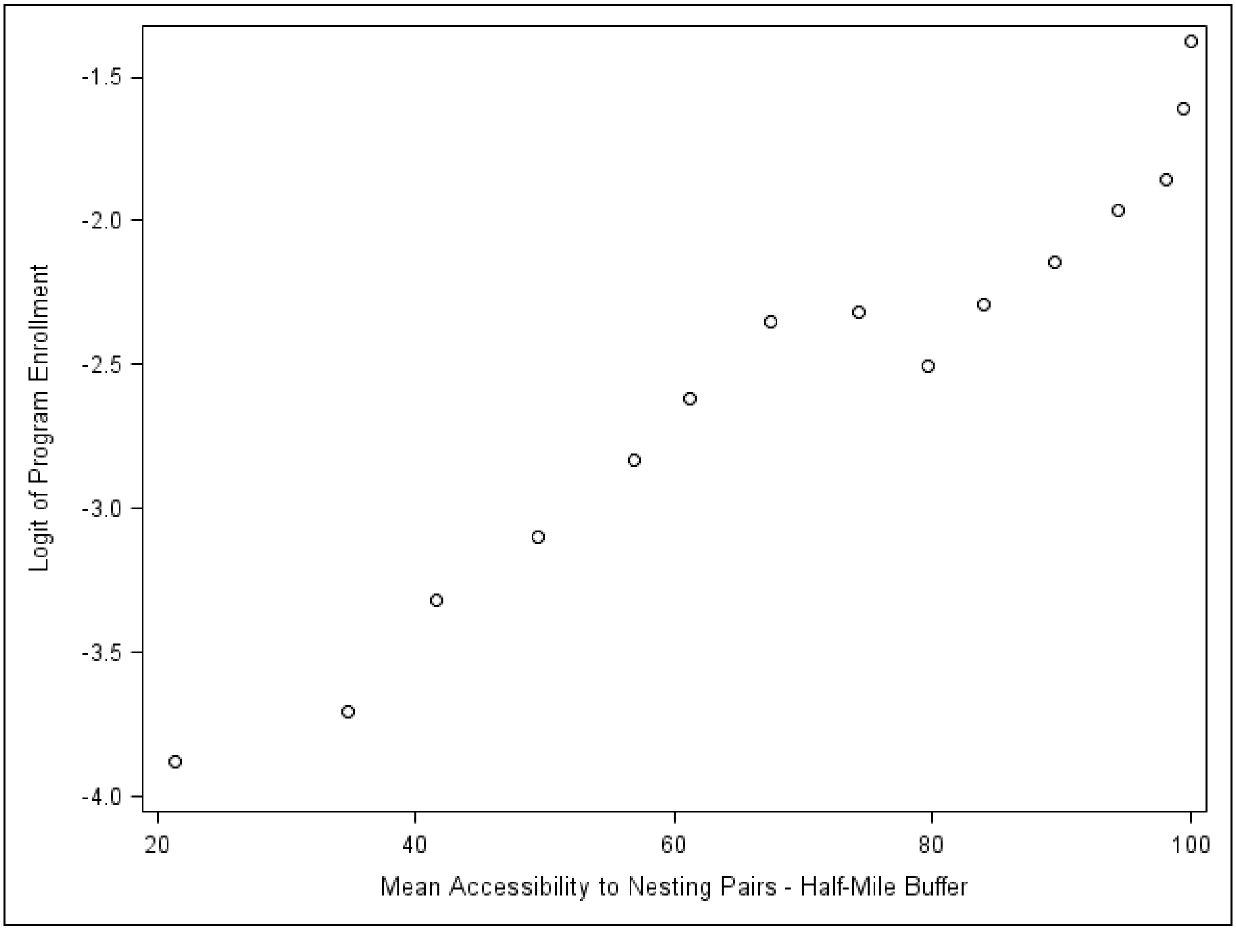


Figure 21 – Logit of Program Enrollment by Mean Accessibility to Nesting Pairs of Grassland Birds (One-Mile Buffer)

