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Location Affects Protection: Observable Characteristics Drive Park Impacts in Costa Rica *

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Abstract

To support conservation planning, we ask whether a park's impact on deforestation varies with observable characteristics that planners could use to prioritize sites. Using matching methods to avoid common biases in impact estimation, we find that deforestation impact varies with site characteristics. Avoided deforestation is greater on parks located closer to the capital city, on land closer to a national road, and on flatter land. In allocating scarce conservation resources, policy makers have to consider many factors, such as ecosystem services provided by a site and the costs of acquiring a site. Holding such factors fixed, Pfaff et al. 2004 conjecture that impact can be raised by protecting first, in a sequencing of protection, the sites less likely to survive outside parks. We provide empirical support for this argument in the context of Costa Rica's renowned park system. This insight, combined with information on eco-services and land costs, should guide investments.

Keywords: forest, protected areas, parks, reserves, Costa Rica

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1. Introduction

Protected areas, such as national parks and forest reserves and refuges, have long been the most common approach to forest conservation. Every year, about $6.5 billion is spent on more than 100,000 protected areas around the world (http://www.iucn.org/dbtw-wpd/edocs/PAG-013.pdf). Looking ahead, their importance will continue. For instance, the Convention on Biological Diversity's Work Program on Protected Areas, or "2010 targets" (www.cbd.int/protected/targets.shtml), suggests an expansion of protected areas.

Protected areas will continue to be popular despite the increased attention over the last two decades to alternative conservation policies.[1] In fact, recent developments in international climate change policies may actually reinforce expansion of protected areas. Proposals to allow the sale of avoided deforestation credits on global carbon markets will require nations to choose not only whether to lower deforestation, relative to an agreed baseline, but also exactly how to lower it. Given that for regulating land cover change nations are already familiar with the use of protected areas, the potential to receive such carbon payments is likely to increase the incentives to new establish protected areas.

Generating avoided deforestation credits will require that protected areas actually lower deforestation, in the view of the global carbon markets, as inferred through the establishment of well-defined baselines and accurate monitoring of forest over time (e.g. via remote sensing). Payments will be made only when parks in fact have such impacts.

Much of the protected area literature implicitly assumes that protected areas slow deforestation. For example, the literature on optimal reserve location focuses on species' locations.[2] This literature implicitly assumes that if the high priority locations are offered legal protection, conservation impacts will be realized. Little attention has been given to whether the legal protection indeed leads to the conservation impacts that are assumed.

In Costa Rica, the initially forested protected areas remain essentially uncleared,[3] which suggests that protection is indeed effective at reducing deforestation. However, to what should one compare this outcome? Much of the forest outside of protected areas also remains uncleared. To infer park impact, we would like to precisely estimate what would have happened to the forest in the protected areas had the areas not been protected.

Existing impact analyses have, for the most part, used average deforestation patterns in unprotected forested areas to estimate the deforestation that protected areas would have experienced had they not been protected.[4] This approach can fail, and grossly so, if the protected areas are not randomly distributed (as some research has suggested[5]).

[1] See, e.g., Chomitz et al. 1998, Ferraro 2001, Pagiola 2002, Miranda et al. 2003, Sierra and Russman 2006.
[2] Some examples of reserve siting analyses of increasing complexity include Tubbs and Blackwood 1971, Gehlbach 1975, Williams 1980, Kirkpatrick 1983, Saetersdal et al. 1993, Cocks and Baird 1989, Church et al. 1996, Csuti et al. 1997, Camm et al. 2000, Polasky et al. 2000, and Polasky et al. 2001 to name a few.
[3] Sanchez-Azofeifa et al. 2003. Some encroachment is starting to occur at the edges of some national parks.
[4] For example, see Oliveira et al. 2007, Bruner et al 2001 and Stern et al. 2001.
[5] Analyses of distributions of protected areas and remaining gaps are in Oldfield et al. 2004; Fearnside and Ferraz 1995; Powell et al. 2000; Hunter and Yonzon 1993; Ramesh, et al. 2003, and Andam et al. 2008.

There are a number of reasons for such non-random location. If maximizing the impact on deforestation, an agency might prioritize locations that, all else equal, feature stronger than average deforestation pressure (Pfaff et al. 2004). In contrast, if one wanted a new protected area to remain forested for as long as possible, one might prioritize lower pressure. Likewise, if seeking to protect species, one might prioritize relatively pristine locations, which may be those facing lower pressure. Thus, conservation planners may locate protected areas based on observable characteristics thought to affect deforestation.

Andam et al. 2008 have shown that a non-random distribution of protected areas matters when measuring impact. Their location-corrected (i.e. matching) estimates of protection's impact on 1963-1997 deforestation are less than a third as large as the estimates from typical methods of estimating impact. More generally, correcting for the impacts of observable characteristics that affect both policy location and forest outcomes is important in evaluating any conservation policy. Recent analyses of Costa Rica's well known payments for eco-services program find that contracts between 1997 and 1999 were located on relatively low pressure land and thus impact estimates that do not correct for non-random payment location overestimate the program's impact on deforestation.[6]

Here, to support conservation planning, we add to such spatial average impacts new analysis of how protected areas' impacts would vary across potential reserve sites.[7] Thus, unlike Andam et al. 2008, we focus on how the slowing of deforestation will vary due to observable characteristics of locations that are candidates for new protected areas.[8]

Information on how protection's impacts differ is critical for conservation policy. We find, for instance, that while protected areas within 85 km of San Jose prevented on average about 3% of their forest area from being cleared during 1986-1997, those further away on average prevented only 1% (lower versus higher elevation compare similarly). Protection within 7.5 km of national roads prevented about 5% of the forest from being cleared, while protection placed on land with slope less than 7.12 degrees prevented 14% of the forest from being cleared during this period. These differences make clear that, along with information on species and land costs, impacts can guide future investments.

The paper proceeds as follows. In Section 2, we give background on Costa Rican deforestation processes and protected areas. We also concisely sketch a model of the deforestation impacts of protection in order to illustrate challenges for impact estimation. In Section 3, we describe the data, as well as the matching methods that we are applying. In Section 4 we present the results, then in Section 5 we discuss the policy implications.

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[6] Sanchez et al. 2007, Pfaff et al. 2007, Robalino et al. 2007

[7] We focus on more recent clearing during 1986-1997. Underlying deforestation process is slower on average than during the 1963-1997 period but the importance of addressing the non-random location of protected areas is the same. Our matching estimates are less than a third of typical estimates, suggesting that about 2% (versus over 9%) of the protected forest would have been deforested without protection.

[8] Methodologically, breaking protected areas into subsets highlights the fact that some protected areas have much poorer matches among the unprotected locations, as seen in Figures 3 and 4 and as discussed below.

2. Costa Rican Protection & Its Impacts

2.1 Deforestation & Protection Over Time

2.1.1 Land-Use History

From the arrival of the Spanish until the middle of the 20^{th} century, thousands of hectares of forest were cleared for agriculture and cattle (Sader & Joyce 1988, Sanchez-Azofeifa et al. 2001). Policies prioritized demographic and agricultural growth (see, e.g., Harrison 1991, Solorzano et al. 1991, Rosero-Bixby & Palloni 1998, Sanchez-Azofeifa et al. 1999). Clearing depended upon biophysical features such as where coffee can grow or the coastal shape that facilitates a port, and thus a port city, which affects land demand.

Until the clearing boom in the mid-20^{th} century, most of the clearing occurred in the central plateau and near one major western port. The boom involved trade growth that increased the influence of international commodity prices, yielding expansion of cattle in the north, coffee in the center, banana in the Atlantic region, and sugar-cane plantations. The distribution of the forest impact of this expansion depended in part on the variation in precipitation and temperature that greatly influenced which crops could grow where.

