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Identifying the Opportunity Cost of Critical Habitat Designation under the U.S. Endangered Species Act

Erik J. Nelson, John C. Withey, Derric Pennington, and Joshua J. Lawler

Abstract. We determine the effect of the US Endangered Species Act's Critical Habitat designation on land use change from 1992 to 2011. We find that the rate of change in developed land (constructed material) and agricultural land is not significantly affected by Critical Habitat designation. Therefore, Sections 7 and 9 of the Endangered Species Act do not appear to be more heavily applied in lands designated as Critical Habitat areas versus lands within listed species' ranges, but without critical habitat designation. Further, there does not appear to be any extraordinary conservation activity in critical habitat areas; for example, environmental non-profits and land trusts do not appear to be concentrating activity in these areas. Before we conclude that the opportunity cost of Critical Habitat designation is negligible we need to examine the land management impacts of designation.

Keywords. Critical Habitat, Opportunity Cost, Land Use Change, Matching Analysis
JEL Codes. Q24, Q28, Q57

I. Introduction

The US Endangered Species Act (ESA), like any land use-based regulation, can create costs by limiting economic activity that would have otherwise occurred in an unregulated landscape. Restrictions on *land management* is one category of cost created by the ESA. For example, ESA regulations could prevent a harvester on Forest Service land from adopting a more intensive method of logging, or a farmer could be prevented from converting land from pasture to more lucrative cropland if the pasture is deemed habitat for a listed species.

The ESA may also prevent *land-use change*. In this case a farmer may not be able to sell land to a housing developer, if regulating agencies find that development would jeopardize the existence of a listed species. The clearing of trees to build a public road could also be prevented if the Fish and Wildlife Service decides that this action could destroy a listed species or its habitat.

In this paper, we estimate the magnitude of the cost incurred by preventing land-use change in critical habitat (CH) areas, which we focus on as portions of the US landscape that can be definitively connected to the ESA.[1] Specifically, we estimate the impact of the CH area designation on two types of land-use behavior from 1992 to 2011: 1) the rate of conversion from semi-natural or agricultural cover to developed land and 2) the rate of conversion from semi-natural to agricultural cover. We then convert the land-use change impact into a monetary value using a spatially explicit database of land-use values.

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[1] We investigate the potential costs due to restrictions on land management in another paper.

Estimating costs created by Critical Habitat designation

Unlike other well-known environmental regulations, there are few, if any, comprehensive estimates of ESA costs. One reason for the lack of cost estimates is that range maps and habitat associations for many listed species are imprecise and incomplete, and identifying where and how the ESA has affected decision-making by both government officials and private landowners can be difficult to determine. Private landowners, who may have better knowledge of some species' ranges and habitats than federal authorities, have no incentive to make the wildlife data better as such information could increase their regulatory burdens. Furthermore, accurate measurement of ESA-generated costs requires a land-use and land-management counterfactual— a US landscape modeled without the ESA. Whereas assessors of the Clean Air Act Amendments and other US environmental regulations have built credible models of counterfactual US economies that do not include the regulation in question (e.g., Chan et al. 2012), we know of no previous attempts to model the US landscape without the impacts of the ESA.

The recent publication of digital CH maps, fine scale spatial datasets of US land use in different decades, and listed species range maps have given us the opportunity to create several ESA-related counterfactuals. First, consider the information CH maps provide. When a species is listed under the ESA, the regulating agency responsible for the species, the Fish and Wildlife Service (FWS, for terrestrial and freshwater species) or the National Marines Fisheries Service (NMFS, for marine and anadromous species) must designate specific areas on the landscape that are deemed vital to the recovery of the species.[2] Any proposed activity occurring on federal lands, involving Federal funding, or requiring a Federal permit in CH areas can be prevented or modified if the regulating agencies find that it would adversely modify the species' habitat. Other sections of the ESA that impact private landowner and public land manager decision making, such as sections 7 and 9, also apply in the CH areas. These sections of the Act prevent land-use and land-management decisions that would result in "taking"[3] of listed species from the wild or put the species in jeopardy. In fact, given the dearth of other listed species range maps in the Federal Register as well as their imprecise nature, the suite of CH maps is the only set of ESA-related data that precisely indicates the places in the US where ESA regulations *must* matter.

To determine how much these areas effect land-use behavior we needed: 1) a spatial dataset of land-use at different times in CH areas and 2) a counterfactual map of land-use behavior in CH areas if these areas were never designated as CH areas. We derived the actual history of land use in CH areas by overlying CH maps on hectare-level land-use maps for the entire US from the years 1992, 2001, 2006, and 2011 (Jin et al. 2013). We built the counterfactual history of land use in CH areas with matching methods. Using this approach, we identify "control areas" on the landscapes that were nearly identical to CH areas just prior to CH

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[2] As one federal court put it: "Critical Habitat is the area 'essential' for 'conservation' of listed species. Conservation means more than survival; it means recovery" (Suckling and Taylor 2005).

[3] "Taking" has been interpreted by US courts to include the killing, harming, harassing, pursuing, or removing of the species from the wild on private and public land.

designation. We then tracked the trajectory of land use change in the “treated areas” (the areas that became CH areas) to the control areas.

Given that all CH areas are within one or more listed species’ range, the counterfactual map can only include areas that are also within one or more listed species’ range. The difference between land-use change in the treated and control areas indicates the impact of the CH areas on land use, independent of the effect of listing itself. Hereafter, we represent CH areas by C_{CH} and the set of control areas within listed species ‘ranges by C_{ESA}.

> Hypothesis: On average, land development rates, both conversion to developed areas and agricultural, in C_{CH} were lower from 1992 to 2011 than in C_{ESA}. Developed areas are comprised of impervious surface or constructed materials. Agricultural areas include cropland and pasture.

A different counterfactual would be control areas that are not in any listed range space, but in that case, the ‘treatment’ would be both listing under the ESA and designation of CH. However, given that information on species’ ranges are often imprecise it is not clear how different the trajectory of land use in control areas C_{ESA} would be compared to matched non-ESA areas.

Finally, by applying the counterfactual land-development rates to the treated (CH) areas, we estimated changes in land values due to CH designation through changes both to developed and to agricultural lands. We converted these changes to a monetary figure with a recently published dataset of county-level land values by land-use type (Withey et al. 2012).

II. Background

Regulatory context for the Critical Habitat regulation of the Endangered Species Act

The ESA has the potential to create significant opportunity costs (Brown and Shogren 1998). Section 9 of the Act prohibits any takings (see footnote 3) of listed species on private and public land. For example, the conversion of land from forest to residential use could be prevented by Section 9 if the forest contains a listed species or is considered listed species habitat. Section 7 of the Act requires that Federal actions do not jeopardize the continued existence of the species. Compliance with these sections could limit the development decisions that private and public landowners are able to make, thereby generating opportunity costs.

Along with ESA costs due to listing itself, designation of critical habitat can create additional opportunity costs (Plantinga et al. 2014). When a species is listed, the regulating agency responsible for the species must designate any area deemed vital to the recovery of the species as CH. Any proposed activity in CH areas that occur on federal lands, involve Federal funding, or require a Federal permit also requires consulting with the FWS or NMFS and can be prevented or modified if the regulating agencies find that it would adversely modify the species’ habitat. As Plantinga et al. (2014) notes, “in order for the designation of critical habitat to have incremental economic effects, it must prevent otherwise economical activities, *excluding* those activities already prohibited by the jeopardy standard (section 7) or take restrictions (section 9)” (p. 128). For example, Suckling and Taylor (2005) claim that a Hawaiian road was re-routed from a planned path through a CH to avoid costly consultation with FWS.

They do not, however, determine if CH regulations, section 7 or 9 of the Act, or a combination of these regulations created the road modification.

