The Perils of Shortcuts in Efficient Conservation Portfolio Design

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1. Introduction

A large body of sophisticated work has developed methods for cost-effective conservation reserve site planning. However, modern conservation planning tools require the planner to have information about spatial distributions of conservation costs and benefits. Climate change creates unprecedented uncertainty about future land values and species habitat ranges, such that conservation scientists cannot map costs and benefits with certainty anymore. Ando and Mallory (2012) pioneered the use of Modern Portfolio Theory (MPT) for spatial conservation planning, showing how this methodology from finance can be used to choose portfolios of land for conservation that reduce overall uncertainty about the benefits that will flow from future reserves. This tool is promising, but extensive data are needed to carry out an MPT analysis correctly. Conservation planners might in practice face data or time limitations that make shortcuts tempting. This paper further develops the MPT approach to conservation planning in the face of climate uncertainty by demonstrating baseline features of the MPT approach to conservation reserve diversification and investigating whether the technique is robust to shortcuts such as neglecting costs or using benefit indexes rather than true measures of conservation benefits.

Previous work developed cost-effective spatial strategies for choosing conservation investments. Conservation biologists and ecologists use biophysical information to target conservation at places to gain the highest total conservation benefit (Wilson *et al*. 2006). Economic research has shown the importance of considering variation in other factors such as costs (Ando *et al*. 1998) and development threat (Costello and Polasky 2004); economists have also studied dynamic elements of conservation planning such as endogenous future land prices (Dissanayake and Onal 2011), endogenous future threat (Armsworth *et al*. 2006) and responses

of one set of conservation agents to policy or actions taken by another (Albers *et al*. 2008, Lichtenberg *et al*. 2007).

All this research is based on a foundation of knowledge: the ability to measure factors influencing the costs and benefits of conservation across space. Only a few papers have grappled with the problem of conservation planning in the absence of full information. However, that work (Polasky *et al*. 2000; Arthur *et al.* 2004) simply allows for species occurrence in a portion of the landscape to be uncertain in a manner that reflects lack of knowledge. This type of uncertainty does not capture the spatial patterns of uncertainty in future ecological benefit and conservation costs that are associated with climate-change induced uncertainty.

Ecologists have made many suggestions for changing conservation planning practice to cope with climate change uncertainty, (Williams *et al.* 2005; Hannah *et al* 2007; Hodgson *et al*. 2009; Beier and Brost 2010) but most of that work does not employ decision tools that grapple with uncertainty directly (Ando and Hannah 2011). A few papers recommend practices that sound like spatial conservation portfolio diversification but do not use the information about covariances in outcomes across space that would be necessary to accomplish efficient risk management (Anderson *et al*. 2010; Pyke and Fischer 2005). Most work that has applied efficient portfolio analysis to conservation problems has studied questions of portfolios of species or populations rather than areas of space (Figge 2004; Koellner and Schmitz 2006; Crowe and Parker 2008; Moore *et al*. 2010; Schindler *et al.* 2010). Ando and Mallory (2012) present the first development of a conservation tool based on Modern Portfolio Theory (MPT) that enables conservation policy makers and planners to choose a portfolio of investments in a landscape that minimizes uncertainty in conservation outcomes for a given level of expected conservation returns. However, that paper was only a first step in the research needed on this

approach to conservation. It did not monetize ecological values, and it did not study the implications of different patterns of correlation between the responses of conservation benefits and conservation costs to climate change. Cost-effective conservation must consider land values in the targeting process (Ando *et al.* 1998; Murdoch *et al.* 2010). The literature on land value responses to climate change is developing but still unsettled (Mendelsohn *et al.* 1994; Mendelsohn and Dinar 2003; Schlenker *et al.* 2005; Deschenes and Greenstone 2007; Schleker and Roberts 2009); it is valuable to understand how sensitive conservation portfolio recommendations are to variation in land-value change predictions.

This paper advances the literature on conservation policy and planning in the face of climate change uncertainty in several ways. It advances a new method for using MPT for conservation planning when both conservation and land values will change with climate, exploring the robustness of the method to shortcuts that might be taken to simplify its application. It identifies unexpected dimensions of the problems that arise if land values are ignored in portfolio analysis. It explores the implications for portfolio recommendations of variation in the correlations between ecological and land-value responses to climate change. Finally, it demonstrates the sensitivity of portfolio recommendations to the manner in which ecological benefits are quantified.

2. Methodology

Markowitz (1952; 1959) developed the concept of MPT as we know it today, and much of modern finance traces its roots from here. Notable examples are the Capital Asset Pricing Model (Sharpe 1964; Linter 1965), Arbitrage Pricing Theory (Ross 1976), and their derivatives. The insight of Markowitz' portfolio theory is that investors care about the expected return and

variance of their entire portfolio – not just those of individual assets. Portfolio return and variance depends on the covariance between each pair of assets, in addition to the expected return and variance of each asset individually. Therefore, considering each asset individually is inefficient because accounting for correlations guides one to select assets that jointly reduce risk of the entire portfolio without sacrificing expected return.

Stated more formally, the objective is to minimize the variance of the portfolio return, R, subject to a minimum level of return, μ:

$$(1) \qquad \min_{w} w^T \Sigma w, \text{ subject to } \sum_i w_i = 1, \text{ and } E\left[R^T\right]w = \mu,$$

where w is a vector of portfolio weights, Σ, is the covariance matrix of asset returns, i indexes potential assets in the portfolio, and E and T are the expectation and transpose operators, respectively. By solving the problem in (1) repeatedly over a continuum of μ, one obtains a set of risk-return pairs that make up the efficient frontier. In this paper we illustrate how the framework of MPT can be used to inform a non-financial choice under uncertainty: conservation site choice in the PPR when conservation benefits are uncertain. Therefore, assets are tracts of land, and returns in this example are defined by $R = Benefit/Cost$.