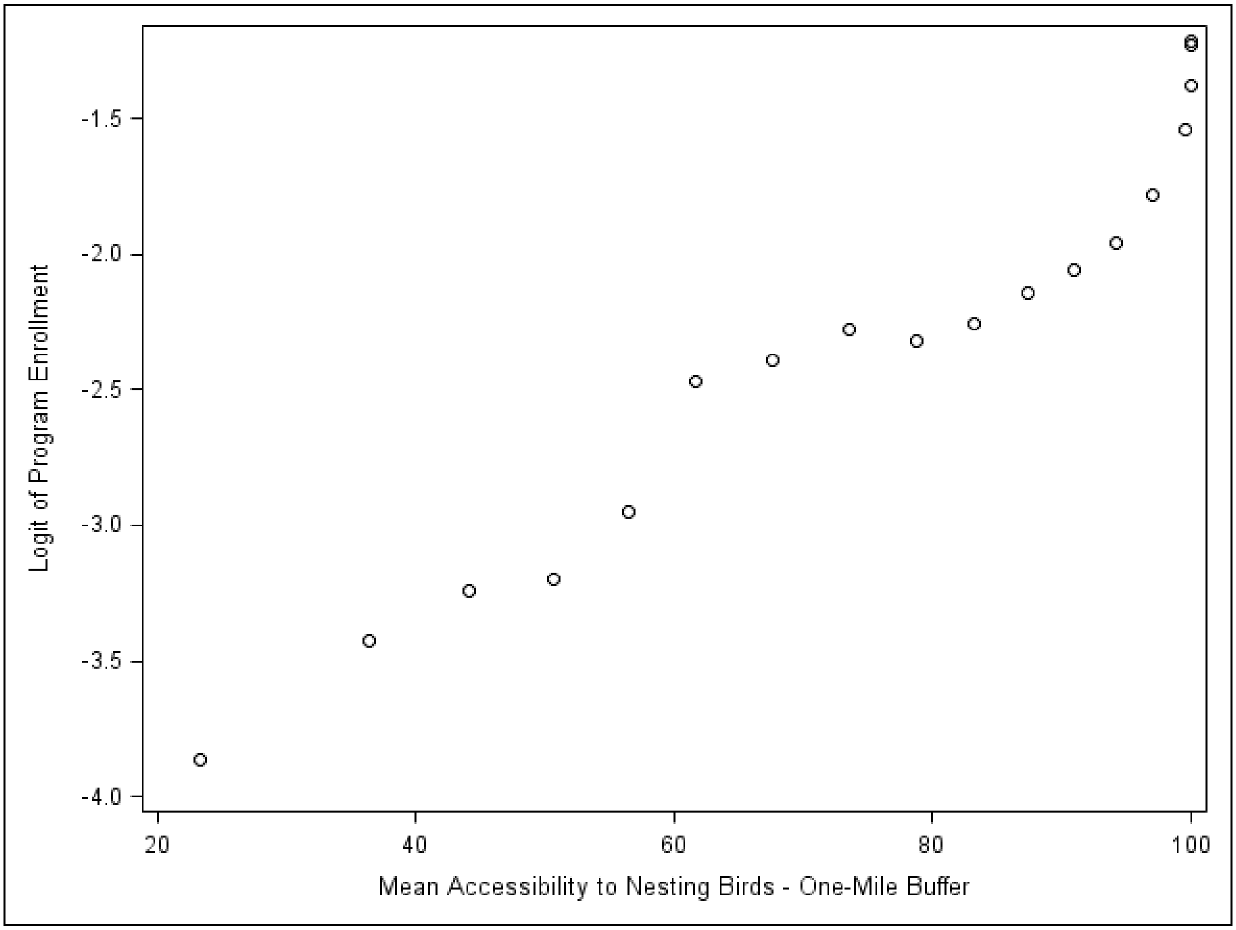


Figure 22 – Logit of Program Enrollment by Sum of Wetland Basin Perimeters (Tract)

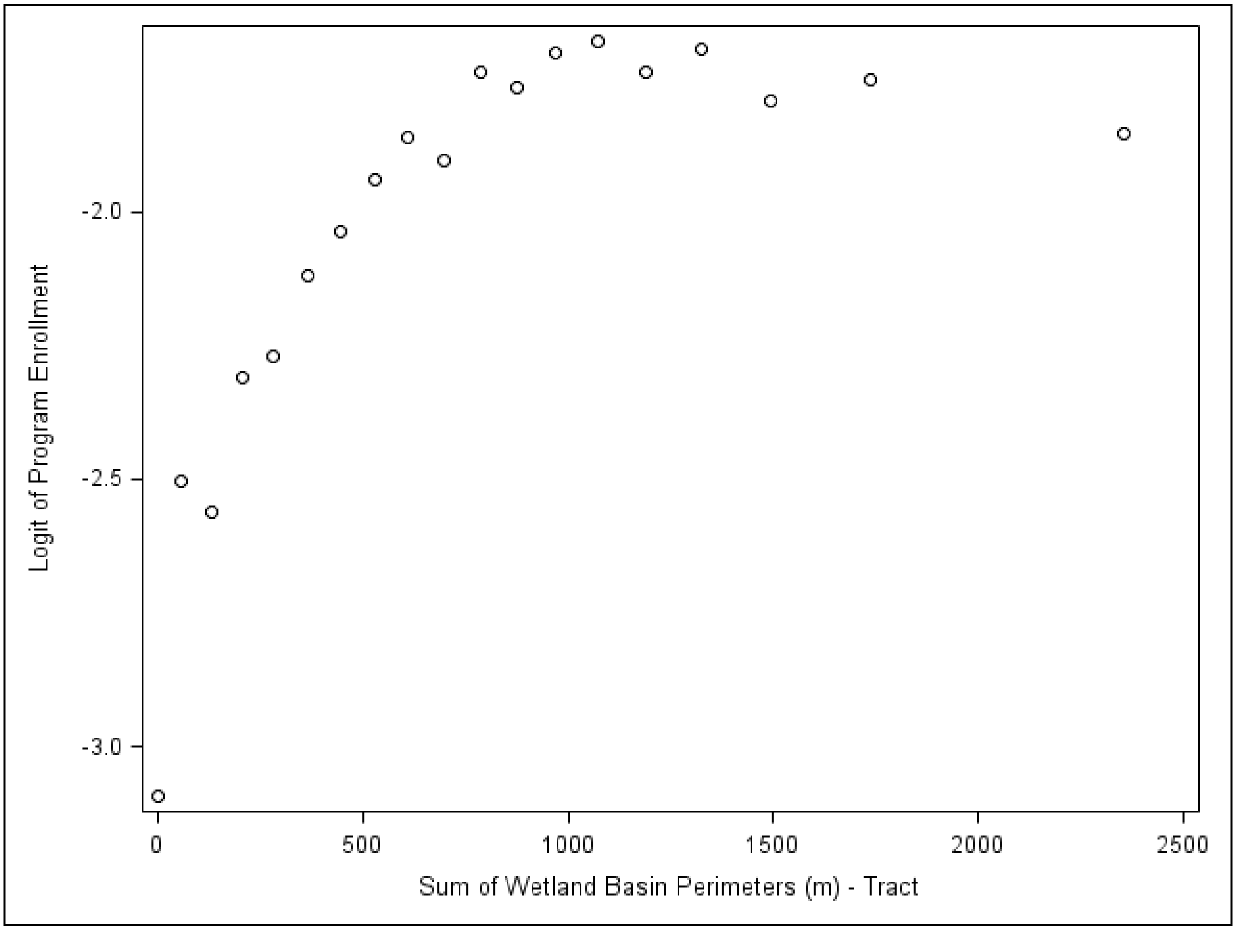


Figure 23 – Logit of Program Enrollment by Sum of Wetland Basin Perimeters (Half-Mile Buffer)