In addition to costs caused by CH regulations in action, the mere presence of CH maps could modify land-use decision-making vis-à-vis non-CH ESA areas in ways that are not observable to regulating authorities or distant analysts. First, landowners in CH areas could be more hesitant to make land-use changes than land owners in non-CH listed species' ranges due to the preciseness of the CH maps versus the vagueness of listed species ranges. Landowners in CH areas cannot claim that there is no official evidence to tie their land to ESA regulations. The landowner in a CH may suspect that his or her actions, especially any harmful actions, will be scrutinized by federal authorities and conservation non-profits, given that the land is officially in a regulatory zone.[4] Second, CH designation communicates the importance of the designated area for the recovery of the listed species and gives conservation-minded stakeholders incentive to concentrate recovery activities in the area. Suckling and Taylor (2005) argue that in several cases private CH land owners and government land managers have voluntarily cooperated on habitat management plans that otherwise would not have been created without the CH designation. Further, CH could prompt conservation organizations to try to secure conservation easements and/or purchase lands within the CH area, which would block land development (Suckling and Taylor 2005).

Critical Habitat cost estimates

Several analyses commissioned by Federal agencies and academic studies have attempted to measure the impact of a few CH areas on housing and land markets (List et al. 2006, Zabel and Paterson 2006, Zabel and Paterson 2011, Plantinga et al. 2014). Although these studies find some evidence of differences in economic activity inside CH boundaries versus outside, they are not able to attribute the differences to any specific provision of the ESA, nor are the cost lessons learned in these few case studies extrapolated to all CH areas. List et al. (2006) focus on the potential impact CH designation can have on the timing of development. For example, just prior to final designation but after announcement of the proposed CH, private interests in the soon-to-be CH may pre-emptively develop (or otherwise alter habitat) in order to avoid post-designation regulatory restrictions on land use: the so-called "shoot, shovel and shut-up" phenomenon. If the quicker pace of development deviates from what would have occurred without CH designation then, assuming rational land markets, the CH designation has generated a suboptimal land use trajectory and therefore an opportunity cost. List et al. (2006) found that parcels in proposed pygmy owl CH, that became part of the final CH a year later, were developed at a rate greater than nearby private parcels similar in every way except that they happened to lie immediately outside the proposed CH border. Likewise, Lueck and Michael (2000) found landowners more likely to harvest timber sooner when the forest plot was closer to red-cockaded woodpecker nests in North Carolina.

In light of the continuing cost uncertainty and piecemeal nature of CH cost estimates, Plantinga et al. (2014) call for a comprehensive retrospective analysis to identify the scope and

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[4] On the other hand, a private landowner on land that was not deemed vital to a species' persistence and not officially linked to a species range with a map published in the Federal Register might be more likely to avoid any scrutiny of his or her actions.

magnitude of economic costs engendered by CH, distinct from costs related to other portions of the ESA. While we agree with the need for such analysis, we do not believe it to be feasible given the data available at this time. We are not aware of a comprehensive dataset that would enable researchers to identify what decisions and choices have been made by regulators, land owners, and land managers due to each part of the Act. However, the data to identify land-use decisions caused or spurred by CH designation in now available. Whether the actions have been motivated by section 7, section 9, the CH rule itself, or the actual mapping of areas regulated by the ESA is unknown. Broadly speaking, we are not bothered by the lack of clear causality. We suggest that our work, the first comprehensive estimate of the land-use opportunity cost created by the Act in a certain subset of the US landscape, will be a valuable contribution to the larger policy debate on the ESA and its economic impacts.

Critical Habitat benefit estimates

The benefits of CH areas have gotten very little attention in the economics literature and only a small amount in the conservation biology literature (e.g., Suckling and Taylor 2005). Several researchers have noted that species with CH designation have better recovery scores (as assigned from the regulating agencies) than species without CH (Taylor et al. 2005, Suckling and Taylor 2005). However, how much of this relatively better performance, if any, can be attributed to CH itself is unknown. One reason for the lack of researcher attention may be the odd mixed signals coming from the regulatory agencies regarding the benefits of CH. Despite their regulatory mandate to designate a species' CH immediately after its listing, the FWS and NMFS have been loath to do so. As of today, more than half of all listed species still do not have a CH area. Both agencies argue that CH areas do not provide any additional protection to listed species above and beyond other ESA regulatory measures, and therefore, the opportunity costs created by CH designation are not counterbalanced by *any* additional recovery or survival benefit (Corn et al. 2012).

III. Methodology

Data

The FWS has provided digital maps for almost all final (as opposed to proposed) CH areas established between 1973 and 2013 (Figure 1). For listed species ranges we used a dataset of all listed species, not just those with CH areas, by HUC8 watersheds based on NatureServe's species location data or "element occurrences" (NatureServe 2014). We have also collected a set of digital maps that describe circa 1990, 2000, 2006 and 2011 land use, and biophysical, demographic, economic, and political conditions across the contiguous US.

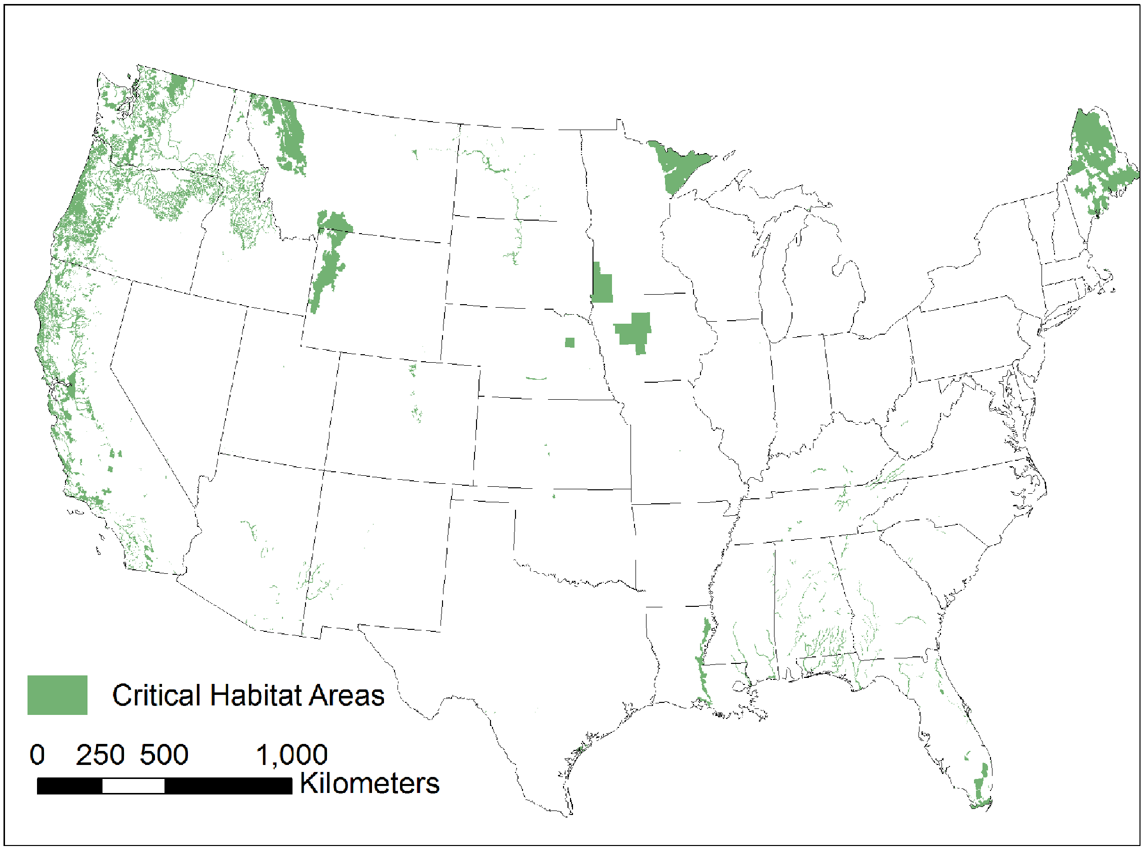

Figure 1: Conterminous U.S. with designated critical habitat areas as of 2013: 314 species with digital shapefiles available for download from http://ecos.fws.gov/crithab/.

First, we describe the species with CH areas and some conditions within these areas. We divide species with CH areas into several cohorts based on the year the species' CH was established (Table 1). We are particularly interested in the cohorts [1985,1994] (class of '92) and [1999,2003] (class of '01) because the establishment of these CH areas overlap the starting years for the two maps of US land-use change that drives our analysis (Appendix A lists these species). We then compare the conditions of the lands in CH to lands in the contiguous US as a whole (Table 2, Figure 2). Interestingly, the two cohorts of interest are quite different on the few metrics presented in Table 2. The earlier cohort, the class of '92, is comprised of much smaller CH areas, which are on poorer soil, more public lands, and in colder areas when compared to the set of CH areas that comprise the class of '01. The CH areas in the most recent cohort were established on better soils and in areas with more private land than pervious CH areas. Was the FWS reluctant to establish these due to the potential for higher economic opportunity costs, or is this difference just a function of the particular species listed? Finally, as presented in Figure 2, the class of '01 generally covers more water than the class of '92. Besides the data on conditions in CH presented immediately below, we also have data on economic, demographic, and political preferences in each CH area as of circa 1990 and 2000.