Research on cost-effective land conservation has usually used the market value of the land to be set aside (either through fee, simple, purchase, or easement) as a measure of the social cost of conservation. If land values change in the future because of climate change, then the opportunity cost to society of lands placed in conservation status will have changed as well.

Assigning an appropriate measure to the benefit of conservation can be more challenging. Nonmarket valuation techniques can often be used to place a monetary value on the environmental goods and services that are the subject of the conservation-planning problem. Under these circumstances, returns can be defined in terms of monetary benefit divided by

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monetary cost; armed with a measure of the probability distribution over possible outcomes, one can proceed with the portfolio analysis in the usual way.

Sometimes it is not possible to place a monetary value on the benefits of conservation. A non-market valuation study may be too difficult or prohibitively expensive to be practical in the time available to the analyst, or the decision maker may find it unpalatable to assign a monetary value to the benefits of conservation in question. It is not uncommon for research in the natural-capital literature to measure outcomes in terms of physical rather than monetary units of measure (Nelson *et al*. 2008). In the absence of monetary benefit estimates, defining appropriate returns can be difficult. We will illustrate some possible ways of dealing with this methodological issue, as well as some possible pitfalls, in our case study.

In addition to defining conservation benefits and costs appropriately, applying MPT in a non-financial context can present other technical issues. For example, in a financial context, there is no restriction on negative portfolio weights in equation (1), because negative portfolio weights simply represent short-selling of a financial asset. In the context of our conservation problem, short-selling a tract of land is not possible. Therefore, in equation (2) we slightly modify the objective from equation (1) to preclude negative portfolio weights from entering the solution.

$$(2) \qquad \min_{w} w^{T} \Sigma w, \text{ subject to } \sum_{i} w_{i} = 1, \ w_{i} \geq 0 \text{ for all } i, \text{ and } \mathrm{E}\left[R\right]^{T} w = \mu \ .$$

3. Case study

The Prairie Pothole Region is an area of the U.S. and Canada (Figure 1) that is naturally home to a mosaic of grasslands and shallow wetlands and that is of key conservation importance to myriad waterfowl species (USGAO 2007). The U.S. Fish and Wildlife Service had 3 million

acres of land in protected status as of 2007 but both government and private conservation agents would like to increase that area several-fold. Historically, the best wetland habitat was in the Central part of the PPR, but scientists have grown to realize that climate change may shift optimal habitat across space in a manner that is difficult to predict. In our case study, we apply MPT to evaluate what combinations of investments in different sub-regions of the PPR yield expected values of ecosystem services with the lowest uncertainty possible.

The sub-sections below describe the details of our sources and approaches for establishing all the components necessary to carry out MPT analysis in this area. We use estimates from previous research to quantify wetland habitat quality over space, the value of wetland habitat, and the cost of protecting land in different parts of the PPR. We also make assumptions about the possible climate outcomes and their probability distributions, and about how land values co-vary with wetland quality under possible climate change outcomes.

3.1 Wetland habitat quality forecasts

Johnson *et al*. (2010) developed a measure of wetland habitat quality called the Cover Cycle Index (CCI) and they model current and future values of the CCI in the PPR under three different possible climate change outcomes: warming of 2º C, warming of 4º C, and warming of 4º C plus precipitation increased by 10%. Figure 2 depicts the U.S. portion of the PPR divided into three sections (Western, Central, and Eastern) with shading to indicate the level of predicted CCI as modeled by Johnson *et al*. (2010) under each of these scenarios. The first section of Table 1 lists the average CCI in each region for each climate change scenario we consider.

3.2 Wetland habitat values

No studies have been done to estimate willingness-to-pay for prairie pothole wetlands, specifically. Hence, we use value estimates from the literature that has generated such estimates

for similar wetland types. Brander *et al*. (2006) review estimates of wetland values; they find that the mean estimated value of per unit area of freshwater marsh is $3,500 with a standard deviation of $1,500. In order to translate our non-monetary measure of wetland quality, CCI, into dollar values we translate the modeled CCI outcomes from Johnson *et al.* (2010) into the monetary values presented by Brander *et al.* (2006) in the following way. We map the interval containing CCI values across the climate and regional scenarios to the interval containing one standard deviation about the mean of wetland values. That is, the set of *CCI* values from the minimum *CCI* to the maximum *CCI*, $\{CCI_{\min}, \ldots, CCI_{\max}\}$ is mapped to $\{WV_{\text{mean-1std}} - WV_{\text{mean+1std}}\}$ as follows:

$$(3) \qquad WV_j^i = WV_{\text{mean-1std}} + \left(\frac{CCI_j^i - CCI_{\min}}{CCI_{\max} - CCI_{\min}} \right) \left(WV_{\text{mean+1std}} - WV_{\text{mean-1std}} \right)$$

for $i \in \{\text{West, Cent, East}\}$ and $j \in \{\text{Hist}, +2\,℃, +4\,℃, +4\,℃ \text{ and } +10\% \text{ precip}\}$. The variable WV_j^i is the wetland value in region *i* and climate scenario *j*, $WV_{\text{mean}\pm\text{1std}}$ is the mean plus or minus one standard deviation of the wetland values. The variable CCI_j^i is the *CCI* in region *i* and climate scenario *j*, and $CCI_{\min}$ is the minimum *CCI*, $CCI_{\max}$ is the maximum *CCI*.

These dollar values are only approximations of the true values of PPR wetlands of varied qualities; however, the numbers are sufficient for us to use in our stylized exploration of the issues associated with measuring conservation benefits in a MPT analysis of conservation targeting in the face of climate change. The final values we use are shown in panel A of Figure 3 and listed in section B of Table 1. This transformation of *CCI* to wetland values preserves the basic variation across regions and climate scenarios so that in the historical scenario the maximum wetland value of $5,000 is found in the central subregion. As with the *CCI* the maximum wetland values move to the east under the warmer climate scenarios.

3.3 Land cost

We assume in the current paper that the decision maker is choosing lands to place

irreversibly into conservation status. The cost of conservation in places like the PPR is largely a

function of the cost of either buying land to place in protected status or the cost of putting lands

under permanent conservation easements. Therefore, conservation costs are higher in places

where land values are high.