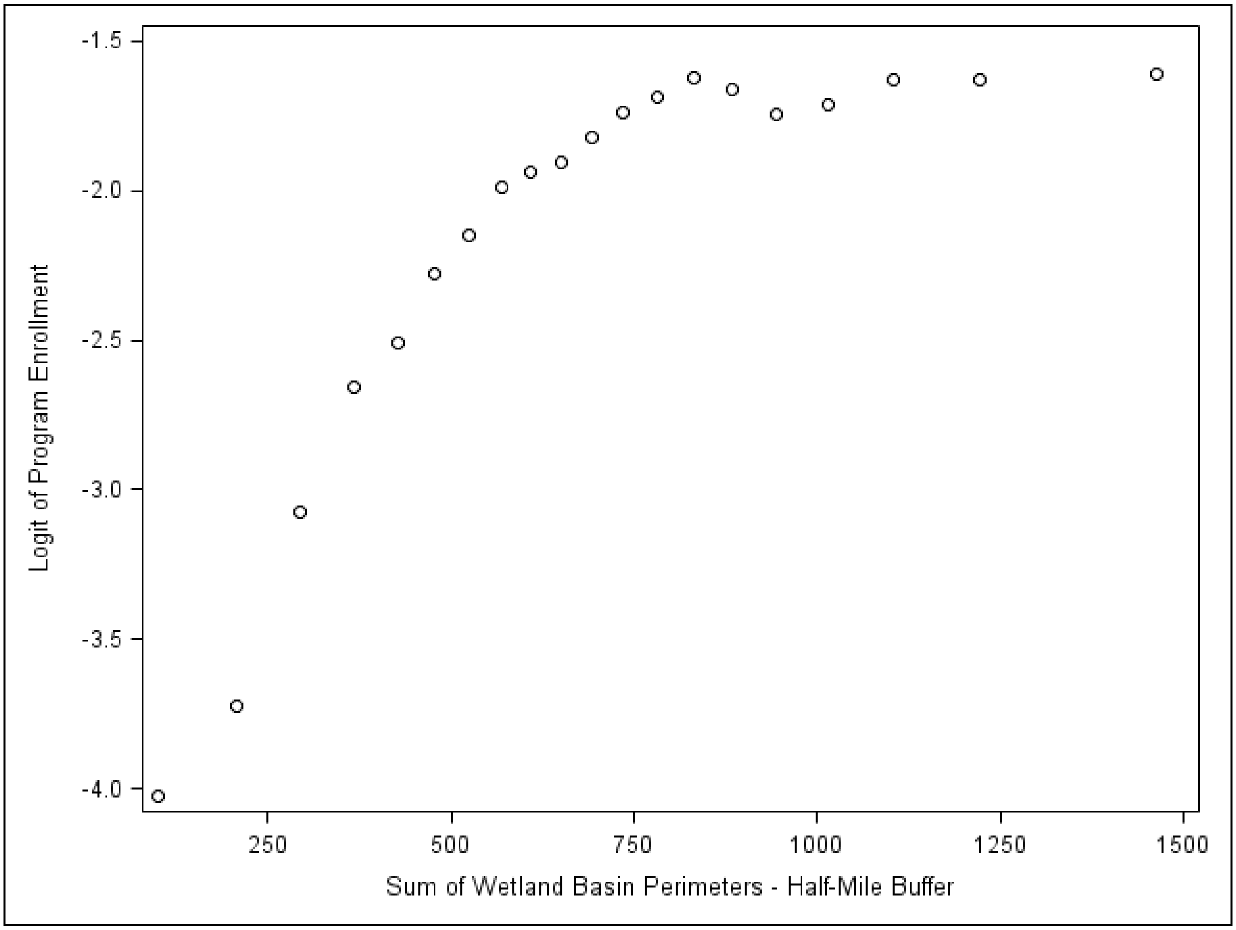


Figure 24 -Logit of Program Enrollment by Sum of Wetland Basin Perimeters (One-Mile Buffer)

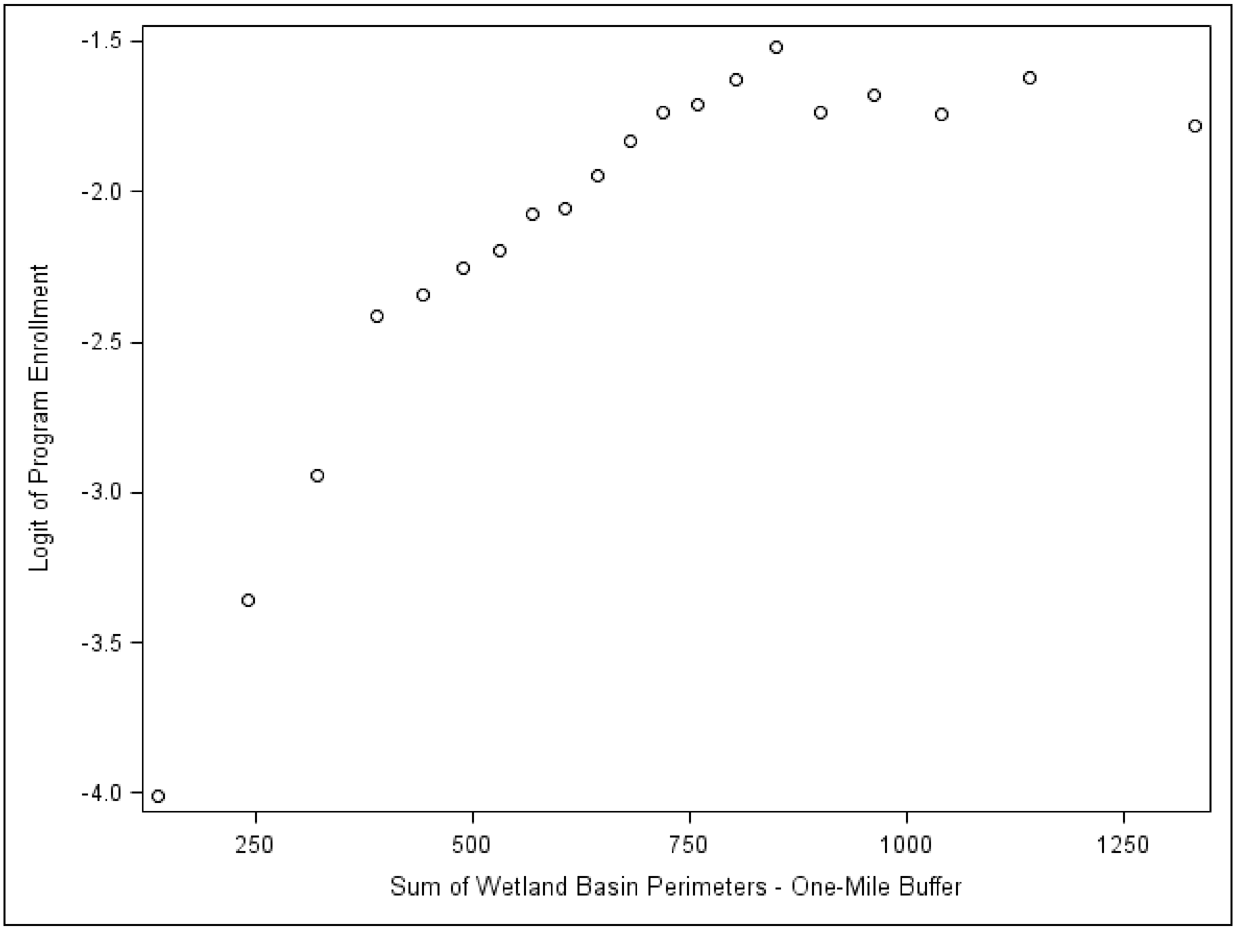


Figure 25 – Logit of Program Enrollment by Grassland Coverage (Tract)