Despite the regulatory directive, CH is often not designated at the time of listing under the ESA. The majority of species (69%) had a gap between listing and CH establishment. It takes a median of 3.1 (mean = 5.1) years to designate CH for those species with CH areas, with a maximum delay (so far) of 30 years. Typically, land in CH is subject to general ESA regulations *before* any CH-related regulations or increased attention. In fact, in many cases a species' CH area is found in the range of another species that was listed even earlier. Therefore, the gap cited above between listing and CH establishment is an underestimate of the gap between a CH's period of ESA regulations in general and CH regulations in particular.

Table 1: Description of CH areas by their establishment cohort.

		Species type			
CH Cohort	**Total CH areas est.**	**Mammals**	**Birds**	**Herps & fish**	**Plants & Invertebrates**
All	314	20	17	104	173
[1968,1984]	44	4	4	23	13
[1985,1994]	44	4	2	26	12
[1999,2003]	46	2	1	17	26
[2007,2013]	120*	7	8	27	78

*The most recent cohort is much larger mainly due to court orders to establish CH areas. These orders were the result of lawsuits brought by several prominent nonprofits (Owen 2012).

Table 2: Mean (standard deviation) conditions in CH areas relative to the contiguous US by their establishment cohort.

CH Cohort	**CH area (ha)**	**Avg. % of CH in good soils***	**Avg. % of CH in private land**	**Monthly average temperature (C^O) in CH / contiguous US during winter months**	
				1961 to 1990	**1990 to 2009**
All	44,948,566	28.2 (30.2)	59.9 (36.4)	5.04 (5.5)	5.68 (5.5)
[1968,1984]	1,725,033	23.2 (32.9)	48.2 (40.8)	4.65 (6.0)	5.32 (6.0)
[1985,1994]	3,155,104	14.21 (29.5)	46.6 (38.3)	0.77 (4.3)	1.42 (4.4)
[1999,2003]	5,149,948	30.3 (28.7)	62.8 (33.1)	5.14 (5.5)	5.63 (5.6)
[2007,2013]	22,508,244	28.4 (28.7)	64.0 (35.0)	7.25 (5.1)	7.90 (5.2)
Cont. US	782,414,741	45.3	73.3	-0.90 (6.81)	-0.13 (6.82)

*Good soils are those in land capability classes (LCCs) I – IV versus V – VIII (USDA NRCS definitions, see http://www.nrcs.usda.gov/). Winter months are December, January, and February.

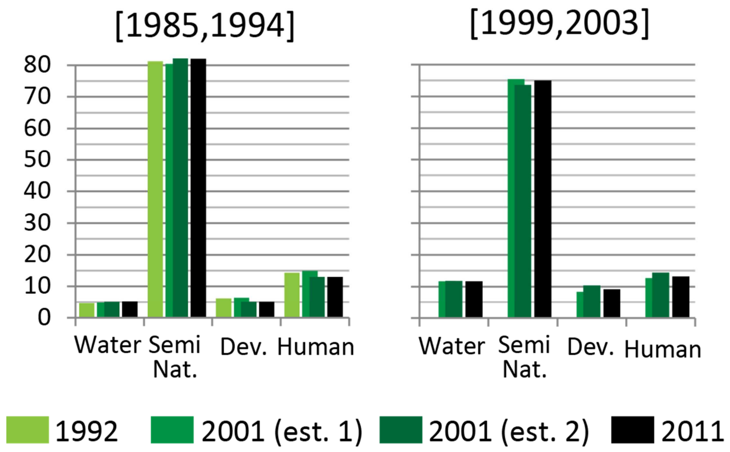

Figure 2: The percentage of the average CH area in different land-cover types in 1992, 2001, and 2011 by CH cohort. Land-cover categories are: water, semi-natural (includes forest, barren, grassland, shrub, and wetland), development (constructed material), and human (development plus agriculture). We do not include 1992 land cover for the second cohort because these were not in CH as of 1992. There are two estimates for 2001; the first is from the 1992-2001 change product and the second is from the 2001-2006 change product. The prevalence of fish in the later cohort can be seen by the higher percentage of water cover in the average CH.

Strengths and weaknesses of the data

All covariate data used to describe CH and control areas (see below) are mapped at the spatial grain of a hectare. However, some of the covariate data has a native resolution of the county level (the BEA and presidential voting data) or from a dataset mapped at 1 km^2 (the population data). NLCD datasets for 1992, 2001, 2006, and 2011 did not use the exact same land cover classifications, and so only the published 1992 to 2001, 2001 to 2006, and 2006 to 2011 "change products" (Fry et al. 2009; Fry et al. 2011; Jin et al. 2013), which have a reduced number of land cover types, should be used for estimating change as we do here.

IV. Identification strategy

Matching methods

Let y_j indicate the rate of land development over time span T in area j on the landscape where j = 1,…J indexes all the possible areas on the landscape. Let y_{1j} indicate the development outcome if area j was treated during time period T (designated as CH or merely in listed species range at the beginning of T) and equal y_{0j} if area j was not treated with CH designation or is out of listed species range during time period T. Let $w_j = 1$ indicate that area j was treated, either with CH or listed range space, and equals 0 otherwise. The average treatment effect on the treated land (ATT) is defined as:

$$\tau_{ATT} = E[y_1 - y_0 | w = 1] \tag{1}$$

In the case of our hypothesis, τ_{ATT} indicates the expected impact of CH designation (the treatment) on development in areas j where $w = 1$. In other words, τ_{ATT} is expected development in CH areas during T less what we could have expected to happen in the treated areas during T if they had never been designated as CH (the counterfactual).

The outcomes y_{0j} and y_{1j} exist for all j during T but we only observe one of them for each j (e.g., either an area is in CH or not during T). If, at the beginning of time period T, we could have assigned CH or listed range space treatment to a random subset of J areas ($w_j = 1$) and assigned no CH treatment or listed species range space to another random subset of J areas ($w_j = 0$) then we could have claimed the sets of observed $\hat{y}_{1j}$ (observed development during T in areas where $w = 1$) and $\hat{y}_{0j}$ (observed development over T in areas where $w = 0$) were statistically independent from the subset of J where $w_j = 1$ and calculated the following,

$$E[y|\ w = 1] = E[y_1|\ w = 1] = E[y_1]; \tag{2}$$

$$\mathrm{E}[y|\ w = 0] = E[y_0|\ w = 0] = E[y_0|\ w = 1] = E[y_0]; \tag{3}$$

and

$$\hat{\tau}_{ATT} = \left(1/\textstyle\sum_{j=1}^{N} w_j\right) \sum_{j=1}^{N} w_j \hat{y}_{1j} - \left(1/\textstyle\sum_{j=1}^{N} 1 - w_j\right) \sum_{j=1}^{N} (1 - w_j) \hat{y}_{0j}\ . \tag{4}$$

where N is the size of the set formed by the union of the treated and control area subsets (Glewwe 2014).

Unfortunately, we are using non-experimental data where w_j is not randomly assigned, but is chosen according to ESA regulations and current scientific knowledge. Consider CH designation. CH will be assigned to areas that are considered vital to imperiled species persistence. There is every reason to expect vitality to be determined by very specific biophysical and land-cover features on the landscape that are not randomly distributed and may or may not be conducive to land development. In addition, regulations allow CH choice to consider economic costs, including the potential cost of prevented or delayed land development. Now consider ESA designation: years of research have documented that ESA listing decisions are not random processes but a function of non-random human activity and political decision-making on the landscape (Easter-Pilcher 1996, Doremus 1997, Waples et al. 2013). In other words, it is very unlikely in both cases that w is statistically independent of y_0 and y_1.