There is much debate about how land values will respond to climate change; this paper

does not aim to resolve or even contribute to that debate. Rather, it carries out hypothetical

portfolio analyses which illustrate the importance of this matter in conservation planning.

Specifically, we perform the portfolio analysis under three different assumptions regarding how

land values might change in response to the climate change outcomes we consider. First, we use

historical land values in our baseline scenarios, and assume those values do not vary across

climate scenarios (panel A of Figure 3 and panel C of Table 1.) Specifically, we use the land

values used in Schlenker *et al*. (2005), which are taken from the Census of Agriculture in 2002.

Second, we generate one alternative picture of the future by imposing strong positive

correlation between land values and wetland quality. Such a correlation might exist in cases

where a given change in temperature and precipitation has similar effects on the ecological value

that is the focus of the analysis and the primary human use of land in the area; for example,

increased temperatures will harm hardwood forests in New England, which also lowers land

values derived from tourism and forestry based on those forests. We create such a correlation in

the following way. In each climate scenario, we average the land values implied by the baseline

model across regions. Then, we impose that the land value in a specific region and under a

specific climate scenario deviates from the baseline mean land value by the same percent as

wetland values deviate from their mean in that region and climate scenario. That is,

$$(4) \qquad LV^{i}_{j,pos\_cor} = \frac{WV^{i}_{j}}{E_i\left(WV_j\right)} E_i\left(LV_{j,baseline}\right),$$

Where $i \in \{$West, Cent, East$\}$ and $j \in \{$Hist, +2 ℃, +4 ℃, +4 ℃ and +10% precip$\}$, LV^{i}_{j,pos_cor} is

the land value in region i under climate outcome j when we assume that land values are

positively correlated with wetland values. The variable $LV_{j,baseline}$ represents land values from the

baseline model under climate outcome j, averaged across regions. Thus we impose that a

region's land value deviates from the mean forecasted by the baseline model by the same

percentage as the predicted wetland value deviates from its mean for each climate change

outcome, j.

For example, from panel B of Table 1 we see that the mean wetland value across regions

in the +2° C scenario is $3,606, and $WV^{Cent.}_{+2°C} = \$4,339$ then $WV^{Cent.}_{+2°C}$ is 20.35% larger than the mean

for this scenario. In this case we assume the land value in the Central region in the +2° C

scenario is also 20.35% larger than the mean land value implied by the baseline model in the +2°

C scenario, or $LV^{Central}_{+2°C,pos\_cor} = 1.2035 * \$698 = \$840$. These land values for each region and

climate change outcome are found in section E of Table 1 and panel A of Figure 4.

Third, we generate another alternative future by imposing negative correlation between

land and wetland values. Such a correlation might exist when changes that are bad for the

ecological value that is the focus of the analysis are actually good for human land uses; e.g.

climate change that is bad for waterfowl can be beneficial for some row crops. We create such a

correlation in a similar way to the previous example. In each climate scenario, we average the

land values implied by the baseline model across regions. Then, we impose that the land value in

a specific region and under a specific climate scenario deviates from the baseline model's mean land value negatively by the same percent as the wetland value deviates from its mean in that region and climate scenario. That is,

$$LV^i_{j,neg\_cor} = \left[1+\left(1-\frac{WV^i_j}{E_i\left(WV_j\right)}\right)\right]E_i\left(LV_{j,baseline}\right).$$

We calculated above that $WV^{Central}_{+2Deg}$ is 20.35% larger than the mean for this scenario, so we assume the land value in the Central region in the +2º C scenario is 20.35% smaller (or $1+\left(1-1.2035\right)=0.7965$) of the mean land value implied by the baseline model's in the +2º C scenario, or $LV^{Cent.}_{+2ºC,neg\_cor}=0.7965 * \$698 = \$556$. These land values are found in section F of Table 1 and panel B of Figure 4.

3.4 Portfolio analyses

We run portfolio analyses using MPT under several different scenarios (in all cases we assume that our four climate outcomes are all equally likely to occur). First, we do the portfolio analysis where returns are calculated as predicted wetland values in dollars divided by predicted land values in dollars. There are three versions of that analysis: one uses baseline land-value predictions, one assumes land values that are positively correlated with wetland values, and one assumes land values that are negatively correlated with wetland values. Second, we perform the analysis using wetland values only to highlight the implications of ignoring costs in conservation planning. Third, we do an MPT analysis in which costs are considered but benefits are measured in an index that is a monotonic but nonlinear transformation of wetland values, to mimic an analysis that might occur if a hypothetical ecological index was used in place of monetary benefit estimates.

4. Results

4.1 Benefit/Cost MPT Analysis for Multiple Land-Cost Predictions

Figure 5 shows the efficient frontiers for the MPT analyses carried out on ratios of

wetland values to land costs for each of the three land cost scenarios, and Figure 6 shows the

portfolio weights associated with those frontiers. In all three cases, the efficient frontier is

upward sloping; it is only possible to increase expected returns by accepting additional risk. This

is because there are some areas in the study region with returns that are negatively correlated

with each other across climate scenarios. The efficient frontiers for the two hypothetical-land-

value analyses lie above the frontier for the baseline analysis, which means much higher

expected returns can be had for the same uncertainty (except for the low-risk range of the frontier

for the positive-correlation scenario). This is because the Central region has similar high returns

in all three analyses (5.7, 5.45, and 6.13) but the Western and Eastern regions have low expected

returns in the baseline forecasts (3.87 and 3.34, respectively). In contrast, hypothetical land value

changes that are positively correlated with wetland values yield strong benefits relative to

conservation costs in the West (5.41), while land value changes that are negatively correlated

with wetland values produce good expected returns in the East (4.64).