Over the last two decades, deforestation has slowed. This is due in part to falling commodity prices. Falling beef prices encouraged abandonment of cleared land in the Guanacaste Peninsula (Sanchez-Azofeifa 2000) where cattle are the dominant product. The slowing is also due in part to a rise in the returns to forest. The rise in ecotourism since the early 1990s played a major role. Starting in 1997, public payments to owners of forested land were made in return for multiple environmental services provided by forest. ‘Sustainable forestry’ and ‘shade coffee’ have also contributed to the increase in returns from forested land. This is in part due to price premia from timber and coffee labeling.

2.1.2 Protected Areas Network

Starting in the 1960s, Costa Rica created a system of protected areas (Table 1). Between 1974 and 1978, e.g., the fraction of the country in protected areas expanded from 3% to 12%. Currently it is approximately 25% (Sanchez-Azofeifa et al. 2002).

Since 1979, three Forestry Laws (1979, 1986 and 1996) were passed and agency structures have also changed. Prior to 1995, three agencies (Forestry, National Parks, and Wildlife) were responsible for conservation. SINAC (National System of Conservation Areas) was created in 1995, consolidating agencies and the park system. SINAC placed all existing areas into 11 Conservation Areas which form the protected area structure.[9]

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[9] In national parks and biological reserves, no land-cover change should occur. In forest reserves and wildlife refuges, some land-cover change is permitted. Government still owes private land owners for some of the currently protected areas that formerly were private lands (Segnini 2000) -- a 1994 Supreme Court ruling upheld the need for compensation (Busch et al. 2000). Yet the national parks and biological reserves are not in fact cleared (Sanchez et al. 2003) and our analyses assume they will remain so while protected.

New protected areas have been proposed, including areas in the Mesoamerican Biological Corridor (Powell et al. 2000). It has been suggested that the set of protected areas should cover the range of ecological conditions present in Costa Rica and how to do that in a minimal area of new protection has been actively considered (Garcia 1997).

2.2 Modeling Protected Areas' Impacts

Figure 1 presents a simple but useful framework for analyzing protected areas' impacts on deforestation. Rents are determined by opportunity costs of keeping land in forest and forest land is ordered according to the rent it provides, from highest to lowest. Where rents are greater than zero, the land will be deforested in the absence of protection. Where rents are negative, that land will not be deforested even without any protection at all. In the absence of protection, deforestation will take place only above x^N in the figure.

Of all parcels protected, land use changes only for those in that interval above x^N. Thus, a protected area's impact depends on the fraction of its land that is in that interval. If that fraction equals 1, then protection affects land use for every parcel that is protected (here we leave aside countervailing effects on other land as predicted in Robalino 2007).

We estimate that fraction using unprotected locations that are similar to parcels in protected areas. If a large percentage of the locations that are similar to protected parcels were deforested, then protection will be estimated to have had a large impact on forest.

Note from Figure 1 that if all the land in the interval above x^N is protected, then it would not be possible to find very similar unprotected locations, i.e. parcels the same as those protected except in terms of protection. The same is true if all of the land below the clearing cutoff is protected. In our matching methods below that are focused on which are similar locations (also see Figure 4), we show when the most similar land is not similar.

3. Data & Matching Methods

3.1 Data

3.1.1 Forest

We obtained geographic data on forest in 1986 and 1997 from the University of Alberta (Sanchez-Azofeifa et al. 2003). The data were derived from Landsat satellite images (see FONAFIFO 1998) and distinguish forest, non-forest, and mangroves, while also indicating secondary forest at 1:250,000 scale. These maps, in polygon format, allow us to estimate the annual deforestation rate at a national level, as well as to see exactly which of the parcels were deforested between 1986 and 1997. FONAFIFO, using the same maps, found the annual deforestation between 1986 and 1997 to be about 1% .

3.1.2 Protected Areas

We obtained spatial data on all of the protected areas during this period from the Instituto Teconológico de Costa Rica. There are eleven types of protection distinguished in the data and the categories are believed to correspond to actual intensity of protection. Our analyses focus upon the national parks and biological reserves. These are the most protected categories, with rules against any form of land-use change. Sanchez-Azofeifa et al. 2003 show that in fact the deforestation within those areas has been essentially zero.

3.1.3 Other Factors in Land Use

Additional maps from the Ministry of Transport and Instituto Tecnologico show the locations of rivers, cities, national parks, schools, sawmills, national and local roads and slopes. These factors can be used as controls in our tests of the impact of protection. For spatially varying unobserved factors, we also use the ministry of agriculture's administrative divisions (Central, Heredia, Huetar Norte, Huetar Atlanctica, Brunca, Pacifico Central and Chorotega) to generate regional dummies to use as more controls.

We also use a vegetation description based upon the Holdridge Life Zone criteria, which consider precipitation and temperature as proxies for ecosystems' characteristics. Costa Rica has 12 such Life Zones: humid pre-montane, humid lower-montane, tropical humid, very humid pre-montane, very humid lower montane, very humid montane, tropical dry, pluvial pre-montane, pluvial lower-montane, pluvial montane and paramo.

3.1.4 Units of Analysis

Ten thousand locations were randomly drawn across the 51,000 squared kilometers of Costa Rican land. We eliminate some of these locations from the analysis because clouds covered the land when satellite pictures were taken or because, according to the data experts, the information extracted from the satellite picture was inconclusive.

3.2 Matching Approach

To estimate protected areas' deforestation impacts, we need to determine what would have been the deforestation rate without protection. We then compare the actual deforestation rate in protected areas with the estimated counterfactual deforestation rate.

If protection was implemented randomly across all forest, we would need only the average deforestation rate outside of protected areas for a good indicator of protection's impact on clearing. In expectation, all other factors cancel out and thus the difference in the deforestation inside versus outside of protected areas would be due to the protection. However, protection is not randomly distributed. As noted, many rationales could explain why planners base choices on the observable site characteristics that affect deforestation.

We use matching techniques to avoid bias from the non-random allocation of the forest protection. The principle is to compare protected areas, which differ from average locations, with similar unprotected areas in order to better isolate the effect of protection. Thus the control group compared to protected areas is a subset of unprotected locations.

We use the probability of the parcels being enrolled in protected areas to define 'similarity'. Thus, protected-area deforestation is compared to the clearing of unprotected parcels with probabilities of having been protected that are similar to the protected areas. The estimated probabilities for locations result from a probit model for protection, with the regressors being all of the covariates of the treatment (Rosenbaum and Rubin 1983).

We then choose how many of those most similar unprotected locations are used to create the control group. When the number of matched control locations increases, the variance of the estimator decreases given on more data. However, its bias will increase because each additional matched location is less similar that those being used. Below, we use the 4 most similar locations for each protected location to form a comparison group.

Choosing a fixed number of the most similar locations for each protected location implies that we do not fix the level of similarity required for inclusion in a control group. The n^{th} most similar location for a protected Point A may be almost identical to Point A while the n^{th} most similar location for Point B may be very different from B. Concretely, Figure 2 shows that the n^{th} most similar location is less similar given a higher probability, i.e. the places very likely to be protected have less well matched controls (Figures 3 and 4 show that protection far to the southeast has a high probability and low match quality). In section 4.1 of the results below, we discuss the implications of this for impact estimation.

Given a control group, we will estimate counterfactual deforestation and compare it with actual deforestation. We will run a regression using the protected and the matched unprotected points with a protection dummy and including other covariates expected to affect deforestation rates. The standard errors from such a regression are incorrect (even with bootstrapping, as per Abadie and Imbens 2006). Following Hill et al. 2003, we start to (but do not fully) address the issues with the standard errors by weighting unprotected observations using the number of times they are included as controls for protected points.