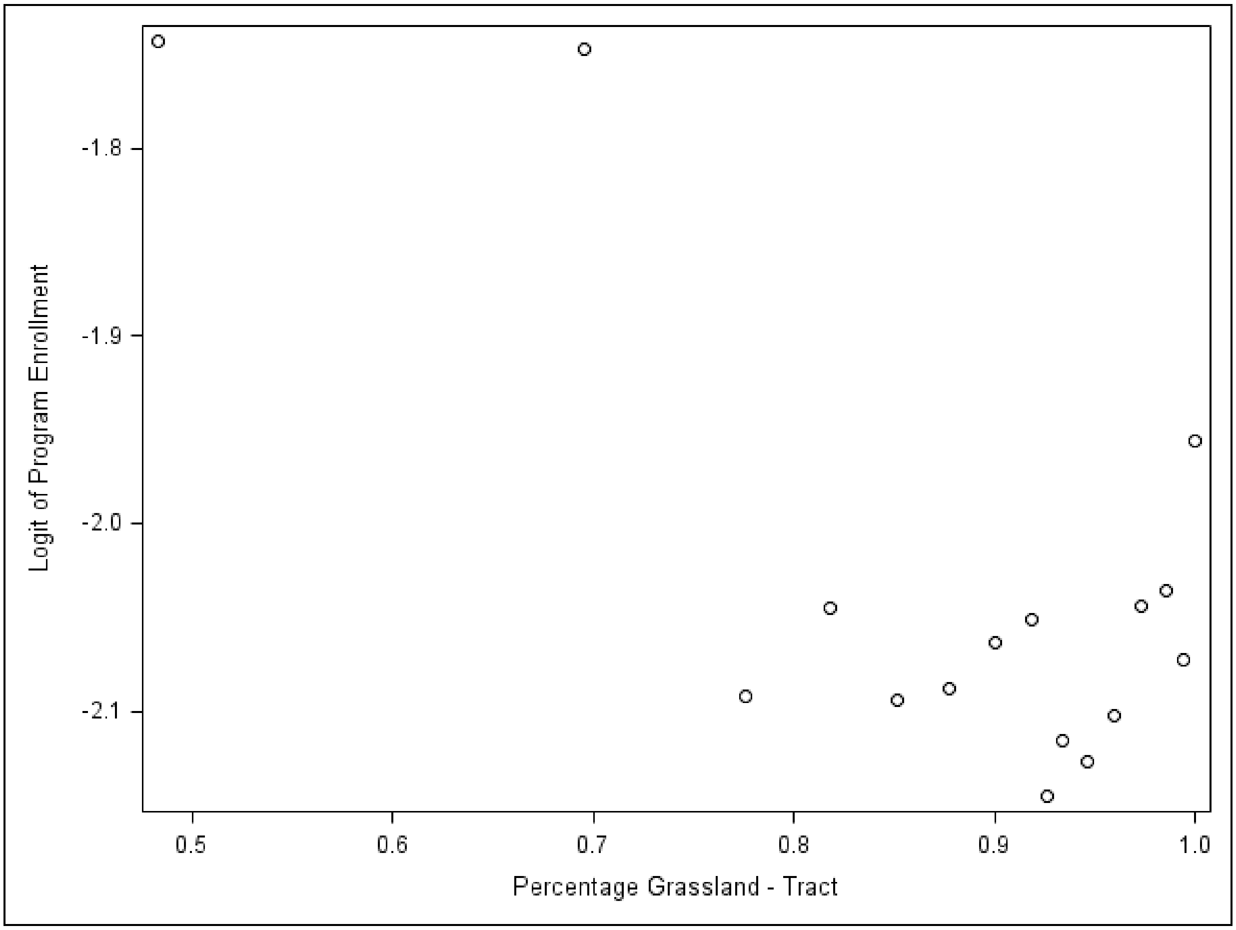


Figure 26 – Logit of Program Enrollment by Grassland Coverage (Half-Mile Buffer)