While the details of efficient risk-diversifying portfolio weights vary across scenarios,

inspection of Figure 6 reveals a common story. Investment in one region is always non-

monotonic with the amount of risk to be borne. In each there is a region with highest return (the

"best bet"), a region that is strongly negatively correlated with the best bet (the "hedge basket")

and a region that contributes less to diversification but has relatively low variance in returns (the

"safer harbor"). To maximize returns, a conservation planner would put all lands in the best bet;

that is the Central region in all three cases. Risk can best be reduced by diversifying investment

into the hedge basket (Eastern region for baseline and negative correlation; Western region for

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positive correlation). If the planner is terribly risk averse and really wants uncertainty to be as low as possible, it shifts much of the investment from the best bet and hedge basket into the safer harbor. However, there can be a steep cost of doing this in a scenario like the positive correlation case where the safer harbor has low expected returns.

4.2 Imperfect MPT Analyses

The analyses described in the previous sub-section require spatial predictions under several climate-outcome scenarios about land costs, ecological changes, and the monetary values associated with ecological outcomes of varied levels of quality. In the face of such demanding information requirements, an analyst might be tempted to use proxies for the monetary values of ecological outcomes, or do the analysis on information about benefits only rather than including data on conservation costs. In this section, we discuss the results of two analyses designed to illustrate the potential pitfalls of such shortcuts.

First, we consider the results of an analysis that considers only wetland value uncertainty – no costs are considered. Panel A of Figure 7 shows the investment weights underlying portfolios that are technically efficient in that analysis. Comparing these findings to those in Figure 6, we see that the portfolio recommendations are completely different. The expected wetland-habitat benefits of a unit of investment are maximized by investing in the East; that region looks like a good target if you focus on the high expected wetland benefits under climate change and ignore the very high conservation costs. Diversification shifts investment first into the Central region (which has benefits that are high but negatively correlated with the Eastern region), and then puts land in the West (which has low but stable wetland quality) if the planner demands very low uncertainty.

If land values are given by the baseline numbers but ignored in the diversification

analysis, a decision maker facing a cost constraint on its investment may not really be diversifying efficiently by using the portfolio recommendations from Figure 7A. To see this, assume baseline conservation costs apply and consider a thought experiment in which a decision maker allocates $1 billion among the three regions according to the recommendations in Figure 7 (wetland values only) or, alternatively, the portfolio recommendations from an analysis done in terms of wetland value/land cost (panel A of Figure 6). We calculate the total wetland habitat benefits that be gained from those investments under each of the four climate outcomes; Figure 8 shows the expected value and standard deviation of the total wetland value of the lands purchased in this thought experiment. Maximum total expected benefits possible are more than 40% greater with portfolio recommendations from the benefit-cost analysis than from the analysis of benefits alone, with risk reductions possible if one is willing to accept lower expected benefits. Using benefits-only guidelines can produce low expected total benefits for given levels of risk because those portfolios are heavily weighted toward the expensive Eastern sub-region, so few acres of land can be purchased under the cost constraint. In our PPR example, diversifying investment with the benefits-only guidelines does not always result in a monotonically increasing relationship between the level of expected total benefits and standard deviation of total benefits because benefit-cost diversification in this region happens to increase total benefits (e.g. from D' to C') by pushing investment into cheaper lands where more total area can be protected.

Second, we study the consequences of measuring benefits with an index that increases monotonically (but in a nonlinear fashion) with actual wetland values. Specifically, benefits are defined as $B = 1000*\ln(WV)$, and the portfolio analysis is done in terms of benefits divided by baseline land values. The resulting portfolio recommendations are summarized in panel B of Figure 7. When benefits are measured by the index B, variation in the numerator of the benefit-

cost ratio is dwarfed by variation in the denominator and so the portfolio recommendations are driven by variation in costs. Returns appear to be maximized by investing all lands in the West, with diversification into the East if the agent is risk averse. The Central region never appears in these efficient portfolios because returns there are similar in expectation to returns in the West but with much higher variance. These recommendations are completely at odds with recommendations from portfolio analysis carried out with true values *WV* (panel A of Figure 6) which maximize returns by investing in the Central region, diversify first into the East, and only diversify into the West in case of extreme risk aversion. Clearly one cannot rely on portfolio recommendations to be invariant to the type of index used to measure benefits for an analysis.

5. Conclusions

This paper has explored several practical issues in the implementation of MPT for spatial conservation portfolio design to deal with uncertainty in future conservation outcomes driven by climate-change uncertainty. Several lessons can be learned from these analyses. MPT can be used under a range of correlations between ecological values and conservation costs to minimize risk for a given level of ecological returns per dollar spent. If land values are likely to change much in response to climate, conservation planners really must forecast them and take them into account because land-value changes affect optimal policy; whether conservation costs are positively or negatively correlated with ecological values can completely change spatial portfolio weight recommendations.

We find there are dangerous pitfalls associated with taking shortcuts in portfolio analysis for conservation planning. Analysts should use benefit indexes that proxy for monetized social conservation benefits with care. Portfolio recommendations can change dramatically if analysts

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use measures of benefits that are convenient indexes rather than true values, even if the indexes are highly positively correlated with true values. In addition, it is critical to diversify in terms of benefit-cost ratios rather than benefits alone if conservation costs are not homogeneous across the planning area. Failure to do so can lead to over-investment in high-cost areas and low total conservation benefits when investment is budget constrained. Ecologists have focused valuable attention on quantifying the biophysical uncertainty associated with climate change. But land value uncertainty introduces another important element of uncertainty to conservation portfolio planning. To employ MPT and develop conservation portfolios that reduce risk in future conservation outcomes, we need to know not just "where will the best habitat be?" but "where might there be bargains?" Conservation planning in the face of climate uncertainty will be more effective if economists resolve the debate over the likely effects of climate change on land values.

Finally, our findings show that while MPT can be used to develop conservation portfolios that reduce uncertainty in total conservation outcomes, achieving very low levels of uncertainty with spatial diversification alone can entail very large losses in expected conservation outcome values. Conservation agents may want to supplement conservation portfolio design with actions taken at conservation sites to mitigate the deleterious effects of climate change on habitat.