4. Results

4.1. Protection's Spatial Average Impact (i.e., all protected areas)

We start by showing the importance of the non-random distribution of protection. Considering all protected areas at once, so the results comment on spatial average impact for the 1986-1997 time period, Table 2a presents the simple naïve estimate of the national parks and biological reserves' impact on deforestation. This estimate does not consider at all the non-randomness of the protected locations. Comparing the deforestation rate with protection, i.e. essentially zero, with deforestation in all unprotected points suggests that about 9% of protected 1986 forest would have been cleared by 1997 without protection.

Even a simple effort to address non-random location suggests much lower impact. Table 2b again compares all protected points with all unprotected points but controlling for sites' observed characteristics. This estimate suggests about 2% of the 1986 forest in protected areas would have been cleared without protection. Site characteristics matter.

This form of control for different characteristics of protected versus unprotected puts a heavy burden on the regression specification. Matching tries to lower that burden by 'comparing apples to apples', i.e. comparing protected with the subset of unprotected points that has the most similar characteristics to the protected. Table 2c shows that using a location's probability of being protected to define 'similarity', as we do, yields a subset of unprotected locations more similar to protected areas than the full set of unprotected.

Table 2d's matching estimate of the impact of protection in this case confirms the conclusion from Table 2b's simple control for site characteristics: the naïve impact of about 9% is over three times as high as the preferred matching estimate of about 2%.

A robustness check following Figures 2-4 and discussions in our methods section produces an estimate of about 3%, or qualitatively the same sort of conclusion as above. Specifically, from Figure 2 we drop the protected points to the right of the figure (those with a probability of being protected above 0.6) because the 4 most similar unprotected points for these protected points clearly are less similar than is the case for other points.[10]

This confirms Andam et al. 2008's matching insight for our period 1986-1997. It also makes clear that the paper's focus, a comparison of the differing impacts on forest of different subsets of the protected areas, should involve comparing matching estimates.

4.2 Protection's Impact Varies With Observable Characteristics

4.2.1 Proximity To Capital City

A natural first comparison involves the distance to the largest city and market, the capital city San Jose. We again demonstrate the importance of a non-random distribution of protection. In Table 3a, the simple naïve estimates mimic Table 2a's average impact of protection while suggesting that being close to San Jose does not matter for such impact.

Again, even simple controls for site characteristics significantly shift the results. Table 3b again includes all unprotected points in the comparison with protected areas but controls for site characteristics. This mimics Table 2b as the average impact of protection drops significantly, while adding that the closer areas in particular seem to have impact.

The matching estimates bear this out. Table 3c shows that protected areas deemed 'close' (or closer, and specifically within 85km) have greater impact at a bit under 3% of the protected forest being saved during this period. In the protected areas that are farther away from the capital city, as seen in Table 3d the impact of protection on deforestation is below 1%. Thus, the average impact result in Table 2d masks a variation over space.

[10] One might presume that this is a better estimate. However, the protected points dropped are those with the worst characteristics for agricultural profitability. For those, we would estimate close to no impact. So while this 3% estimate uses better matches, it does so for an unrepresentative group of protected areas and being unrepresentative in this way biases the estimate up. The 2% average impact may be a better estimate and dropping those protected points with lower quality matches is likely, in this way, to affect comparisons.

4.2.2 Slope

Thinking about factors expected to affect the underlying deforestation process, without any question slope matters (for instance, Robalino and Pfaff 2007 find slope's influence dependable enough to use it to help explore neighbors' impacts on each other). Clearing for agriculture is clearly affected by slope. Park location may respond to it too.

Slope greatly influences protection's deforestation impact, as seen in Tables 4. In Table 4a, the matching estimate of impact for land with slope below 7.12 degrees is 14%. For this subset, noting the this subset has only 690 observations versus 4100 in Table 4b, protection is much more important to forest outcome than it is for all the protected areas.

Not surprisingly, given the 2% matching impact estimate for all protected areas, protection's impact on the relatively high slopes is close to zero. Without question, slope could be used by planners. It is easily observable and greatly affects protection's impact.

4.2.3 Distance to National Roads

Again considering factors that are thought to affect deforestation, and may also drive the location of forest protection, we look at protection within roughly 7.5 km of a national road compared with further from such roads. The importance of transport costs for deforestation is broadly acknowledged; thus we expected this dimension to matter.

That expectation is borne out in the results. Table 5a's matching result for all the protected areas relatively close to national roads suggests that 5% of the protected forest was saved from clearing during the period 1986-1997. In contrast, Table 6b's result for protected area further from national roads suggests close to no impact on deforestation. Once again we see that Table 2d's 2% result, for all protected areas, masks significant variation along an easily observable characteristics of sites that a planners could use.

4.2.4 Elevation

Finally, for a bit more completeness in examining easily observable gradients across the landscape, we consider the dimension of elevation. Priors on elevation and rates of deforestation are, in our view, much weaker in the literature than are the priors concerning slope (noting that of course those two dimensions of variation across space may be correlated; see the Discussion for more on distinguishing causal effects upon the impacts of protection from correlations, in particular concerning a protected area's size).

Comparing Tables 6 finds a mild impact of elevation upon impacts of protection. Table 6a finds that protection at lower evelation, specifically under 450m, saves about 2% of the forest. Table 6b, finds that for higher elevations the impact of protection on deforestation is lower. This feature of potential new sites for protection is observable, to be sure, but in comparison with slope and the distances noted above seems less useful.

5. Discussion

In support of conservation planning, we considered whether observable characteristics of forested locations being considered for protection could predict the impact of protection. We found that they could. Avoided deforestation, during 1986 - 1997, was greater within the protected areas closer to the capital city, closer to a national road, and on flatter land. With data on ecoservices and land costs, this insight should help guide future investment.

The underlying point is that deforestation rates vary across the landscape due to a variety of factors. It is the deforestation rate that would have occurred without protection that determines the impact on forest of a protected area that remains completely forested. Thus for well-protected areas, avoided deforestation varies with the threat that is blocked.

For market distance, distance to national roads and slope, we interpret correlations with impact to be causal. Thus, all else equal, variation along those dimensions will cause the threat of deforestation (and, in turn, the forest impact of protection) to vary. As noted earlier, however, not all statistical associations with impact need be causal. For instance, it turns out that smaller protected areas have a statistically significantly higher association with forest impact than do larger protected areas. Lacking a strong causal prior as to why that should be the case, we examined what the correlates of protected area size. We found that smaller protected areas are more likely to be found closer to the capital city, closer to national roads, and on flatter land than are larger protected areas. Thus the association of smaller protected areas with greater deforestation impact may not reflect any differential in protection based on size *per se* but agency choice rules yielding non-random location.

It could reflect land cost. Land that is better for agricultural production and profit, e.g. land with lower slope and lower cost of transport to market, may have a higher price. All else equal, for conservation a planner would like to acquire habitat at a lower cost per hectare (which could explain why only smaller protected areas were created in profitable locations). Yet our results suggest that focusing on lower cost could yield lower benefit.

We show that the forest saved by protection is higher for the more profitable sites. This point does not discount the obvious fact that cost matters. However, it may indicate that holding eco-services constant, in some cases one may prefer a higher-cost location, when the gain in actual impact on deforestation outweighs the cost from the higher price.

We do feel that the causal drivers of deforestation we highlight here will continue to be important for future protected area planning. However, it is important to recognize that land-use dynamics inevitably shift as time passes, especially if development occurs. Given global marketplaces for many products, external forces will shift relevant prices. Put another way, land not currently under high threat could be highly pressured later on. Such evolution of driving forces without question makes any impact prediction uncertain.

Nonetheless, the core point of this paper, that planners should consider impact, remains important. Simply adding to protection planners' core questions "How is threat evolving across space?" helps greatly by stimulating collection of relevant information.