However, we can still identify τ_{ATT} if we make several assumptions. First, assume the regulator's choice of w is strongly influenced by observable vector of landscape variables $\mathbf{x}$. Let this overlap assumption (Rosenbaum and Rubin 1983) be that for all unique $\mathbf{x}$ in the J areas on the US landscape we have $0 < \mathrm{P}[w = 1|\mathbf{x}] < 1$ where $\mathrm{P}[\mathrm{w} = 1|\mathbf{x}]$ is the probability area with characteristics $\mathbf{x}$ is assigned CH or in listed range space. The expression $\mathrm{p(x)} = \mathrm{P}[\mathrm{w} = 1|\mathbf{x}]$ is known as the propensity score. Also, assume that, conditional on the value of each area's $\mathbf{x}$, w is independent of y_0 and y_1. In other words, $\mathrm{E}[y_0|\mathbf{x},\mathrm{w}] = \mathrm{E}[y_0|\mathbf{x}]$ and $\mathrm{E}[y_1|\mathbf{x},\mathrm{w}] = \mathrm{E}[y_1|\mathbf{x}]$. This assumption is known as ignorability of treatment (Rosenbaum and Rubin 1983). The two assumptions together are known as strong ignorability.

There are several methods that use strong ignorability to identify τ_{ATT}. We use so-called matching methods. The basic idea behind matching is to compute "counterfactual" y_0's for each treated area and their observed $\hat{y}_{1j}$'s. We can either find one unique match for each observed $\hat{y}_{1j}$ (one $\hat{y}_{0j}$) or we can find multiple matches for each observed $\hat{y}_{1j}$. If we find multiple matches we have to reduce the multiple values to one representative $\hat{y}_{0j}$ value. In general,

$$\hat{\tau}_{ATT} = (1/K)\sum_{k=1}^{K}\left(\hat{y}_{1k} - \sum_{q\in C(k)} \alpha_{kq}\hat{y}_{0q}\right) \tag{5}$$

where $k = 1,\ldots,K$ indexes all the CH or listed species range areas on the landscape at the beginning of time period T, $q = 1,\ldots,Q$ indexes all the possible counterfactual areas on the landscape, $\hat{y}_{0q}$ is a "counterfactual" outcome, $C(k)$ is the set of k's set matched "counterfactual" outcomes, and α_{kq} is the fractional weight of matched "counterfactual" outcome $\hat{y}_{0q}$. If we find one unique match for each observed $\hat{y}_{1k}$ then the set $C(k)$ only has one member and $\alpha_{kq} = 1$. If we find multiple matches for each treated area on the landscape then $C(k)$ has two or more members, $\alpha_{kq} < 1$ for all q, and $\sum_{q\in C(k)} \alpha_{kq} = 1$.

One method for finding match(s) for each observed $\hat{y}_{1k}$ is to use the Mahalanobis distance where the character distance between k and some q is,

$$d(\mathbf{x}_q, \mathbf{x}_k) = \left[(\mathbf{x}_q - \mathbf{x}_k)'\boldsymbol{\Sigma}_{\mathbf{x}}^{-1}(\mathbf{x}_q - \mathbf{x}_k)\right]^{0.5} \tag{6}$$

where $\boldsymbol{\Sigma}_{\mathbf{x}}^{-1}$ is the sample $R\times R$ covariance matrix of **x** with length R (Glewwe 2014) If we are using a unique match we assign to $\hat{y}_{1k}$ the $\hat{y}_{0q}$ associated with the $\mathbf{x}_q$ that minimizes $d(\mathbf{x}_q, \mathbf{x}_k)$. If the size of $C(k)$ equals Z we assign to $\hat{y}_{1k}$ the set of $\hat{y}_{0q}$'s associated with the $\mathbf{x}_q$'s that have the Z smallest $d(\mathbf{x}_q, \mathbf{x}_k)$ values where $\alpha_{kq} = 1/Z$ for each q. Assuming we conduct this matching with replacement, one q can be matched to more than one k.

We can also use the propensity score to find "counterfactual" outcomes to match with the treated outcomes. If we use the nearest neighbor match with replacement algorithm, then each k is assigned the q that minimizes $\left\| p(\mathbf{x}_q) - p(\mathbf{x}_k)\right\|$. Again, more than one k can be matched with the same q. The function $p(x) = P[w = 1|\mathbf{x}]$ is typically estimated with a probit or logit model.

The key to identifying $\hat{\tau}_{ATT}$ is constructing an **x** such that the means of the covariates in the matched areas on the landscape are essentially no different than the means of the covariates in the treated areas (in this case the covariates are "balanced" across the treated and matched areas). Balance is more likely if the construction of **x** follows these guidelines:

- Only variables that simultaneously influence treatment status and the outcome variable should be included (see e.g. Sianesi 2004 and Smith and Todd 2005)
- Only variables that are unaffected by treatment should be included in the model. To ensure this, variables should either be fixed over time or measured before participation.

Once **x** is constructed and $p(\mathbf{x}_q)$ and $p(\mathbf{x}_k)$ are estimated for all q and k, we may need to throw out the k whose minimal norm $\|p(\mathbf{x}_q) - p(\mathbf{x}_k)\|$ is greater than some tolerance level δ to balance the covariates (caliper matching; Cochran and Rubin 1973). In addition, variables that are not well-balanced can be improved on this metric by including higher order terms of the variable and/or interactions between the covariates in the explanatory variable matrix **x** (guidelines in Caliendo and Kopeining 2008 and Dehejia and Wahba 1999).

*Constructing **x** for our hypothesis*

Let us consider the **x** that we will use to test our hypothesis. Here we are only considering areas, both treated and untreated, that are in listed species range space at the beginning of *T*. Therefore, **x** should only include variables that we believe simultaneously influence whether CH is applied to an area within listed range space and the outcome variable within the CH areas. First and foremost, the mix of land cover within listed range space areas at the beginning of *T* will affect treatment status and the outcome variable. Habitat vital to a listed species persistence can only be fulfilled by certain land-cover mixes in its range and therefore, treatment choices will be affected by its presence. Furthermore, development rates in an area are a function of the mix of land cover present at the beginning of the period and the potential value of land that could emerge in the area. For example, housing and cropland development will be more profitable in dry grasslands versus wet marshes. Further, areas in counties with high urban values are more likely to be developed than areas in low value counties. Biophysical conditions in an area are also important determinants in defining the most vital habitat areas (e.g., species prefer certain temperature and elevation niches) and development rates in an area (e.g., people prefer to live in temperate areas that are not too high in elevation or difficult to access). Economic issues will also effect both treatment decisions and outcomes as well. Regulators may avoid establishing CH in areas where opportunity costs from conservation will be high. Development is more likely in areas that have significant economic activity and are close to supporting infrastructure. Finally, political preferences across the landscape may affect both CH location and development outcomes. For example, regulators may avoid placing CH in areas with voters who tend to find the land regulation portion of the CH regulations most objectionable.

Finally, the year that an area was first included in *any* listed species' range, not just the species for which the CH was designated, is also part of **x**. We include this covariate for two reasons. First, as described above there is typically a delay between listing and the establishment of CH. Therefore, this variable will affect the probability that an area will be placed in CH. In addition, by including this variable we construct a control set of polygons that have been under ESA regulation, on average, as long as areas that become CH at time *T*. This minimizes the portion of $\hat{\tau}_{ATT}$ that can be explained by the amount of time spent subject to ESA regulation.

Table 3: Covariates that can be included in the **x** vector.

Covariate category	**For each area *k* and *q* on the landscape we have the following data**	**Sources**
Land cover	For the years 1992, 2001, 2006, and 2011: 1. Hectares in open water 2. Hectares in developed (areas with a mixture of constructed materials and vegetation; ranges from low to high intensity of constructed materials) 3. Hectares in barren 4. Hectares in forest 5. Hectares in grassland/shrub 6. Hectares in agriculture 7. Hectares in wetlands 8. Hectares in other	Fry et al. 2009; Fry et al. 2011; Jin et al. 2013.
Biophysical conditions	9. Average elevation (m) 10. 1961 to 1990 and 1990 to 2009 average annual precipitation (inches) 11. 1961 to 1990 and 1990 to 2009 monthly average temp (d C) during Dec., Jan., & Feb. 12. Percentage of area in land capability classification (LCC) 1-4 (the best) 13. Percentage of area in land capability classification (LCC) 5-8 (the worst) (Table 3 continues)	Gesch 2007; Gesch et al. 2002; PRISM Climate Group 2014; Kalnay et al. 1996; Radeloff et al. 2012.