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U.S. Government Accountability Office: Washington, DC.

Williams, P., L. Hannah, S. Andelman, G. Midgley, M. Araújo, G. Hughes, L. Manne, E.
Martinez-Meyer, and R. Pearson. 2005. Planning for climate change: Identifying minimum
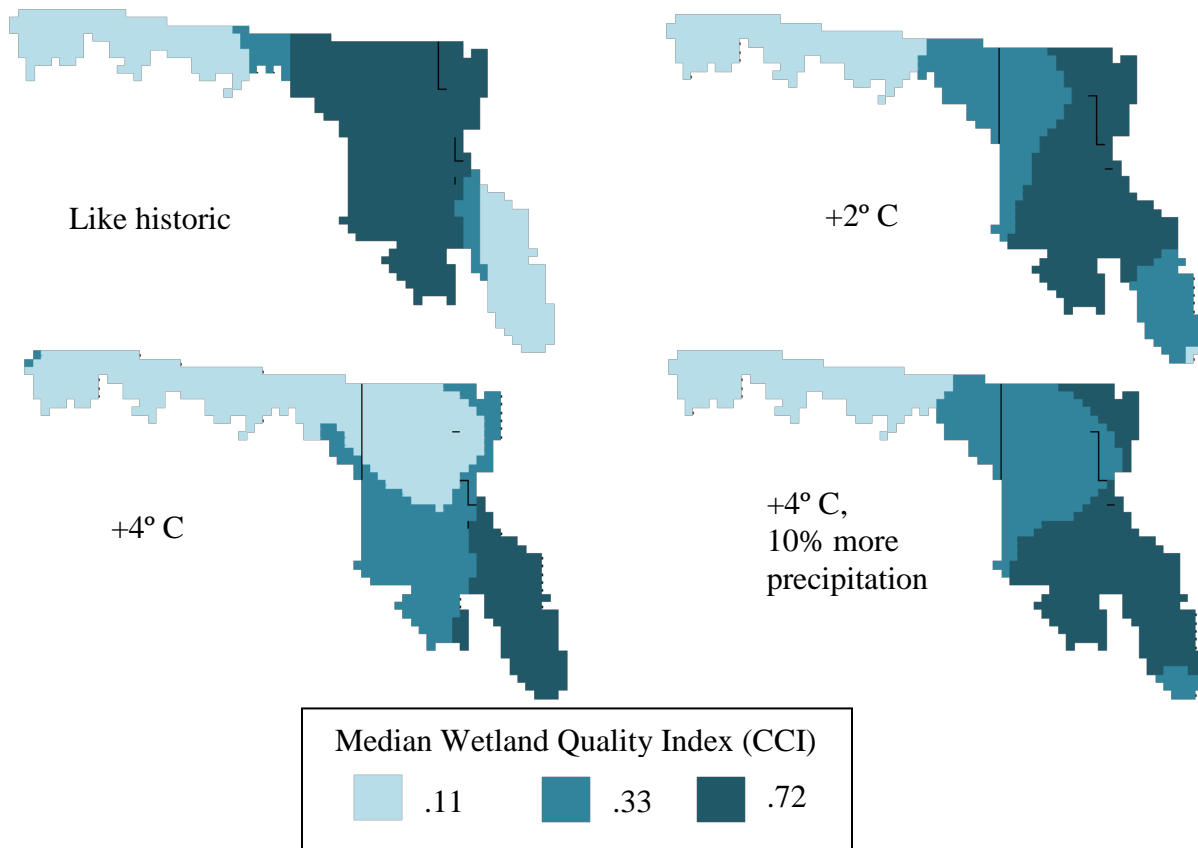dispersal corridors for the Cape Proteaceae. *Conservation Biology* 19: 1063-1074.

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conservation efforts. *Nature* 440: 337-340.

Figure 1: The Prairie Pothole Region of North America
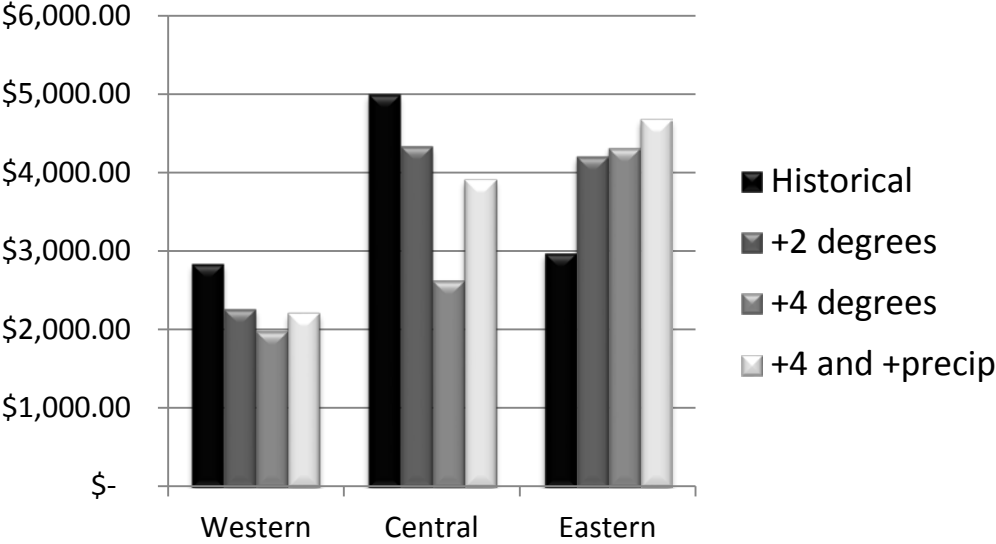