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Table 1 -- establishment dates and characteristics of 132 protected areas

Category	Number	Area (ha)	Number Started Per Decade					Nat'l %[i]
			< 60s	*60s*	*70s*	*80s*	*90s*	
National Parks	24	54,1576	1	1	11	1	10	10.6
Biological Preserves	9	39,644	-	-	5	2	2	0.8
National Wildlife Refuges	39	181,018	-	-	-	9	30	3.5
Forestry Reserves	12	291,513	-	2	6	1	3	5.7
Protection Zones	31	178,677	-	-	10	11	10	3.5
Wetlands	14	50,465	-	-	1	1	12	1.0
Special categories	3	1,650	-	1	1	-	1	< 0.1
Total	132	1,284,543	1	4	34	25	68	25.1

[i]: indicates the percent of the national territory within these types of protected areas

Table 2a – All Protected Areas, simple naïve estimate
(all unprotected observations as controls, without covariates)

```
Ordinary Least-squares Estimates
Dependent Variable = Defor
R-squared      =    0.0223
Rbar-squared   =    0.0221
sigma^2        =    0.0676
Durbin-Watson  =    1.9077
Nobs, Nvars    =   4229,     2
```

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.093907**	**-9.829889**	**0.000000**
CONSTANT	0.095995	21.112217	0.000000

Table 2b – All Protected Areas, improved naïve estimate
(all unprotected observations as controls, with covariates)

```
Ordinary Least-squares Estimates
Dependent Variable = Defor
R-squared      =    0.0803
Rbar-squared   =    0.0755
sigma^2        =    0.0639
Durbin-Watson  =    1.9858
Nobs, Nvars    =   4229,    23
```

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.019945**	**-1.668850**	**0.095222**
REGION1	0.009710	0.421815	0.673181
REGION2	0.033241	1.249535	0.211539
REGION3	0.036318	1.780352	0.075091
REGION4	0.052066	2.514125	0.011970
REGION5	0.030650	1.612327	0.106966
REGION7	-0.057887	-2.388762	0.016949
DISTSANJOSE2	-0.000006	-3.077554	0.002101
DISTSANJOSE	0.000550	1.216702	0.223786
DISTNATROAD2	0.000070	0.996723	0.318956
DISTNATROAD	-0.002162	-1.100943	0.270984
DISTLOCROAD2	0.000007	0.086797	0.930837
DISTLOCROAD	-0.003088	-1.384463	0.166290
DISTWIDERIV2	0.000146	0.518723	0.603981
DISTWIDERIV	-0.002174	-0.665324	0.505880
PROXTOCLEAR2	0.003391	5.114027	0.000000
PROXTOCLEAR	-0.035226	-5.553926	0.000000
SLOPE	-0.002757	-4.113935	0.000040
ELEVATION2	0.011278	1.446797	0.148028
ELEVATION	-0.040957	-1.777245	0.075600
RAIN2	-0.002795	-0.894130	0.371303
RAIN	0.019292	0.732862	0.463684
CONSTANT	0.143181	2.627530	0.008632

Table 2c – All Protected Areas, improving the comparison by matching
(characteristic means for protected, all unprotected, and matched subsets)

Characteristic	PROTECTED	ALL UNPROTECTED	MATCHED	Test	Improved?
Deforestation	0.0021	0.0960	0.0193		
REGION1	0.1263	0.1798	0.2210	5.96e-011	NO
REGION2	0.0449	0.0896	0.0277	0.0060	YES
REGION3	0.0668	0.0978	0.0462	0.0090	YES
REGION4	0.4447	0.2614	0.3014	3.69e-017	YES
REGION5	0.1921	0.1764	0.2944	2.63e-010	NO
REGION7	0.0084	0.0559	0.0078	0.8706	YES
DISTSANJOSE2	12526.6824	10373.5447	11996.7439	0.1546	YES
DISTSANJOSE	101.2737	90.0316	98.0642	0.0677	YES
DISTNATROAD2	313.8794	72.9136	252.0197	6.29e-010	YES
DISTNATROAD	14.9478	6.3887	13.4420	1.81e-006	YES
DISTLOCROAD2	153.1400	46.2170	127.2587	4.28e-009	YES
DISTLOCROAD	10.6341	4.5823	9.9316	0.0005	YES
DISTWIDERIV2	22.5497	16.4423	23.3138	0.5767	YES
DISTWDERIV	3.9049	3.1942	3.9959	0.3698	YES
PROXTOCLEAR2	18.4279	1.7862	12.2732	1.30e-020	YES
PROXTOCLEAR	3.1583	0.6829	2.8031	2.20e-005	YES
SLOPE	14.1976	8.6119	15.0935	0.0022	YES
ELEVATION2	2.5700	0.8603	2.7791	0.0251	YES
ELEVATION	1.3255	0.6278	1.4031	0.0158	YES
RAIN2	17.3445	15.3361	17.5676	0.4480	YES
RAIN	4.0418	3.7768	4.0827	0.2470	YES

Table 2d – All Protected Areas, Propensity Score Matching estimate
(only matched unprotected observations as controls, with covariates)

```
Ordinary Least-squares Estimates
Dependent Variable = Defor
R-squared      =    0.0444
Rbar-squared   =    0.0400
sigma^2        =    0.0150
Durbin-Watson  =    2.0175
Nobs, Nvars    =   4790,    23
```

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.022134**	**-4.815909**	**0.000002**
REGION1	-0.020007	-1.421567	0.155218
REGION2	0.015087	0.862225	0.388607
REGION3	0.006598	0.536604	0.591566
REGION4	0.004816	0.370051	0.711361
REGION5	-0.004724	-0.403994	0.686235
REGION7	-0.006781	-0.302341	0.762406
DISTSANJOSE2	-0.000003	-2.982239	0.002876
DISTSANJOSE	0.000430	1.685203	0.092015
DISTNATROAD2	-0.000038	-1.316933	0.187924
DISTNATROAD	0.000023	0.022111	0.982361
DISTLOCROAD2	-0.000109	-1.793332	0.072983
DISTLOCROAD	0.002018	1.353085	0.176093
DISTWIDERIV2	0.000126	1.081303	0.279617
DISTWIDERIV	-0.001656	-1.061060	0.288716
PROXTOCLEAR2	0.001609	5.589103	0.000000
PROXTOCLEAR	-0.014486	-5.513313	0.000000
SLOPE	-0.000641	-2.188485	0.028683
ELEVATION2	0.011475	3.466206	0.000533
ELEVATION	-0.037765	-3.688085	0.000228
RAIN2	-0.002304	-1.522070	0.128058
RAIN	0.021040	1.538422	0.124012
CONSTANT	0.034466	1.219348	0.222772

Table 3a – Protected Areas Closer/Farther from San Jose, simple naïve estimate
(all unprotected observations as controls, without covariates but distance interaction)

```
Ordinary Least-squares Estimates
Dependent Variable = Defor
R-squared      =    0.0224
Rbar-squared   =    0.0219
sigma^2        =    0.0676
Durbin-Watson  =    1.9077
Nobs, Nvars    =   4229,     3
```

Variable	Coefficient	t-statistic	t-probability
Close*Protect	**0.004175**	**0.248453**	**0.803796**
Protection	**-0.095995**	**-7.544627**	**0.000000**
CONSTANT	0.095995	21.109874	0.000000

Table 3b – Protected Areas Closer/Farther from San Jose, improved naïve estimate
(all unprotected observations as controls, with covariates and distance interaction)

```
Ordinary Least-squares Estimates
Dependent Variable = Defor
R-squared      =    0.0810
Rbar-squared   =    0.0760
sigma^2        =    0.0639
Durbin-Watson  =    1.9873
Nobs, Nvars    =   4229,    24
```