Covariate category	**For each area *k* and *q* on the landscape we have the following data**	**Sources**
Economic conditions	14. 1990 population (people per ha) 15. 2000 population (people per ha) 16. 1980 per capita income (in 1980 $) 17. 1990 per capita income (in 1990 $) 18. 2000 per capita Income (in 2000 $) 19. 1980 jobs per 100 people 20. 1990 jobs per 100 people 21. 2000 jobs per 100 people 22. 1980 wage per job (in 1980 $) 23. 1990 wage per job (in 1990 $) 24. 2000 wage per job (in 2000 $) 25. Lot price per acre for recently developed parcels in host county (1990 – 1997 average) 26. cropland land cost in $/acre (1997)	National Atlas of the United States 2006; Seirup and Yetman 2006; Seirup et al. 2012; Withey et al. 2012
Political preferences	27. 1992 Clinton votes (Votes per ha) 28. 1992 non-Clinton votes (Votes per ha) 29. 2000 Gore votes (Votes per ha); and 30. 2000 non-Gore votes (Votes per ha)	Leip 2014
ESA listing	31. First year the area was in one or more listed species' range.	NatureServe 2014

As noted above, is also recommended that variables in **x** should either be fixed over time or measured before participation (i.e., at or near the beginning of *T*). Given that much of our covariate data, particularly the land cover data, is from the early 1990s and the early 2000s, we are limited to estimating treatment effects for CH areas that were established circa 1990 (between 1985 and 1994) and circa 2000 (between 1995 and 2004).[5] In each case, the effect of CH treatment on land development rates is observed until 2011 (i.e., $\hat{\tau}_{ATT,92-11}$ and $\hat{\tau}_{ATT,01-11}$). The potential match areas, $q_{92-11} = 1,\ldots,Q_{92-11}$, for estimating $\hat{\tau}_{ATT,92-11}$ are randomly selected from listed species ranges for species that were listed from 1975 to 1995. We also verified that no portion of any q_{92-11} has ever been part of CH area. The potential match areas, $q_{01-11} = 1,\ldots,Q_{01-11}$, for estimating $\hat{\tau}_{ATT,01-11}$ are randomly selected from listed species ranges for species that were listed from 1975 to 2004. Again we verified that no portion of any q_{01-11} has ever been CH area.

Finally, the covariates in $\mathbf{x}_{92\text{-}11}$ include all the 1992 land cover data; all the biophysical data; the 1990 population, income, wage, and job data; and the 1992 vote data. The covariates in $\mathbf{x}_{01\text{-}11}$ include all the 2001 land cover data; all the biophysical data; the 2000 population, income, wage, and job data; and the 2000 vote data. As recommended by the matching literature, we experimented with including higher order terms and interactions between the covariates in $\mathbf{x}_{92\text{-}11}$ and $\mathbf{x}_{01\text{-}11}$.

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[5] See Appendix A for the list of species that had CH established circa 1992 and 2001.

In order to put the results from our matching analysis into some context we did the following. First, we took 44 random draws from the statistical distribution $\hat{\tau}_{ATT,92-01,dev}$ as determined by one-to-one matching (we assume the distribution of $\hat{\tau}_{ATT,92-01,dev}$ is normal). Then we assigned each of the random draws of $\hat{\tau}_{ATT,92-01,dev}$ to a CH *k* = 1,…,44 in the class of 1992 and calculated the following for each *k*,

$$V_{k,92-01,dev} = A_k\left(\hat{\tau}_{ATT,92-01,dev}/100\right)\left(2.471 Value_{urban,k}\right) \tag{7}$$

where $V_{k,92-01,dev}$ indicates the additional urban value created by CH treatment as of 2001 in CH *k*, A_k is the area of CH *k* in hectares, $Value_{urban,k}$ is the lot price per acre for recently developed parcels across the years 1990 to 1997 in CH *k* (in 1997 dollars), and the 2.471 constant converts value per acre into value per hectare. $V_{92-01,dev} = \sum_{k=1}^{44} V_{k,92-01,dev}$ indicates the additional urban value created by CH treatment by the end of 2001 across the entire class of 1992. We calculated $V_{92-01,dev}$ 1000 times, each time with a new set of random draws from the statistical distribution $\hat{\tau}_{ATT,92-01,dev}$ as determined by one-to-one matching. We repeated this entire process with the statistical distribution $\hat{\tau}_{ATT,92-01,dev}$ as determined by nearest neighbor matching and again with the statistical distribution $\hat{\tau}_{ATT,92-01,dev}$ as determined by Mahalanobis Calibration. Therefore, in the end we have a vector of 3000 $V_{92-01,dev}$ estimates. We use the same methodology to create a vector of 3000 $V_{92-01,ag}$ estimates where $Value_{ag,k}$ is given by the average of cropland land cost and pasture land cost per acre in 1997 ($1997 $) in CH *k* and $V_{92-01,ag}$ indicates the additional agricultural value created by CH treatment as of 2001 across the class of 1992 CH areas. Finally, we create 3000 estimates of $V_{01-11,dev}$ and $V_{01-11,ag}$ for the class of 1992 again using $Value_{urban,k}$ and $Value_{ag,k}$ as inputs. $V_{01-11,dev}$ and $V_{01-11,ag}$ for the class of 1992 indicate the additional urban and agricultural value, respectively, created in class of 1992 CH areas from 2001 to 2011 due to CH treatment.

We also created vectors of 3000 simulations of $V_{01-11,dev}$ and $V_{01-11,ag}$ for the class of 2001, indexed by *j* = 1,…,42. In these simulations we use $Value_{dev,j}$, the lot price per acre for recently developed parcels across the years 1990 to 1997 in CH *j* (in 1997 dollars), and $Value_{ag,j}$, the average of cropland land cost and pasture land cost per acre in 1997 in CH *j* as inputs. $V_{01-11,dev}$, and $V_{01-11,ag}$ indicate the additional urban and agricultural value, respectively, created in class of 2001 CH areas from 2001 to 2011 due to CH treatment.

V. Model Results

Critical Habitat designated 1985-1994

In Table 4 we give the average percentage change in developed (*dev*) land in CH areas less the average percentage change in developed land in the control polygon group from 1992 to 2001. A positive value means that land-development rates were *greater* in CH areas than in control areas, while a negative value means that land-development rates were *smaller* in CH areas than in controls.[6] Here we present results using 3 different matching techniques for the class of 1992 CH areas.

As an example of how to read the key results of these tables: suppose the average change in developed land in "class of 1992" CH areas from 1992 to 2001 was 2.5% (the area of developed land in a class of 1992 CH increased, on average, by 2.5%). Further, suppose the average change in developed land in the control set from 1992 to 2001 was 2% (the area of developed land in a control polygon increased, on average, by 2%). Then, $\hat{\tau}_{ATT,92-01,Dev} = 0.5$.

Table 4: The difference in percentage change in **developed land** in CH areas versus non-CH areas between 1992 and 2001. CH areas used are class of 1992.

							On support	
Matching Technique	$\hat{\tau}_{ATT,92-01,dev}$	**mean bias***	**se**	**-2 x se**	**2 x se**	**t stat**	**CH areas**	**Matches**
One to One	0.27	8.05	0.32	-0.36	0.91	0.86	39	1303
Nearest Neigh. (3)	0.22	3.61	0.31	-0.40	0.84	0.70	37	1303
Mahalanobis Cal. (4)	0.16	4.10	0.42	-0.68	1.00	0.39	30	1303

***The standardized bias should be less than 5% after matching (Rosenbaum and Rubin 1985). At 5% or less the covariates are well balanced and a good control group has been built.

In Table 5 we compare *dev* rates in the class of 1992 to their control set (selected according to circa 1992 conditions) from 2001 to 2011. In other words, what is the effect of the second decade of CH designation on land development? The negative values mean that development rates are lower in the class of 1992 CH areas compared to their matched control polygons.

Table 5: The difference in percentage change in **developed land** in CH areas versus non-CH areas between 2001 and 2011. CH areas used are class of 1992.