Source: U.S. Geological Survey, Northern Prairie Wildlife Research Center

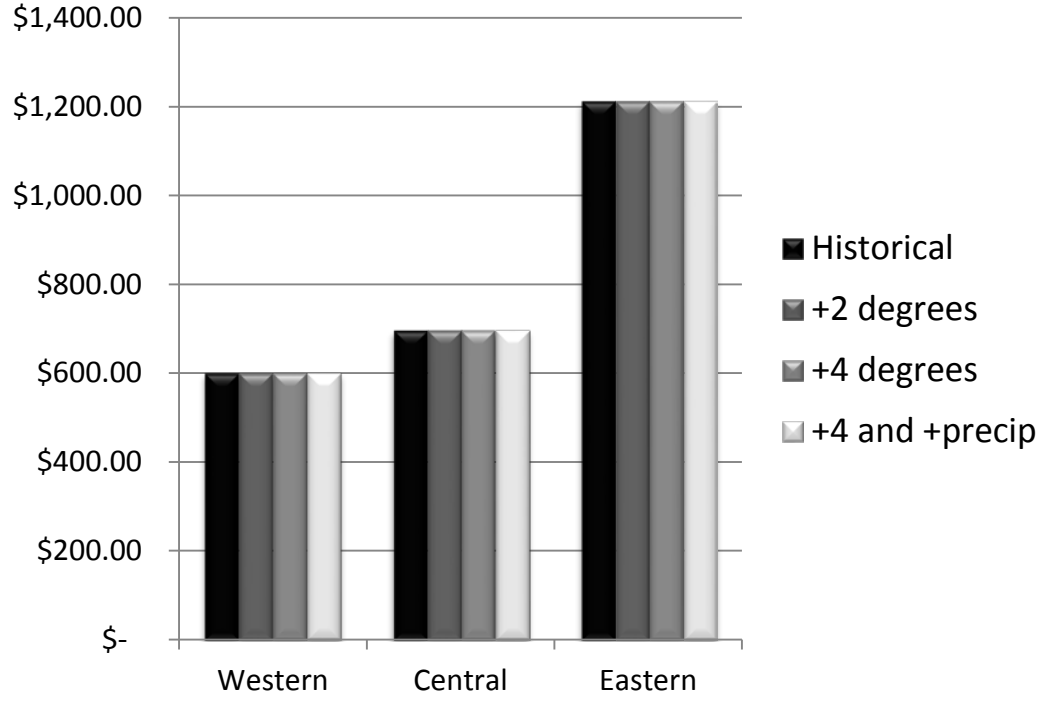**Figure 2: Wetland Quality Predictions in U.S. PPR for Four Climate Scenarios**

Like historic

+2º C

+4º C

+4º C,
10% more
precipitation

Median Wetland Quality Index (CCI)

.11   .33   .72

Data source: Johnson *et al*. (2010)

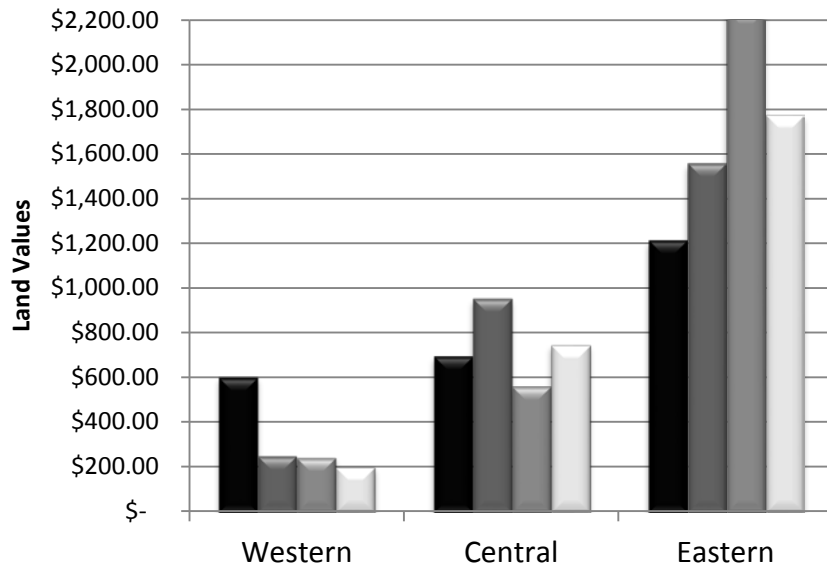**Figure 3: Baseline Conservation Benefits and Costs**

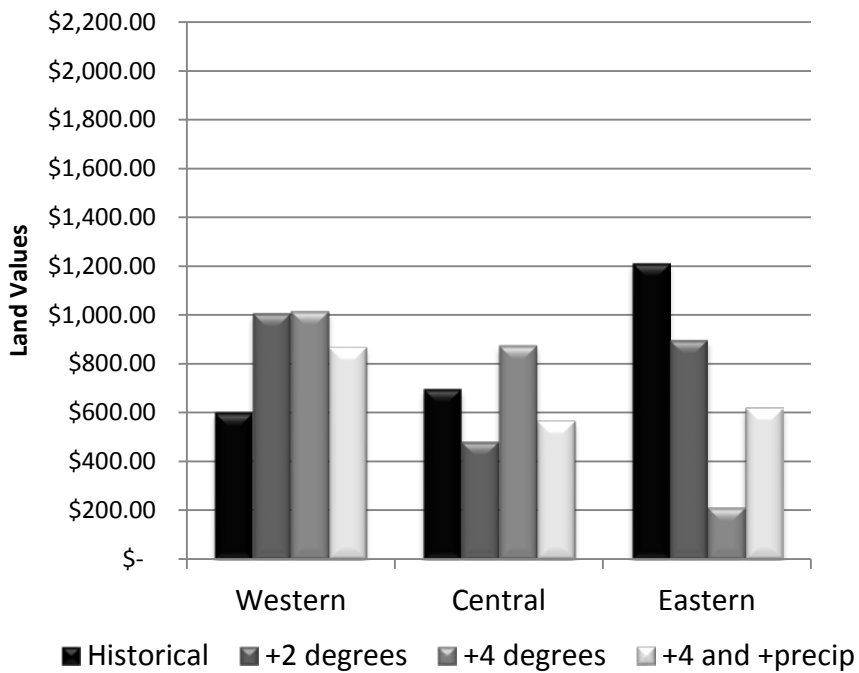Panel A: Average Wetland Habitat Values/Acre