Variable	Coefficient	t-statistic	t-probability
Close*Protect	**-0.032218**	**-1.735680**	**0.082694**
Protection	**-0.002563**	**-0.164408**	**0.869418**
REGION1	0.007992	0.346946	0.728649
REGION2	0.032706	1.229608	0.218913
REGION3	0.035324	1.731327	0.083467
REGION4	0.052117	2.517193	0.011866
REGION5	0.028917	1.519441	0.128727
REGION7	-0.059640	-2.459579	0.013950
DISTSANJOSE2	-0.000006	-3.140919	0.001696
DISTSANJOSE	0.000518	1.144909	0.252312
DISTNATROAD2	0.000074	1.051068	0.293288
DISTNATROAD	-0.002335	-1.187836	0.234965
DISTLOCROAD2	0.000020	0.228692	0.819119
DISTLOCROAD	-0.003244	-1.453454	0.146172
DISTWIDERIV2	0.000151	0.533909	0.593432
DISTWIDERIV	-0.002115	-0.647299	0.517474
PROXTOCLEAR2	0.003209	4.782133	0.000002
PROXTOCLEAR	-0.034562	-5.440566	0.000000
SLOPE	-0.002631	-3.904705	0.000096
ELEVATION2	0.011590	1.486759	0.137153
ELEVATION	-0.041771	-1.812595	0.069966
RAIN2	-0.003225	-1.028833	0.303617
RAIN	0.022523	0.853668	0.393338
CONSTANT	0.142453	2.614715	0.008962

Table 3c – Protected Areas Closer To San Jose (< 85 kilometers)
(only matched unprotected observations as controls, with covariates)

WOrdinary Least-squares Estimates
R-squared = 0.0386
Rbar-squared = 0.0296
sigma^2 = 0.0054
Durbin-Watson = 1.9157
Nobs, Nvars = 2395, 23

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.026724**	**-2.498370**	**0.012544**
REGION1	0.060265	0.648262	0.516878
REGION2	0.087532	0.927708	0.353653
REGION3	0.090247	0.967212	0.333537
REGION4	0.071361	0.771835	0.440289
REGION5	0.057718	0.618476	0.536321
REGION7	0.022733	0.232256	0.816359
DISTSANJOSE2	-0.000014	-2.964942	0.003058
DISTSANJOSE	0.001984	2.978616	0.002925
DISTNATROAD2	-0.000116	-3.291064	0.001013
DISTNATROAD	0.005407	3.240653	0.001209
DISTLOCROAD2	0.000269	2.782089	0.005444
DISTLOCROAD	-0.012583	-4.916938	0.000001
DISTWIDERIV2	-0.000077	-0.207288	0.835803
DISTWIDERIV	-0.000868	-0.268564	0.788289
PROXTOCLEAR2	0.002040	3.053427	0.002288
PROXTOCLEAR	-0.013019	-2.598146	0.009431
SLOPE	0.000049	0.187032	0.851651
ELEVATION2	0.003500	0.750474	0.453044
ELEVATION	-0.012063	-0.741704	0.458340
RAIN2	0.005188	1.149077	0.250640
RAIN	-0.048936	-1.250590	0.211207
CONSTANT	0.083610	0.644016	0.519627

Table 3d – Protected Areas Further From San Jose (> 85 kilometers)
(only matched unprotected observations as controls, with covariates)

WOrdinary Least-squares Estimates
R-squared = 0.0302
Rbar-squared = 0.0221
sigma^2 = 0.0005
Durbin-Watson = 1.9374
Nobs, Nvars = 2395, 21

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.008189**	**-1.571203**	**0.116269**
REGION3	0.019949	2.304931	0.021256
REGION4	0.034028	3.130122	0.001769
REGION5	0.015012	1.519994	0.128646
REGION7	-0.002675	-0.076653	0.938906
DISTSANJOSE2	0.000003	1.200891	0.229913
DISTSANJOSE	-0.000740	-1.025908	0.305039
DNREGION2	0.000166	5.055522	0.000000
DISTNATROAD	-0.006585	-6.087315	0.000000
DISTLOCROAD2	0.000035	0.602675	0.546782
DISTLOCROAD	0.000164	0.127472	0.898578
DISTWIDERIV2	-0.000107	-1.232891	0.217738
DISTWIDERIV	0.002951	2.704889	0.006882
PROXTOCLEAR2	-0.000160	-0.702289	0.482568
PROXTOCLEAR	-0.000342	-0.170638	0.864523
SLOPE	0.000020	0.138046	0.890216
ELEVATION2	0.005720	2.710616	0.006764
ELEVATION	-0.020845	-3.391228	0.000707
RAIN2	-0.000991	-0.805360	0.420692
RAIN	0.009500	0.876580	0.380804
CONSTANT	0.059731	1.068311	0.285489

Table 4a – Protected Areas On Lower Slopes (< 7.12 degrees)
(only matched unprotected observations as controls, with covariates)

```
Ordinary Least-squares Estimates
R-squared      =    0.4289
Rbar-squared   =    0.4109
sigma^2        =    0.0047
Durbin-Watson  =    1.8576
Nobs, Nvars    =   690,    22
```

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.142320**	**-4.273667**	**0.000022**
REGION1	-1.116725	-4.490690	0.000008
REGION2	-1.145040	-8.709349	0.000000
REGION3	-0.345198	-3.312689	0.000974
REGION4	-0.535433	-4.529874	0.000007
REGION5	-0.369000	-3.913559	0.000100
REGION7	-0.596732	-4.776213	0.000002
DISTSANJOSE2	0.000005	0.660540	0.509135
DISTSANJOSE	-0.002390	-1.270619	0.204307
DISTNATROAD2	0.002898	7.324782	0.000000
DISTNATROAD	-0.027052	-3.082030	0.002141
DISTLOCROAD2	-0.003840	-9.021938	0.000000
DISTLOCROAD	0.031449	4.394130	0.000013
DISTWIDERIV2	-0.007380	-4.596790	0.000005
DISTWIDERIV	0.086901	6.399890	0.000000
PROXTOCLEAR2	0.017864	1.673176	0.094761
PROXTOCLEAR	-0.179938	-4.341587	0.000016
ELEVATION2	0.007208	0.121664	0.903201
ELEVATION	0.160740	1.434787	0.151816
RAIN2	0.031403	3.537923	0.000431
RAIN	0.014515	0.190881	0.848677
CONSTANT	0.002276	0.011584	0.990761

Table 4b – Protected Areas On Higher Slopes (> 7.12 degrees)
(only matched unprotected observations as controls, with covariates)

```
Ordinary Least-squares Estimates
R-squared      =    0.1334
Rbar-squared   =    0.1287
sigma^2        =    0.0054
Durbin-Watson  =    2.1263
Nobs, Nvars    =  4100,    23
```

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.010533**	**-0.727089**	**0.467213**
REGION1	-0.225357	-7.651017	0.000000
REGION2	-0.215615	-5.605371	0.000000
REGION3	-0.163188	-5.259963	0.000000
REGION4	-0.078825	-2.750098	0.005984
REGION5	-0.104443	-3.805232	0.000144
REGION7	-0.214722	-3.772689	0.000164
DISTSANJOSE2	-0.000005	-2.243407	0.024924
DISTSANJOSE	-0.000134	-0.261090	0.794036
DISTNATROAD2	-0.000317	-5.667032	0.000000
DISTNATROAD	0.006552	3.221211	0.001287
DISTLOCROAD2	0.000172	1.360427	0.173770
DISTLOCROAD	-0.006450	-1.956425	0.050483
DISTWIDERIV2	0.000587	2.820509	0.004818
DISTWIDERIV	-0.009496	-3.492312	0.000484
PROXTOCLEAR2	-0.002905	-5.064699	0.000000
PROXTOCLEAR	0.025473	5.053717	0.000000
SLOPE	0.001857	4.525075	0.000006
ELEVATION2	0.018411	3.572735	0.000357
ELEVATION	-0.058393	-3.092183	0.002000
RAIN2	-0.020758	-5.140552	0.000000
RAIN	0.171230	4.869609	0.000001
CONSTANT	-0.090593	-1.288183	0.197755