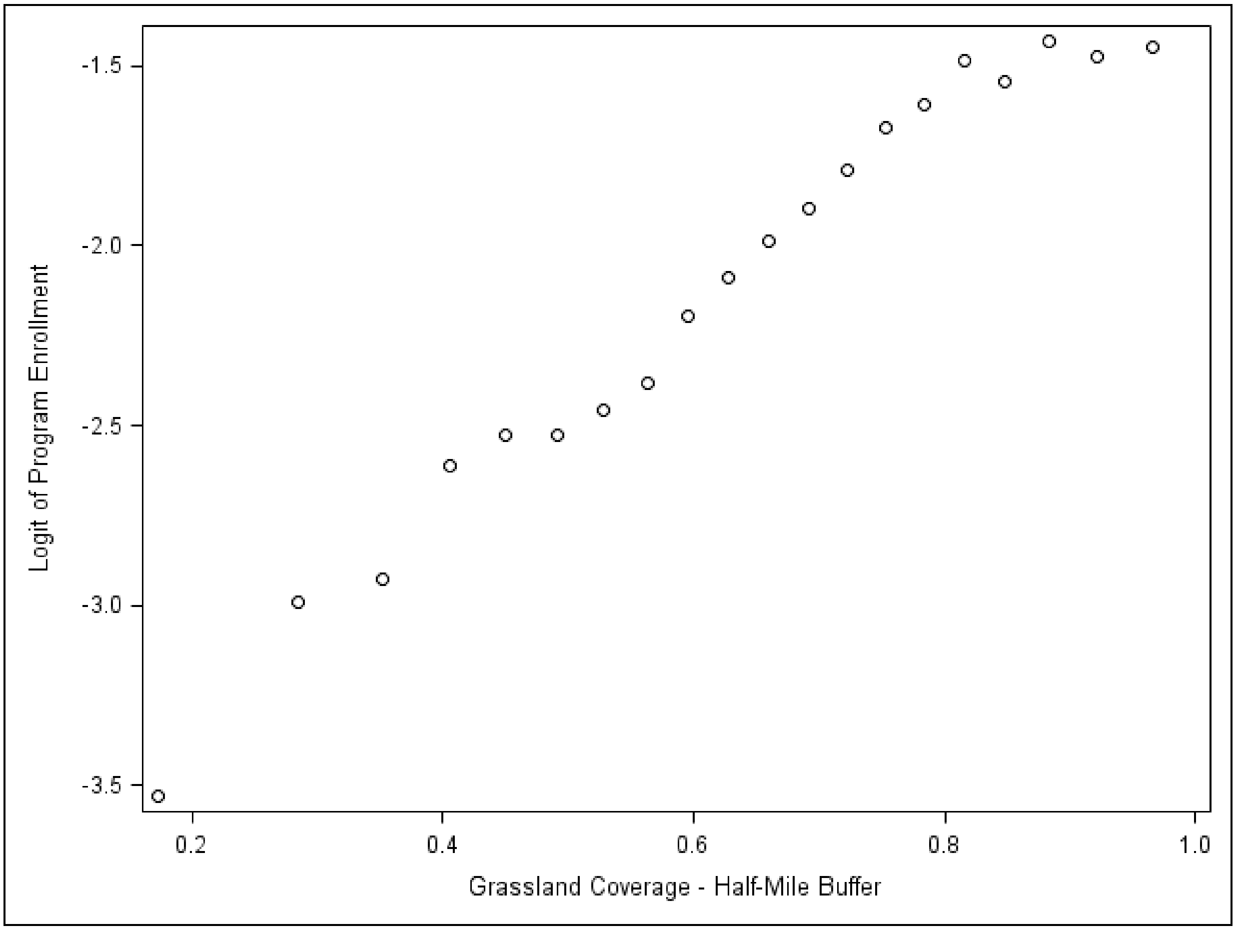


Figure 27 - Logit of Program Enrollment by Grassland Coverage (One-Mile Buffer)

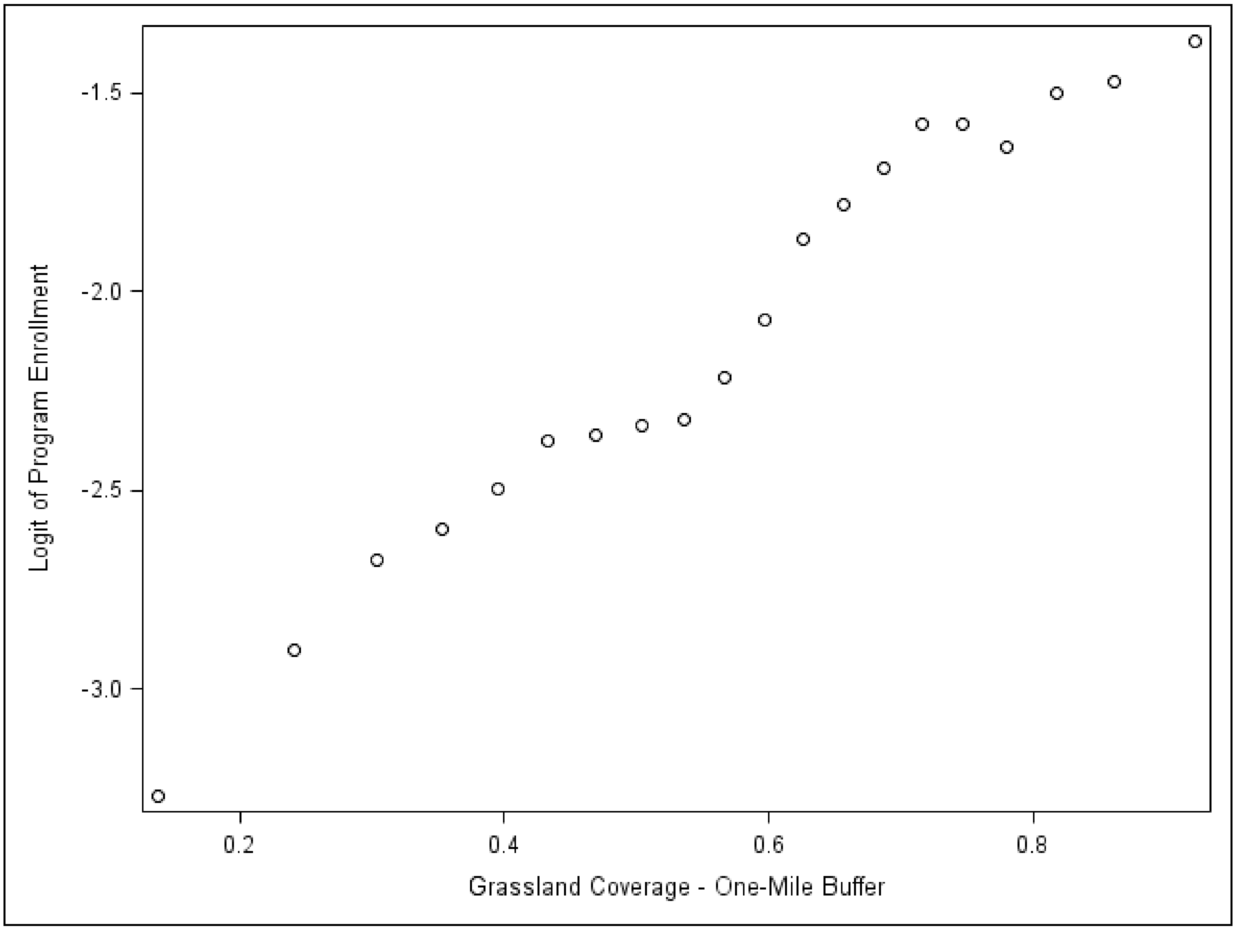


Figure 28 - Logit of Program Enrollment by Net Number of Grassland Easements (Half-Mile Buffer)