							On support	
Matching Technique	$\hat{\tau}_{ATT,01-11,Dev}$	**mean bias**	**SE**	**-2 x se**	**2 x se**	**t stat**	**CH areas**	**Matches**
One to One	-0.07	8.05	0.21	-0.49	0.34	-0.37	39	1303
Nearest Neigh. (3)	-0.11	3.61	0.16	-0.43	0.21	-0.67	37	1303
Mahalanobis Cal. (4)	-0.26	4.10	0.22	-0.69	0.18	-1.18	30	1303

The lack of statistically significant $\hat{\tau}_{ATT,92-01,Dev}$ estimates may be due to small number of CH areas in the class of 1992 (of the 314 CH areas, only 44 were established from 1985 to 1993).

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[6] The denominator in the percentage calculations is the area of the entire CH or control polygon. We use this denominator instead of area in the land use type in the base year to avoid any infinite percentages (e.g., a CH area goes from 0 developed hectares in 1992 to 100 developed hectares by 2011).

In Tables 6 and 7, we provide the average percentage change in agricultural land (*ag*) in class of 1992 CH areas less the average percentage change in agricultural land in the control polygons. Table 6 shows change from 1992 to 2001 and Table 7 shows change from 2001 to 2011.

Table 6: The difference in percentage change in **agricultural land** in CH areas versus non-CH areas between 1992 and 2001. CH areas used are class of 1992.

							On support	
Matching Technique	$\hat{\tau}_{ATT,92-01,ag}$	**mean bias**	**se**	**-2 x se**	**2 x se**	**t stat**	**CH areas**	**Matches**
One to One	0.53	8.05	0.42	-0.31	1.36	1.26	39	1303
Nearest Neigh. (3)	0.44	3.61	0.32	-0.20	1.08	1.39	37	1303
Mahalanobis Cal. (4)	0.56	4.10	0.35	-0.13	1.25	1.63	30	1303

Table 7: The difference in percentage change in **agricultural land** in CH areas versus non-CH areas between 2001 and 2011. CH areas used are class of 1992.

							On support	
Matching Technique	$\hat{\tau}_{ATT,01-11,ag}$	**mean bias**	**se**	**-2 x se**	**2 x se**	**t stat**	**CH areas**	**Matches**
One to One	-0.44	8.05	0.75	-1.93	1.06	-0.58	39	1303
Nearest Neigh. (3)	0.23	3.61	0.14	-0.05	0.50	1.65	37	1303
Mahalanobis Cal. (4)	0.39	4.10	0.30	-0.22	1.00	1.29	30	1303

The development of, or potentially reduced conversion of, agricultural lands is greater in CH areas, especially in the first decade of CH designation, than in matched control areas ($\hat{\tau}_{ATT,92-01,Ag} > 0$ and $\hat{\tau}_{ATT,02-11,Ag} > 0$).[7]

In Tables 9 and 10 we provide the average percentage change in semi-natural land (*nat*) land (as previously defined this includes forest, barren, grassland, shrub, and wetlands) in CH areas less the average percentage change in semi-natural cover in selected control polygons. Table 9 shows change from 1992 to 2001 and Table 10 shows change from 2001 to 2011.

Table 9: The difference in percentage change in **semi-natural land cover** in CH areas versus non-CH areas between 1992 and 2001. CH areas used are class of 1992.

							On support	
Matching Technique	$\hat{\tau}_{ATT,92-01,Nat}$	**mean bias**	**se**	**-2 x se**	**2 x se**	**t stat**	**CH areas**	**Matches**
One to One	-0.88	8.05	0.51	-1.90	0.14	-1.73	39	1303
Nearest Neigh. (3)	-0.68	3.61	0.43	-1.55	0.18	-1.58	37	1303
Mahalanobis Cal. (4)	-0.88	4.10	0.51	-1.90	0.13	-1.74	30	1303

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[7] For example, if the CH areas on average lost 0.5% and the control areas on average lost 1% then $\hat{\tau}_{ATT,92-01,Ag} = 0.5$.

Table 10: The difference in percentage change in in **semi-natural land cover** in CH areas versus non-CH areas between 2001 and 2011. CH areas used are class of 1992.

Matching Technique	$\hat{\tau}_{ATT,01-11,Nat}$	**mean bias**	**se**	**-2 x se**	**2 x se**	**t stat**	**On support**	
							CH areas	**Matches**
One to One	-0.06	8.05	1.07	-2.19	2.08	-0.05	39	1303
Nearest Neigh. (3)	-0.23	3.61	0.21	-0.65	0.19	-1.08	37	1303
Mahalanobis Cal. (4)	-0.76	4.10	1.09	-2.94	1.41	-0.70	30	1303

Given the higher rates of land development and agriculture cover retention in CH areas it is not surprising to see that CH areas lost semi-natural cover at a greater rate than their control set.

Critical Habitat designated 1997-2003

In Tables 11-13 we give the average percentage change in developed, agricultural, and semi-natural land cover in class of 2001 CH areas (designated 1997 to 2003) less the average percentage changes in their control set. As before, a positive (negative) value means that land-use change rates for a given land cover were *greater* (smaller) in CH areas than control areas. Here we present results using 4 different matching techniques for the class of 2001 CH areas.

Table 11: The difference in percentage change in **developed land** in CH areas versus non-CH areas between 2001 and 2011. CH areas used are class of 2001.

Matching Technique	$\hat{\tau}_{ATT,01-11,dev}$	**mean bias**	**se**	**-2 x se**	**2 x se**	**t stat**	**On support**	
							CH areas	**Matches**
One to One	-0.25	12.18	0.47	-1.19	0.70	-0.52	32	1309
Nearest Neigh. (3)	-0.02	8.38	0.28	-0.58	0.54	-0.08	32	1309
Caliper (0.2) (3 N)	-0.15	8.49	0.38	-0.92	0.62	-0.40	33	1309
Mahalanobis Cal. (2)	-0.11	4.23	0.27	-0.65	0.44	-0.39	11	1309

Table 12: The difference in percentage change in **agricultural land** in CH areas versus non-CH areas between 2001 and 2011. CH areas used are class of 2001.

Matching Technique	$\hat{\tau}_{ATT,01-11,ag}$	**mean bias**	**se**	**-2 x se**	**2 x se**	**t stat**	**On support**	
							CH areas	**Matches**
One to One	0.11	12.18	0.26	-0.42	0.64	0.42	32	1309
Nearest Neigh. (3)	-0.02	8.38	0.20	-0.42	0.37	-0.13	32	1309
Caliper (0.2) (3 N)	0.04	8.49	0.17	-0.30	0.38	0.22	33	1309
Mahalanobis Cal. (2)	0.20	4.23	0.19	-0.19	0.59	1.02	11	1309

Table 13: The difference in percentage change in semi-natural cover in CH areas versus non-CH areas between 2001 and 2011. CH areas used are class of 2001.

Matching Technique	$\hat{\tau}_{ATT,01-11,nat}$	**mean bias**	**se**	**-2 x se**	**2 x se**	**t stat**	**On support**	
							CH areas	**Matches**
One to One	0.52	12.18	0.93	-1.34	2.39	0.56	32	1309
Nearest Neigh. (3)	0.60	8.38	0.85	-1.10	2.30	0.71	32	1309
Caliper (0.2) (3 N)	1.13	8.49	1.16	-1.18	3.44	0.98	33	1309
Mahalanobis Cal. (2)	-0.15	5.08	0.39	-0.92	0.63	-0.38	11	1309

Unlike the class of 1992, CH designation for the class of 2001 created less development (albeit not statistically different from 0) and greater natural cover retention when compared to their control group. The *t* statistics of the class of 2001's $\hat{\tau}_{ATT,01-11,z}$ measures are generally smaller than those for the class of 1992.

Land Value based on changes in Critical Habitat areas

As we suggested above, CH treatment appears to have accelerated land development in class of 1992 areas (area to the right of 0 in Figure 3 for 1992-2001) rather than permanently increasing such development. The class of 1992's control set had largely matched the class of 1992's value of development by the end of the second decade of treatment. Conversely for the set of CH areas established circa 2001, treatment has appeared to prevent some gains in land development value that would otherwise be expected.