Table 5a – Protected Areas Closer To National Roads (<7.53km)
(only matched unprotected observations as controls, with covariates)

```
Ordinary Least-squares Estimates
R-squared       =    0.1159
Rbar-squared    =    0.0966
sigma^2         =    0.0163
Durbin-Watson   =    2.0080
Nobs, Nvars     =    985,     22
```

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.050488**	**-2.872820**	**0.004158**
REGION1	0.044868	2.004922	0.045251
REGION2	0.006756	0.264652	0.791334
REGION3	0.015383	0.863017	0.388343
REGION5	0.021105	0.893436	0.371847
REGION7	-0.092891	-1.964116	0.049804
DISTSANJOSE2	-0.000007	-2.877120	0.004102
DISTSANJOSE	0.000718	1.586694	0.112910
DISTNATROAD2	0.001459	0.569888	0.568887
DISTNATROAD	-0.011081	-0.662099	0.508066
DISTLOCROAD2	0.002243	4.764050	0.000002
DISTLOCROAD	-0.031096	-5.154004	0.000000
DISTWIDERIV2	0.000050	0.060440	0.951818
DISTWIDERIV	0.004835	0.622627	0.533677
PROXTOCLEAR2	0.015273	3.191563	0.001461
PROXTOCLEAR	-0.069304	-4.225679	0.000026
SLOPE	-0.002221	-2.381886	0.017418
ELEVATION2	-0.017322	-1.677067	0.093854
ELEVATION	0.021820	0.699640	0.484321
RAIN2	-0.002199	-0.617620	0.536972
RAIN	0.002121	0.069739	0.944416
CONSTANT	0.221153	3.130627	0.001797

Table 5b – Protected Areas Farther From National Roads (>7.53km)
(only matched unprotected observations as controls, with covariates)

```
Ordinary Least-squares Estimates
R-squared       =    0.0299
Rbar-squared    =    0.0245
sigma^2         =    0.0016
Durbin-Watson   =    1.9774
Nobs, Nvars     =   3805,     22
```

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.002513**	**-0.300333**	**0.763940**
REGION1	-0.032341	-4.286784	0.000019
REGION2	0.004390	0.272853	0.784981
REGION3	-0.022555	-1.467421	0.142345
REGION5	0.010518	1.395757	0.162869
REGION7	-0.046574	-1.217494	0.223492
DISTSANJOSE2	-0.000003	-1.840089	0.065833
DISTSANJOSE	0.000167	0.486441	0.626682
DISTNATROAD2	-0.000052	-1.344226	0.178956
DISTNATROAD	-0.000177	-0.122896	0.902196
DISTLOCROAD2	0.000162	2.654973	0.007965
DISTLOCROAD	-0.004915	-3.115645	0.001849
DISTWIDERIV2	0.000311	2.595842	0.009472
DISTWIDERIV	-0.005509	-3.523452	0.000431
PROXTOCLEAR2	-0.000787	-2.342718	0.019195
PROXTOCLEAR	0.006843	2.299280	0.021543
SLOPE	0.000346	1.751270	0.079980
ELEVATION2	0.010775	3.908297	0.000095
ELEVATION	-0.035949	-3.706506	0.000213
RAIN2	-0.003690	-1.787951	0.073864
RAIN	0.032283	1.823615	0.068289
CONSTANT	0.030723	0.739934	0.459386

Table 6a – Protected Areas At Lower Elevation (< 450m)
(only matched unprotected observations as controls, with covariates)

Ordinary Least-squares Estimates

R-squared	=	0.0579
Rbar-squared	=	0.0421
sigma^2	=	0.0015
Durbin-Watson	=	2.0437
Nobs, Nvars	=	1215, 21

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.020950**	**-1.651059**	**0.098989**
REGION1	0.115956	2.715338	0.006716
REGION2	0.026501	0.793249	0.427790
REGION5	-0.018464	-0.854894	0.392781
REGION7	-0.023440	-0.689016	0.490947
DISTSANJOSE2	-0.000009	-2.812607	0.004995
DISTSANJOSE	0.001930	2.132743	0.033149
DISTNATROAD2	-0.000012	-0.109617	0.912732
DISTNATROAD	0.000243	0.094469	0.924752
DISTLOCROAD2	-0.000013	-0.083464	0.933496
DISTLOCROAD	-0.002392	-0.823853	0.410188
DISTWIDERIV2	-0.000190	-0.967635	0.333423
DISTWIDERIV	0.002811	0.931580	0.351742
PROXTOCLEAR2	0.007160	4.380825	0.000013
PROXTOCLEAR	-0.046252	-4.956594	0.000001
SLOPE	0.000837	1.647554	0.099707
ELEVATION2	-0.354913	-1.500324	0.133795
ELEVATION	0.150649	1.467752	0.142435
RAIN2	-0.002317	-0.546164	0.585055
RAIN	0.032030	0.967447	0.333517
CONSTANT	-0.102380	-0.949946	0.342332

Table 6b – Protected Areas At Higher Elevation (> 450m)
(only matched unprotected observations as controls, with covariates)

Ordinary Least-squares Estimates

R-squared	=	0.0109
Rbar-squared	=	0.0050
sigma^2	=	0.0007
Durbin-Watson	=	2.0100
Nobs, Nvars	=	3575, 22

Variable	Coefficient	t-statistic	t-probability
Protection	**-0.008131**	**-1.002952**	**0.315952**
REGION1	-0.012006	-1.889350	0.058926
REGION2	-0.057466	-3.900661	0.000098
REGION3	-0.044587	-4.791177	0.000002
REGION5	0.008625	0.854666	0.392794
REGION7	-0.039854	-1.078217	0.281010
DISTSANJOSE2	0.000002	0.968619	0.332801
DISTSANJOSE	-0.000520	-1.670178	0.094972
DISTNATROAD2	0.000002	0.077475	0.938250
DISTNATROAD	-0.000800	-0.682984	0.494661
DISTLOCROAD2	0.000060	0.682793	0.494782
DISTLOCROAD	-0.002149	-1.024979	0.305443
DISTWIDERIV2	-0.000233	-1.090576	0.275534
DISTWIDERIV	0.003566	1.722724	0.085025
PROXTOCLEAR2	0.000832	2.217368	0.026661
PROXTOCLEAR	-0.008022	-2.360510	0.018304
SLOPE	-0.000008	-0.041489	0.966909
ELEVATION2	0.008017	1.700416	0.089140
ELEVATION	-0.042472	-2.540864	0.011100
RAIN2	0.000124	0.059715	0.952386
RAIN	-0.003513	-0.193136	0.846864
CONSTANT	0.134243	2.949241	0.003206