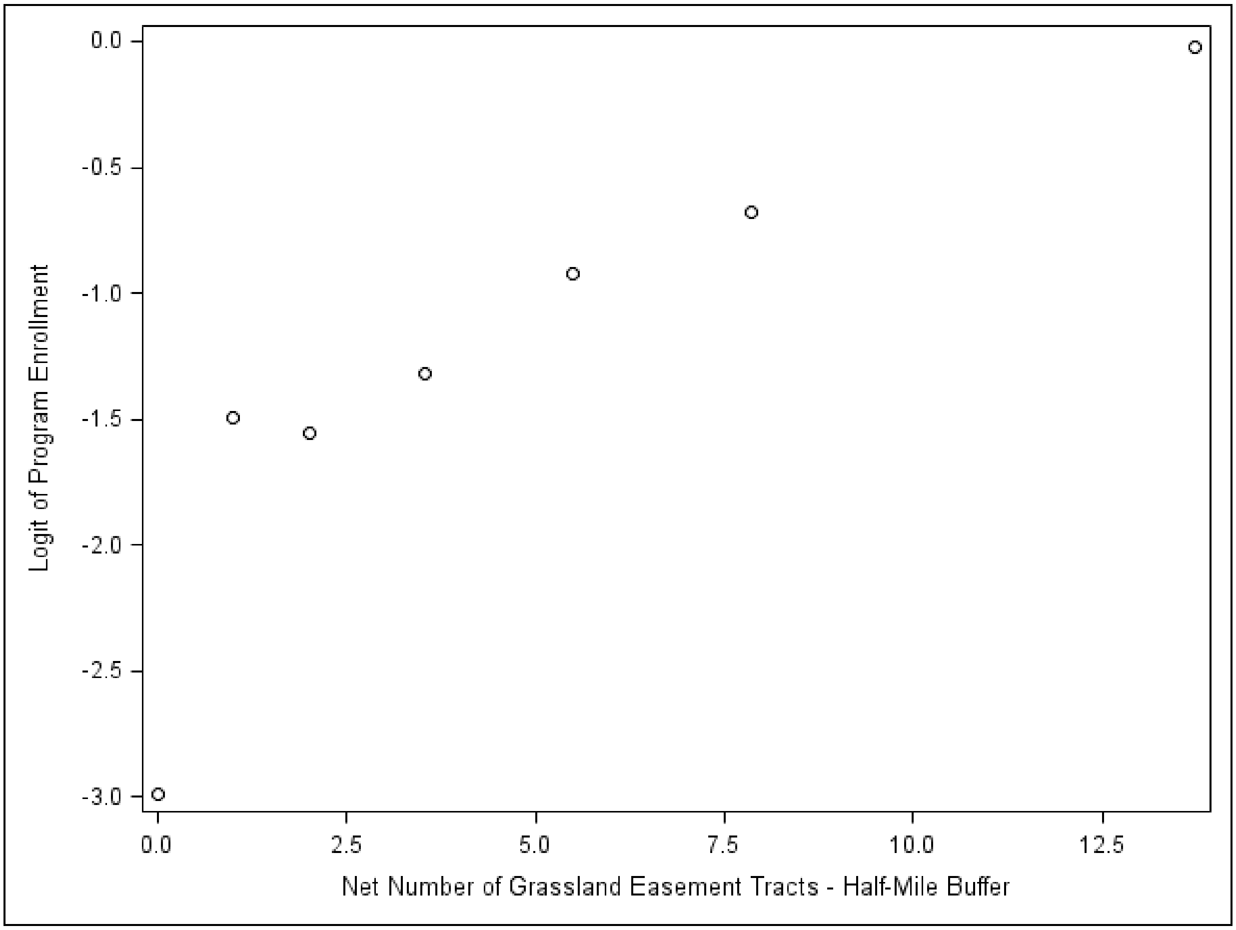


Figure 29 – Logit of Program Enrollment by Net Number of Grassland Easements (One-Mile Buffer)

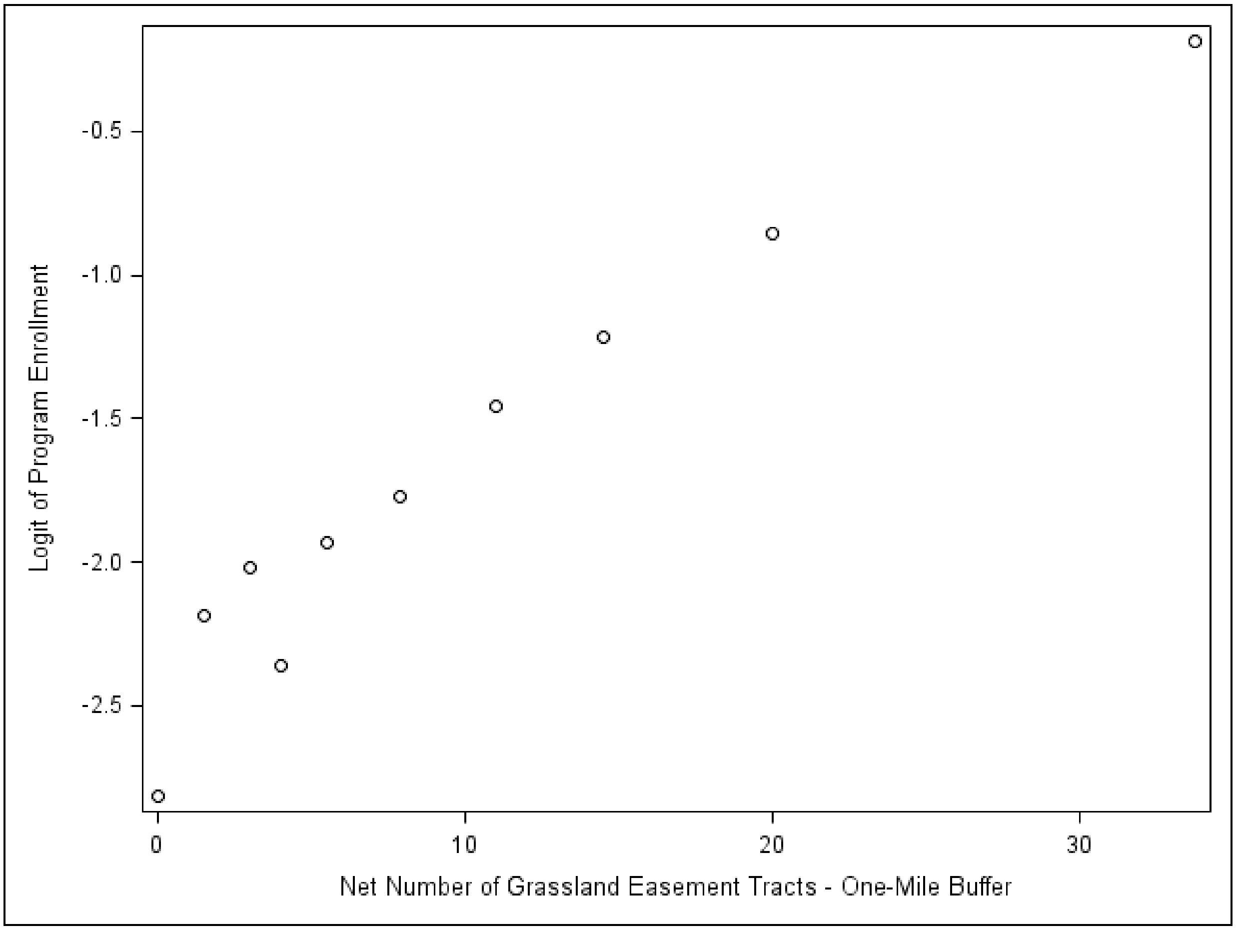


Figure 30 - Histograms of Estimated Propensity Scores for Treated and Control Tracts Before and After Matching