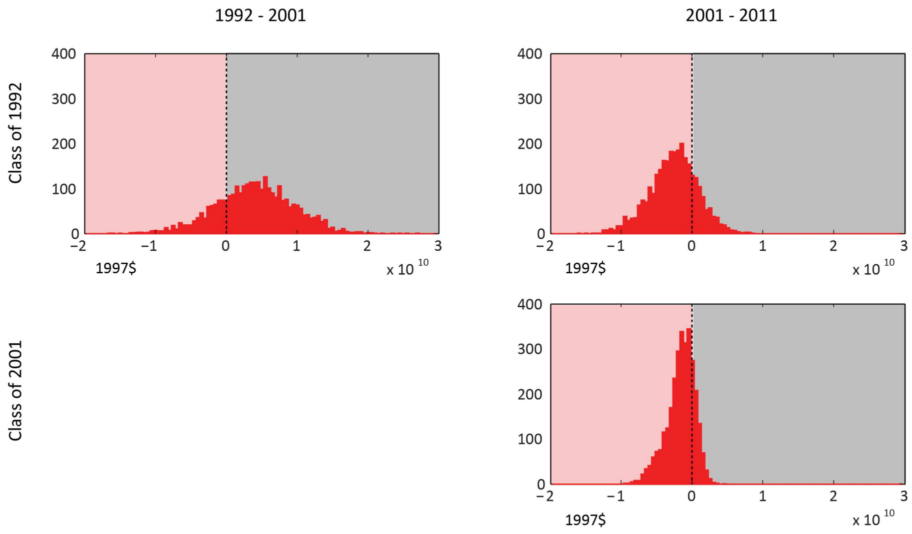

Figure 3: Histograms of $V_{92-01,dev}$ and $V_{01-11,dev}$ for class of 1992 CH and $V_{01-11,dev}$ for class of 2001 CH.

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Critical habitat treatment encourages the maintenance or even the expansion of agricultural value on the landscape (Figure 4). Both classes of CH had more agricultural value than expected by the end of the first decade of treatment. There is weak evidence to suggest that the gap in agricultural land value between the treated and control group grew even more in the second decade of treatment for the class of 1992.

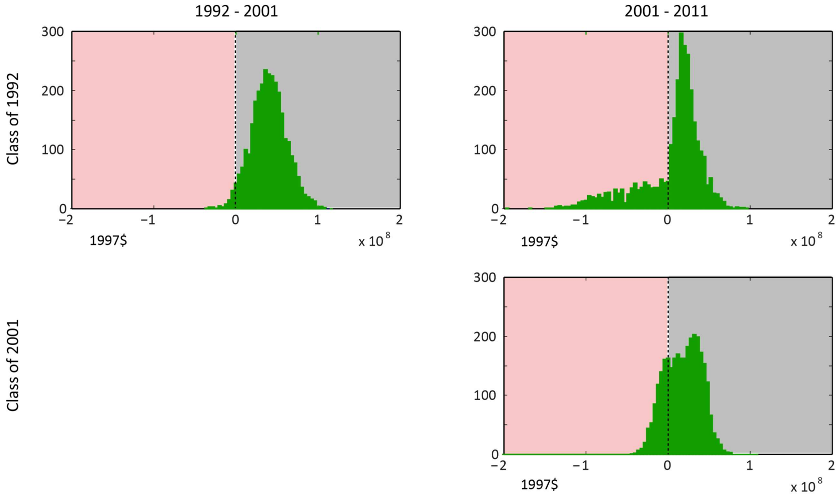

Figure 4: Histograms of $V_{92-01,ag}$ and $V_{01-11,ag}$ for class of 1992 CH and $V_{01-11,ag}$ for class of 2001 CH.

Between 2007 and 2013, 120 more CH areas were established. What impact will CH treatment have on land use and land-use value in these areas between 2011 and 2020? To investigate possible impacts we first assume that the class of 2011 will have a first decade similar to that of the class of 1992. Then we assume the class of 2011 will have a decadal experience similar to the experience of the class of 2001. These projections are summarized in histograms constructed in the manner described in the Methods.

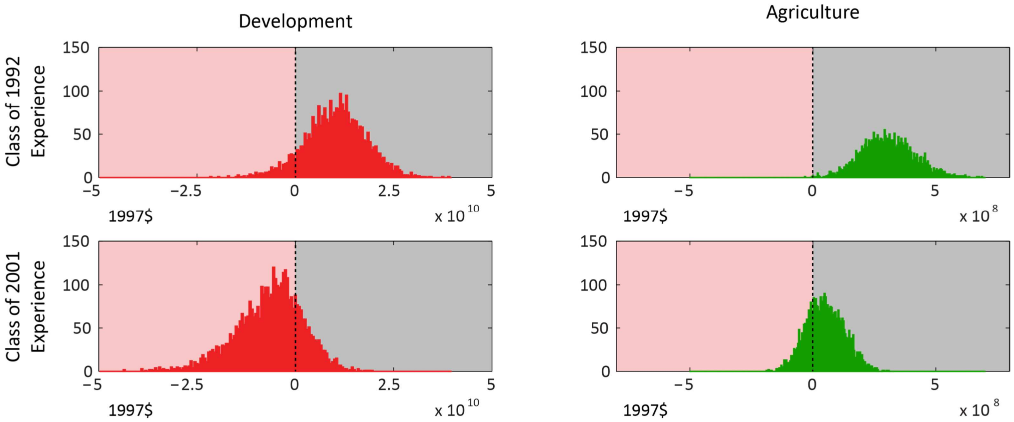

Figure 5: Expected histograms of $V_{11-21,dev}$ and $V_{11-21,ag}$ for class of 2011 CH.

There is a clear distinction between what would be expected by 2020 in increased development value and agricultural lands value based on the class of 1992 experience (i.e. during the 1992-2001 period) compared to the class of 2001 experience (2001-2011; Figure 5).

Uncertainties

Although we have digital critical habitat maps for 314 species, in order to assess land-use change during the periods 1992-2001 and 2001-2011 (years of the National Land Cover Database) we were limited to 44 species with CH established circa 1992 and 46 with CH established circa 2001 (Table 1, Appendix A). At the level of the contiguous US we do not currently have land-use change datasets available to assess change prior to 1992. These subsets of species with CH areas have more fishes and fewer invertebrate species than the full set of species with CH areas.

VI. Comparison with agency projections in its RIA

The ESA does not have a formal Regulatory Impact Analysis overall. Economic impact analyses have been conducted for a majority of critical habitat designations in our dataset (223 of 314, or 71%), especially those completed more recently (95% of designations since 2001 have an EA). However, the methods of these EAs varies widely: some consider only additional administrative costs and consultation expenses, whereas others include estimates of foregone development (residential and/or industrial), which may not be specific to the CH designation, as opposed to listing itself. As a result, estimates of economic impacts vary from $0 (8 species) to over $20M annually (several species including the bull trout, Arroyo toad, and California gnatcatcher). A revision to the ESA that requires an economic analysis to be published at the time of a *proposed* critical habitat designation went into effect on October 30, 2013.

VII. Discussion & Conclusions

Lessons learned

Our overarching hypothesis, that land-conversion rates (to developed and/or agricultural lands) would be lower in critical habitat areas compared to control areas within listed species' ranges, was not supported overall, and in fact critical habitat designation does not appear to have strong impacts on land use change. Our measure of the rates of change ($\hat{\tau}_{ATT}$ values) were not different than 0 (with $\alpha = 0.05$). The direction in the rates of change to developed (Table 4) and to agriculture (Table 6) was *higher* for CH areas in the period 1992 to 2001 compared to their control areas. This set of results gives limited support for a "shoot, shovel, and shut-up" or pre-emptive development dynamic: landowners in newly established CH areas may have developed more quickly than they would have otherwise to avoid any potential conflicts with the CH regulations in particular and ESA regulations in general. Although most of these areas would have been subject to ESA regulations already (due to typical delays of ~3 years between listing and CH designation), recall that CH maps are one of the few ways that a landowner can know for sure that their land is in a listed species' range.

However, these results did not continue through the period 2001 to 2011, both for CH areas designated circa 1992 and circa 2001. For both 'classes' of CH areas the trend was for slightly less development (Table 5, Table 11) and somewhat more agricultural development

(Table 7, Table 12), but with somewhat smaller effect sizes and/or mixed results depending on the matching technique. Still, there is some support to say that CH designation has promoted agricultural development or perhaps alternatively, helped prevent greater conversion compared to control areas.