Figure 1 – land-use choice with and without park

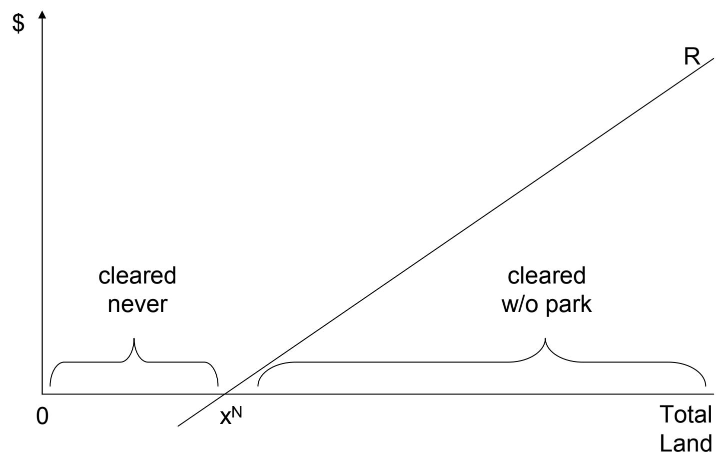

Figure 2 – higher Protection propensity areas are harder to match

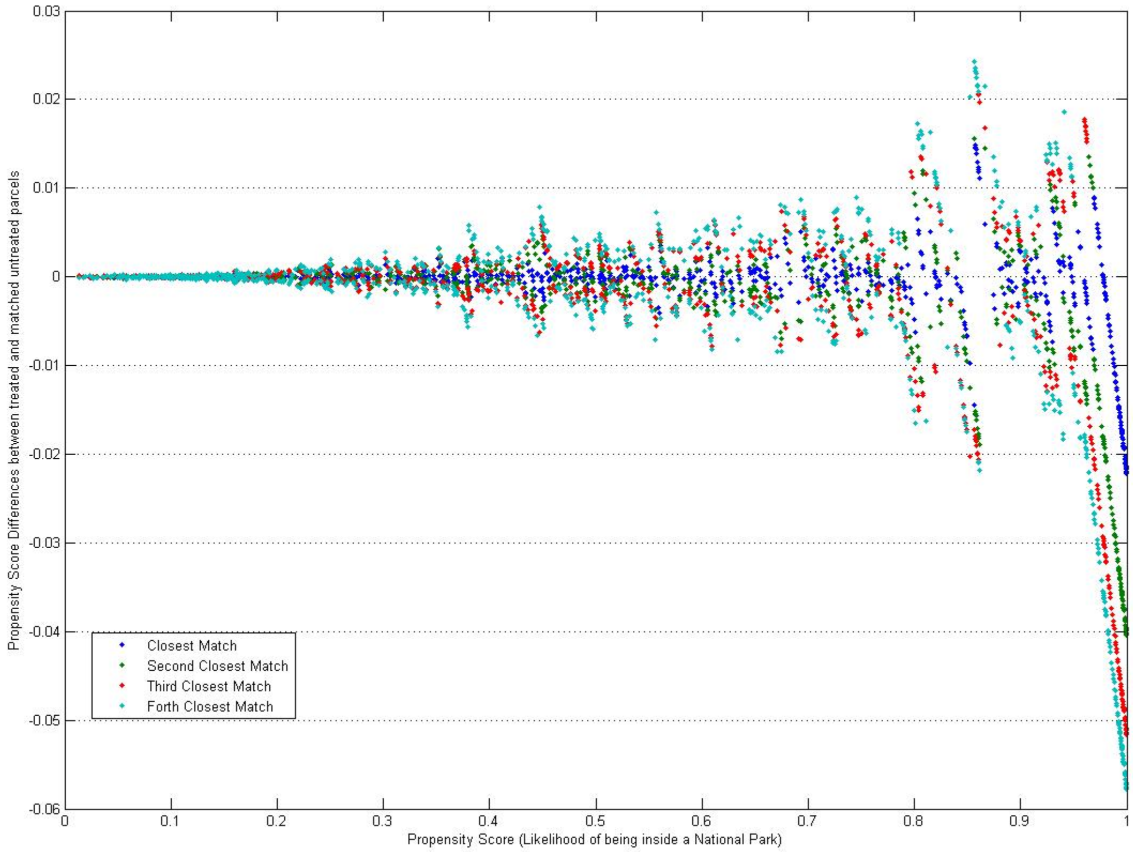

Figure 3 – Protected Areas Differ In Predicted Probability Of Protection

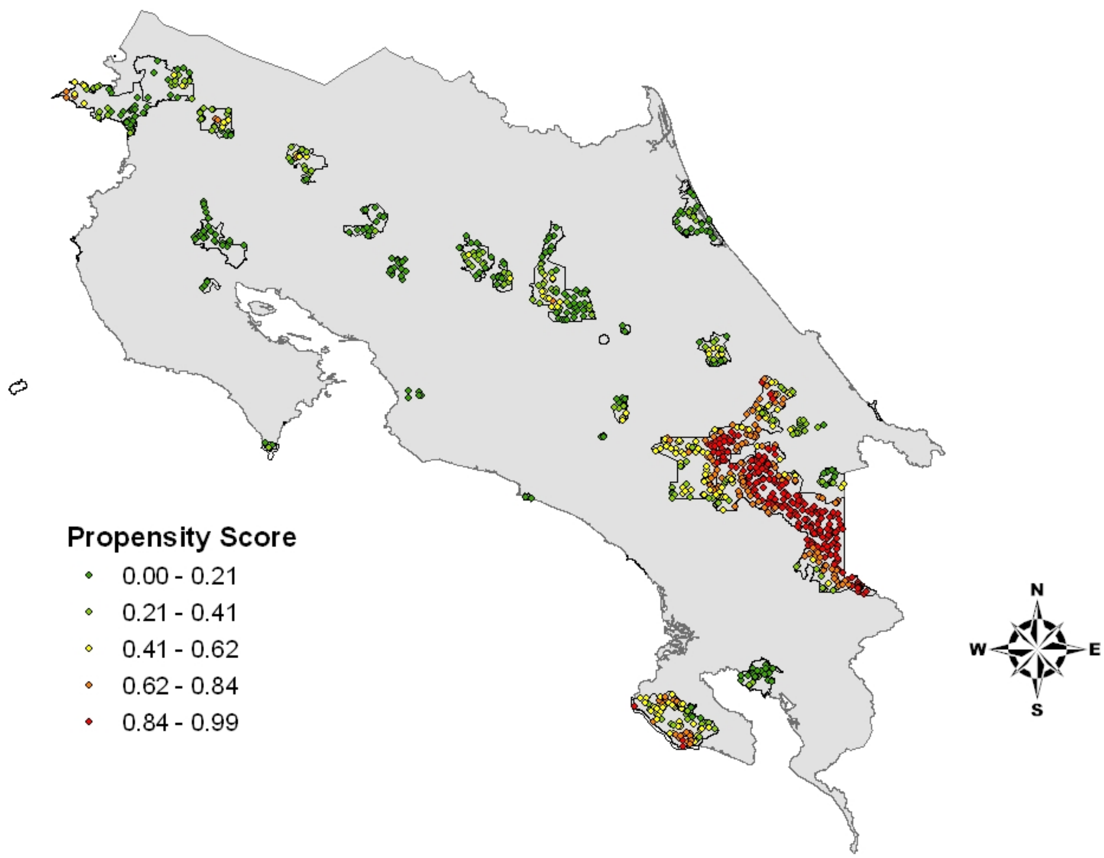

Figure 4a – The Most Likely Locations For Protection Have The Worst Matches (comparing probability of protection with the most similar unprotected location)