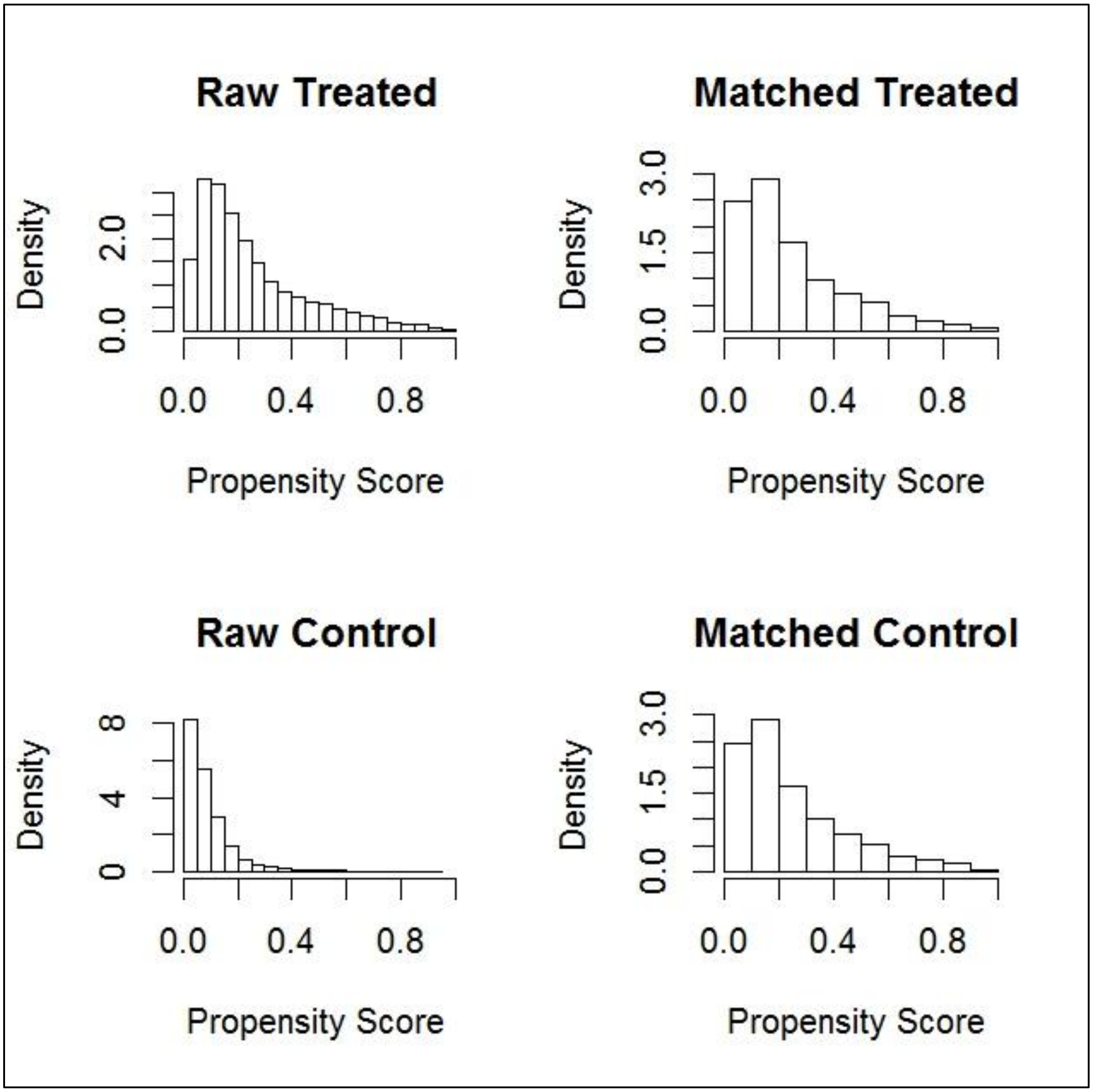


Figure 31 – Distribution of Propensity Scores for Matched and Unmatched Treatment and Control Tracts, Matched Sample 3 (Greedy Matching without Replacement)