One explanation for the difference in results from the 1992-2001 period to the 2001-2011 period is that the class of 1992 was in its second decade after establishment, whereas the class of 2001 was in its first. However, when we compare the first decades for both classes, we do not see any evidence of pre-emptive development in the class of 2001. The first decade for the class of 2001 included a major economic recession in the US, which may have frozen land development everywhere.

In this study we make no claims regarding the social efficiency of the CH rule or the ESA in general. We cannot determine if any additional costs generated in CH areas are less than the additional benefits generated by the program. The existence and nonuse values generated by preventing the extinction of biodiversity can be very large (Richardson and Loomis 2009), although monetary values placed on conserving nature have been criticized as highly arbitrary (Ackerman and Heinzerling 2002).

Conclusions

- Section 7 and 9 of the ESA do not appear to be more heavily applied in lands designated as critical habitat areas versus lands within listed species' ranges, but without critical habitat designation.
- There does not appear to be any extraordinary conservation activity in critical habitat areas; for example, environmental non-profits and land trusts do not appear to be concentrating activity in these areas.
- Any critical habitat regulations that go above and beyond sections 7 and 9 of the ESA do not appear to be affecting land use in critical habitat areas.
- Land management within critical habitat areas may be affected and will be examined in further research.

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Appendix A: Species used for matching analysis results in 'class of '92' and 'class of '01'

Table A.1: Critical habitat established 1985-1994 (class of '92)

Common Name	**Scientific Name (subpop or status)**	**CH Year**
Alabama beach mouse	*Peromyscus polionotus ammobates*	1985
Ash Meadows blazingstar	*Mentzelia leucophylla*	1985
Ash Meadows gumplant	*Grindelia fraxinipratensis*	1985
Ash Meadows ivesia	*Ivesia kingii* var. *eremica*	1985
Ash meadows milk-vetch	*Astragalus phoenix*	1985
Ash Meadows naucorid	*Ambrysus amargosus*	1985
Ash Meadows sunray	*Enceliopsis nudicaulis* var. *corrugate*	1985
Amargosa niterwort	*Nitrophila mohavensis*	1985
Amber darter	*Percina antesella*	1985
Large-flowered fiddleneck	*Amsinckia grandiflora*	1985
Big Spring spinedace	*Lepidomeda mollispinis pratensis*	1985
Conasauga logperch	*Percina jenkinsi*	1985
Desert dace	*Eremichthys acros*	1985
Fresno kangaroo rat	*Dipodomys nitratoides exilis*	1985
Hiko White River springfish	*Crenichthys baileyi grandis*	1985
Modoc Sucker	*Catostomus microps*	1985
Navajo sedge	*Carex specuicola*	1985
Niangua darter	*Etheostoma nianguae*	1985
Owens tui chub	*Gila bicolor snyderi*	1985
Spring-loving centaury	*Centaurium namophilum*	1985
Warner sucker	*Catostomus warnerensis*	1985
White River springfish	*Crenichthys baileyi baileyi*	1985
White River spinedace	*Lepidomeda albivallis*	1985
Desert pupfish	*Cyprinodon macularius*	1986
Desert pupfish	*Cyprinodon macularius*	1986
June sucker	*Chasmistes liorus*	1986
Railroad Valley springfish	*Crenichthys nevadae*	1986
Sonora chub	*Gila ditaenia*	1986
Cape Fear shiner	*Notropis mekistocholas*	1987
Heliotrope milk-vetch	*Astragalus montii*	1987
Inyo California towhee	*Pipilo crissalis eremophilus*	1987
Little Colorado spinedace	*Lepidomeda vittata*	1987
Pecos bluntnose shiner	*Notropis simus pecosensis*	1987
Waccamaw silverside	*Menidia extensa*	1987
Welsh's milkweed	*Asclepias welshii*	1987
Mount Graham red squirrel	*Tamiasciurus hudsonicus grahamensis*	1990

Common Name	**Scientific Name (subpop or status)**	**CH Year**
Rice rat	*Oryzomys palustris* (pop 3)	1993
Bonytail chub	*Gila elegans*	1994
Colorado pikeminnow (=squawfish)	*Ptychocheilus lucius*	1994
Desert tortoise	*Gopherus agassizii* (T)	1994
Delta smelt	*Hypomesus transpacificus*	1994
Humpback chub	*Gila cypha*	1994
Least Bell's vireo	*Vireo bellii pusillus*	1994
Razorback sucker	*Xyrauchen texanus*	1994

Table A.2: Critical habitat established 1999-2003 (class of '01)

Common Name	**Scientific Name (subpop or status)**	**CH Year**
Huachuca water-umbel	*Lilaeopsis schaffneriana* var. *recurva*	1999
Steller sea-lion	*Eumetopias jubatus* (T)	1999
Alameda whipsnake (=striped racer)	*Masticophis lateralis euryxanthus*	2000
Chinook salmon	*Oncorhynchus tshawytscha* (LowColRiver)	2000
Chinook salmon	*Oncorhynchus tshawytscha* (Pug. Sound)	2000
Chinook salmon	*Oncorhynchus tshawytscha* (WA)	2000
Chinook salmon	*Oncorhynchus tshawytscha* (Willamette)	2000
Chum salmon	*Oncorhynchus keta* (OR-WA)	2000
Chum salmon	*Oncorhynchus keta* (WA)	2000
Johnson's seagrass	*Halophila johnsonii*	2000
Sockeye salmon	*Oncorhynchus nerka* (Ozette Lake)	2000
Steelhead	*Oncorhynchus mykiss* (Columbia R.)	2000
Steelhead	*Oncorhynchus mykiss* (OR-WA)	2000
Steelhead	*Oncorhynchus mykiss* (Snake R.)	2000
Steelhead	*Oncorhynchus mykiss* (WA)	2000
Steelhead	*Oncorhynchus mykiss* (Willamette R.)	2000
Virgin River Chub	*Gila seminuda*	2000
Woundfin	*Plagopterus argentissimus* (E)	2000
Zapata bladderpod	*Lesquerella thamnophila*	2000
Wenatchee Mountains checkermallow	*Sidalcea oregana* var. *calva*	2001
Morro shoulderband (=Banded dune) snail	*Helminthoglypta walkeriana*	2001
Piping Plover	*Charadrius melodus* (E)	2001
Spruce-fir moss spider	*Microhexura montivaga*	2001

Common Name	**Scientific Name (subpop or status)**	**CH Year**
Zayante band-winged grasshopper	*Trimerotropis infantilis*	2001
Spineflower, Scotts Valley	*Chorizanthe robusta* var. *hartwegii*	2001
Appalachian elktoe	*Alasmidonta raveneliana*	2002
Cushenbury milk-vetch	*Astragalus albens*	2002
Carolina heelsplitter	*Lasmigona decorate*	2002
Purple amole	*Chlorogalum purpureum*	2002
Purple amole	*Chlorogalum purpureum*	2002
Otay tarplant	*Deinandra (=Hemizonia) conjugens*	2002
Gaviota Tarplant	*Deinandra increscens* ssp. *villosa*	2002
Lompoc yerba santa	*Eriodictyon capitatum*	2002
Cushenbury buckwheat	*Eriogonum ovalifolium* var. *vineum*	2002
Parish's daisy	*Erigeron parishii*	2002
Santa Cruz tarplant	*Holocarpha macradenia*	2002
San Bernardino Mountains bladderpod	*Lesquerella kingii* ssp. *bernardina*	2002
Cushenbury oxytheca	*Oxytheca parishii* var. *goodmaniana*	2002
Kneeland Prairie penny-cress	*Thlaspi californicum*	2002
San Bernardino Merriam's kangaroo rat	*Dipodomys merriami parvus*	2002
Baker's larkspur	*Delphinium bakeri*	2003
Yellow larkspur	*Delphinium luteum*	2003
Gulf sturgeon	*Acipenser oxyrinchus desotoi*	2003
Rio Grande silvery minnow	*Hybognathus amarus* (E)	2003
Keck's Checker-mallow	*Sidalcea keckii*	2003
Scotts Valley Polygonum	*Polygonum hickmanii*	2003