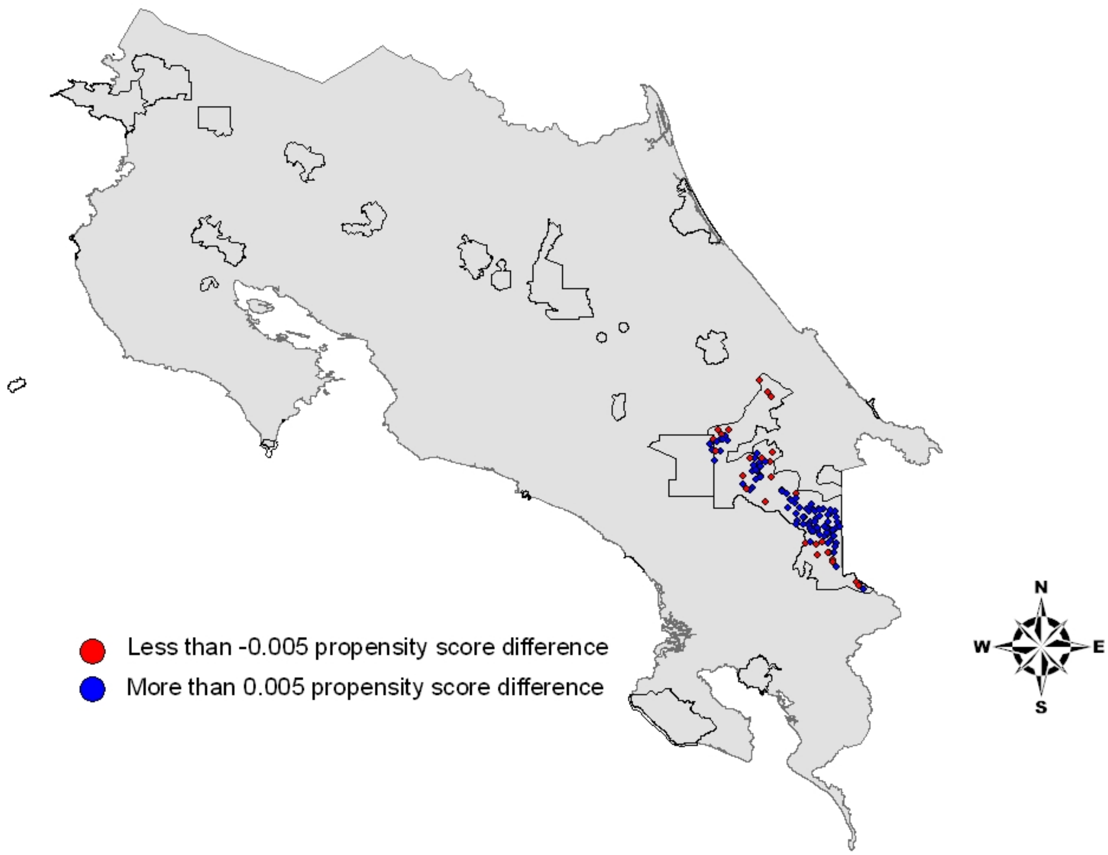

Figure 4b – The Most Likely Locations For Protection Have The Worst Matches (comparing probability of protection with 2^{nd} most similar unprotected location)

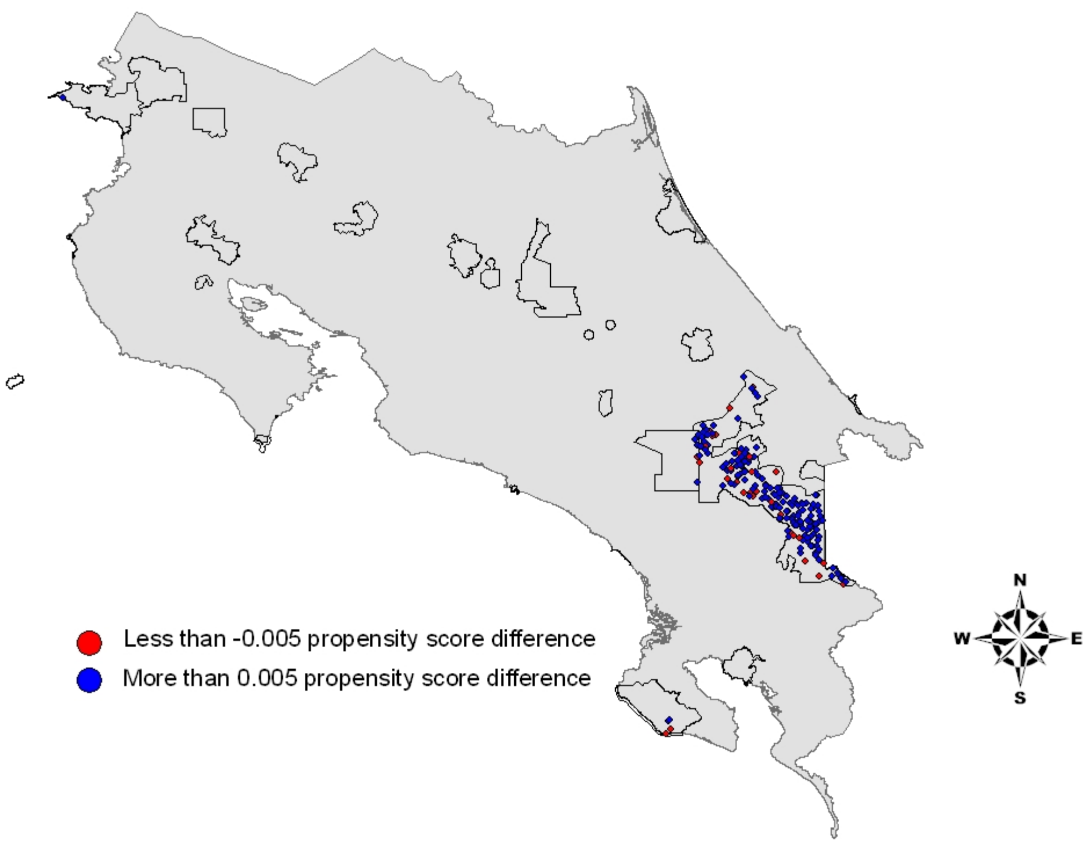

Figure 4c – The Most Likely Locations For Protection Have The Worst Matches (comparing probability of protection with 3rd most similar unprotected location)

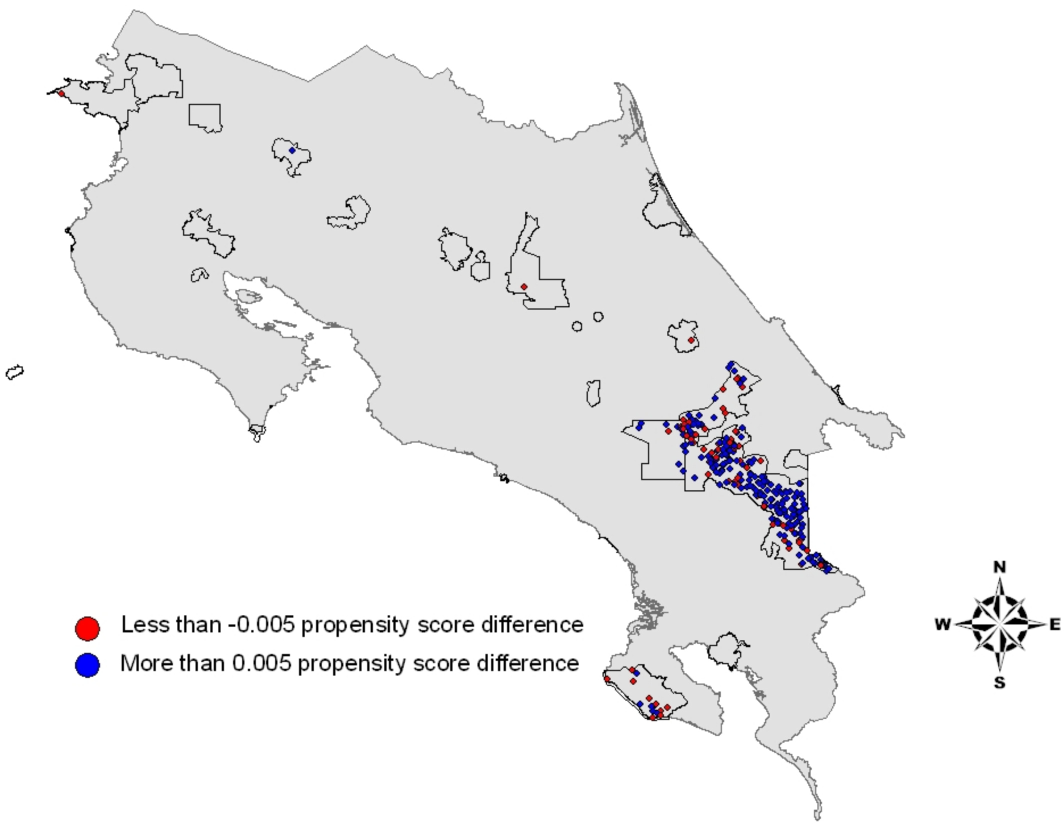

Figure 4d – The Most Likely Locations For Protection Have The Worst Matches (comparing probability of protection with 4^{th} most similar unprotected location)