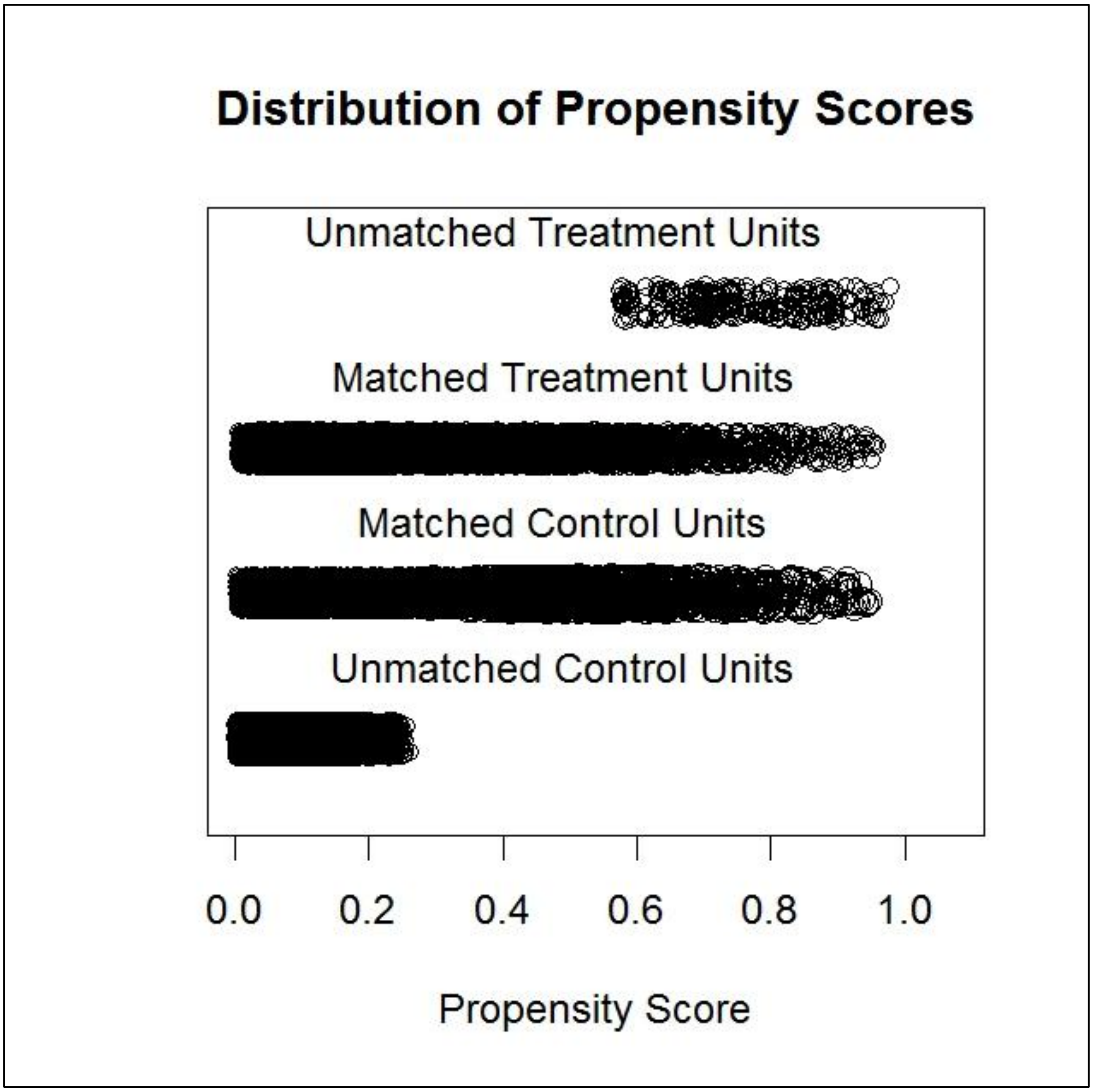
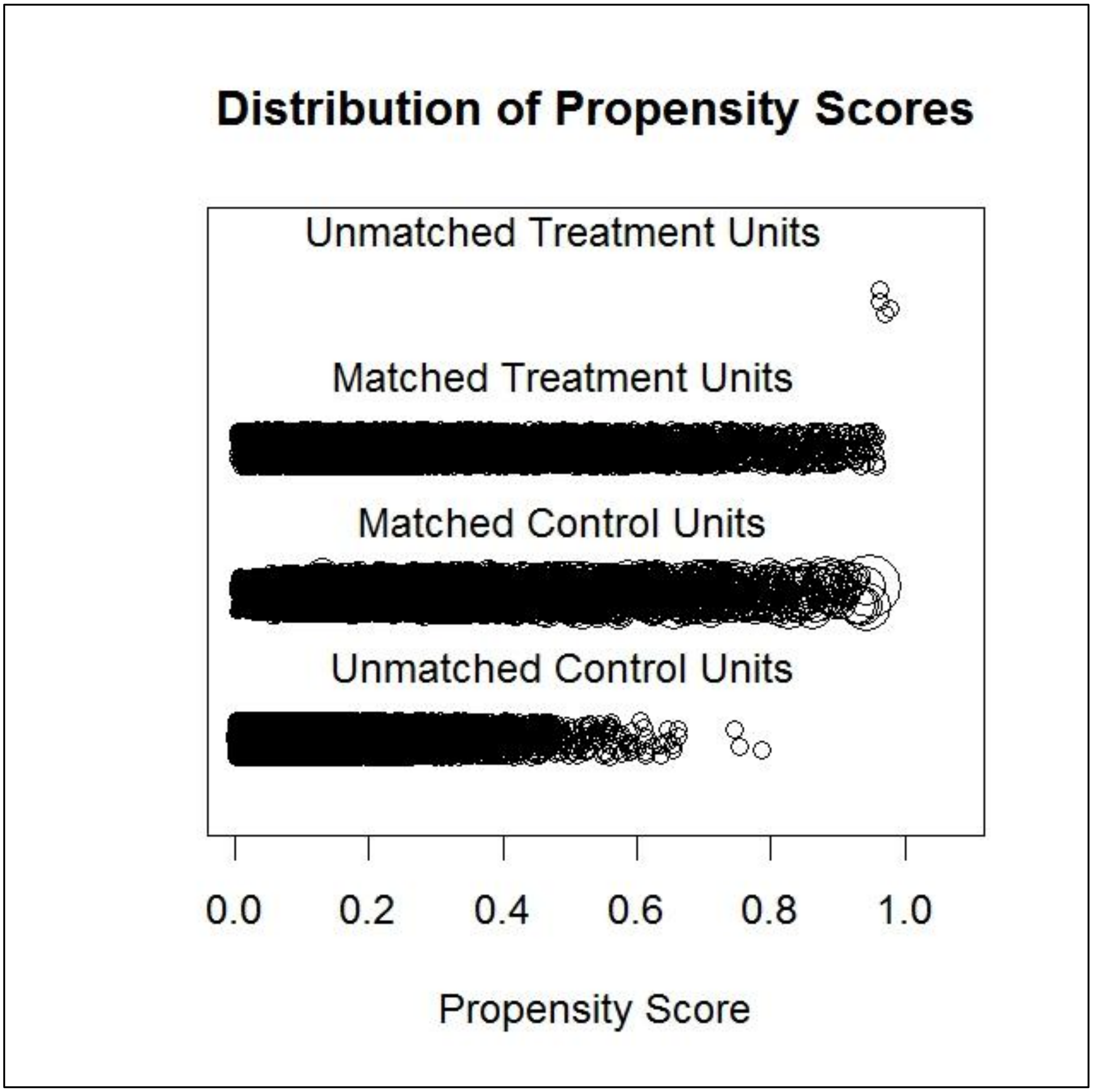


Figure 32 – Distribution of Propensity Scores for Matched and Unmatched Treatment and Control Tracts, Matched Sample 4 (Greedy Matching with Replacement)



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