Panel B: Average Land Cost/Acre

Figure 4: Alternative Land Value Forecasts

Panel A: Land Values Positively Correlated with Wetland Quality

Panel B: Land Values Negatively Correlated with Wetland Quality

Figure 5: Efficient Frontiers for Monetized Benefit/Cost

Baseline Land Values

Positive Correlation between Land Values andWetland Values

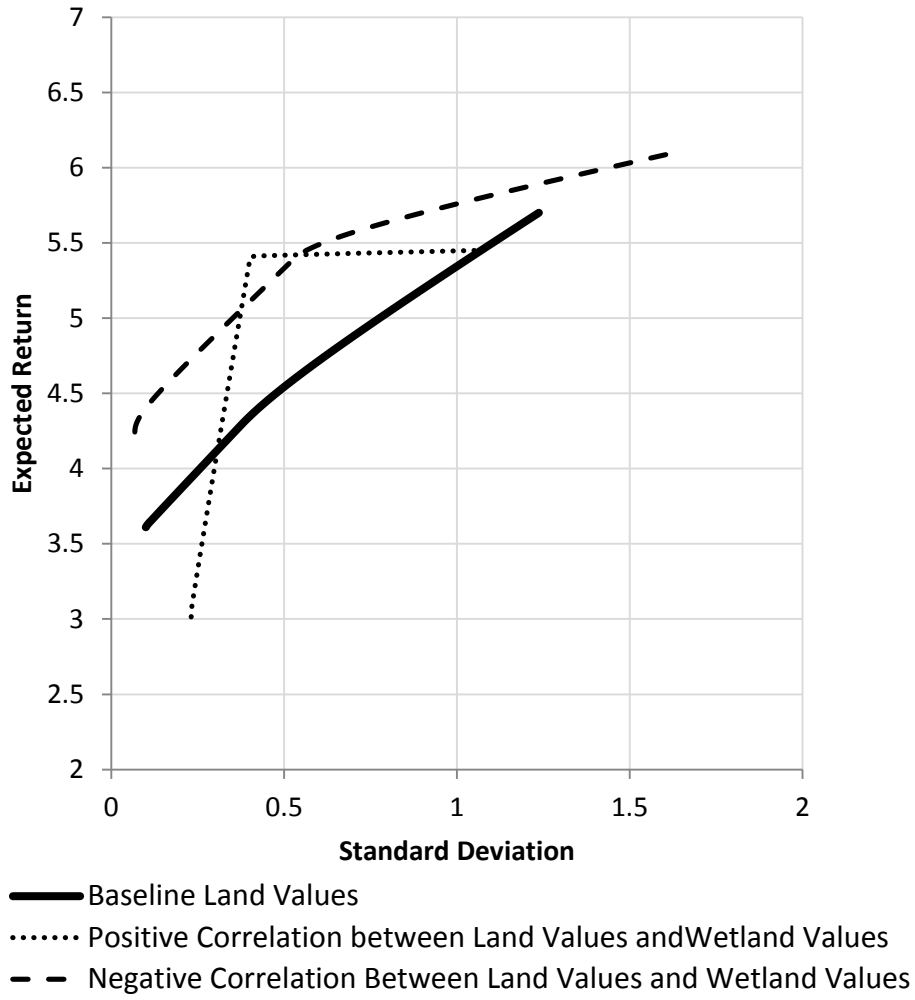Negative Correlation Between Land Values and Wetland Values

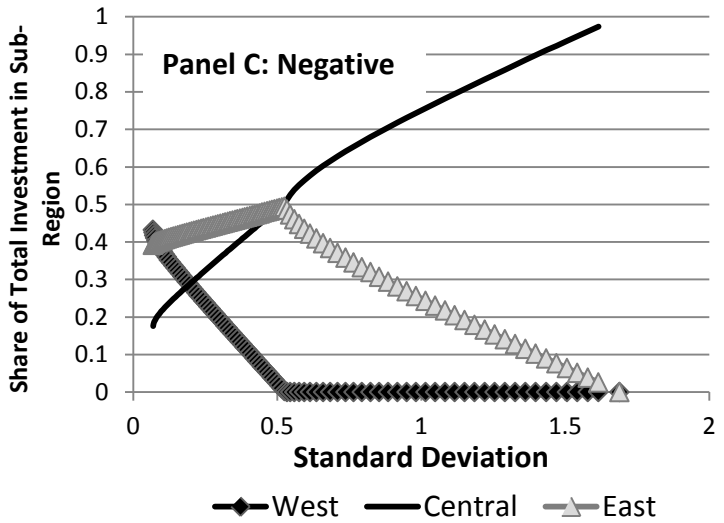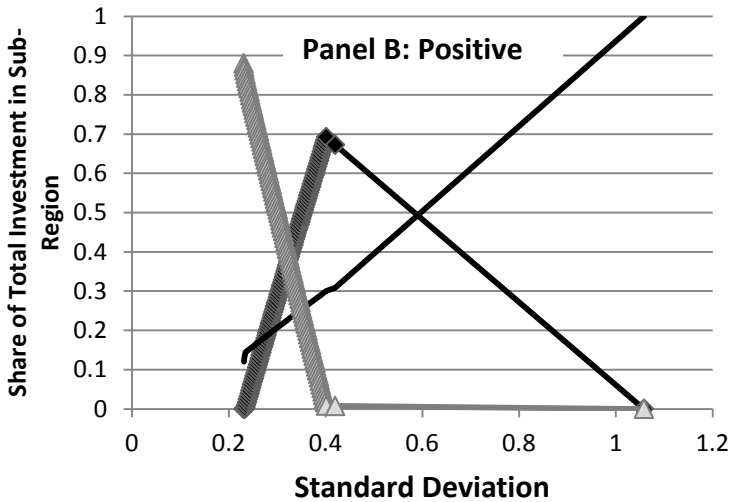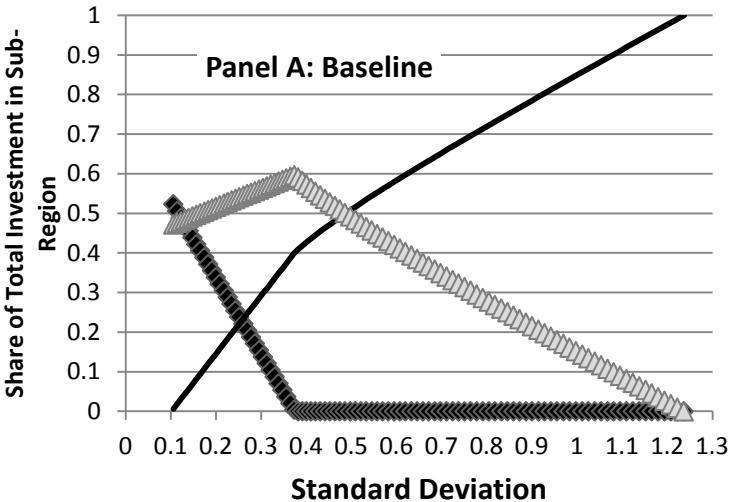**Figure 6: Portfolio Weights Underlying Efficient Frontiers of $ Benefit/Cost Analyses**

Figure 7: Portfolio Weights of Efficient Frontiers Derived Using Shortcuts

Panel A: Benefits-Only Analysis

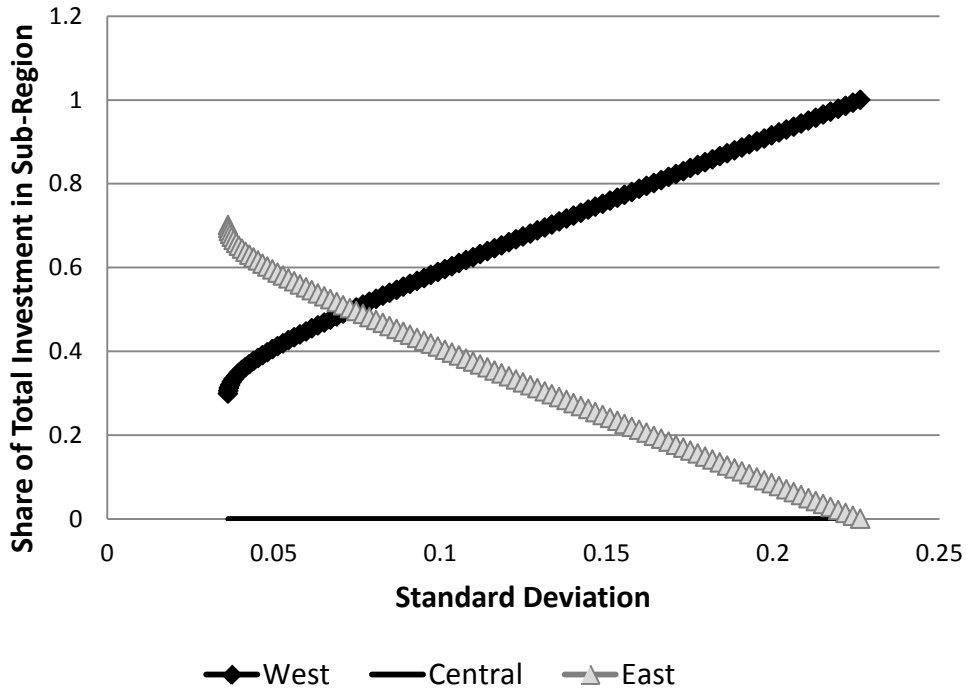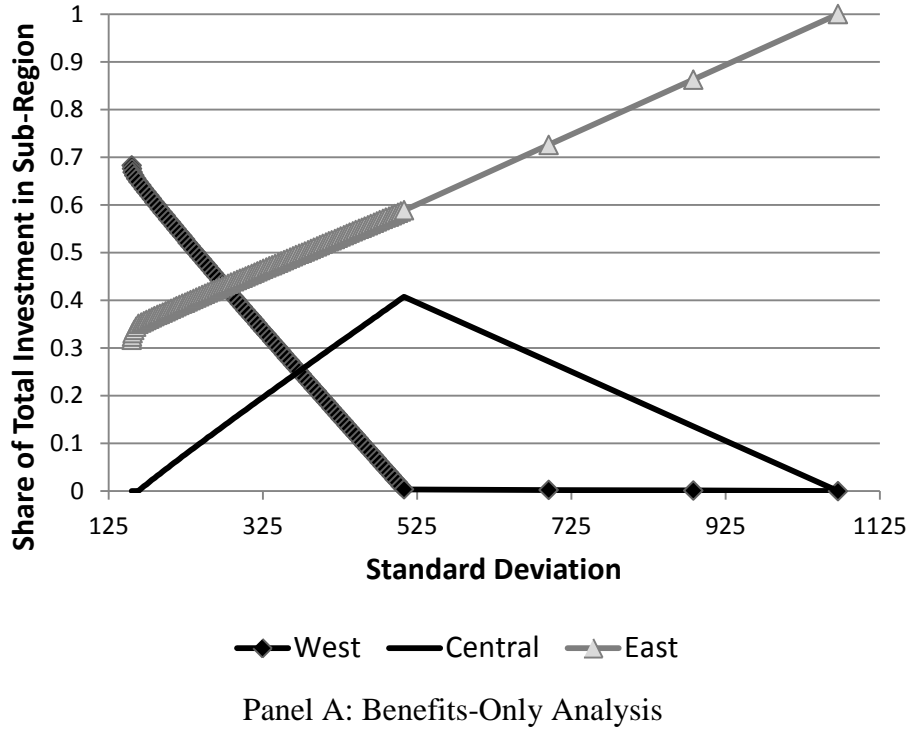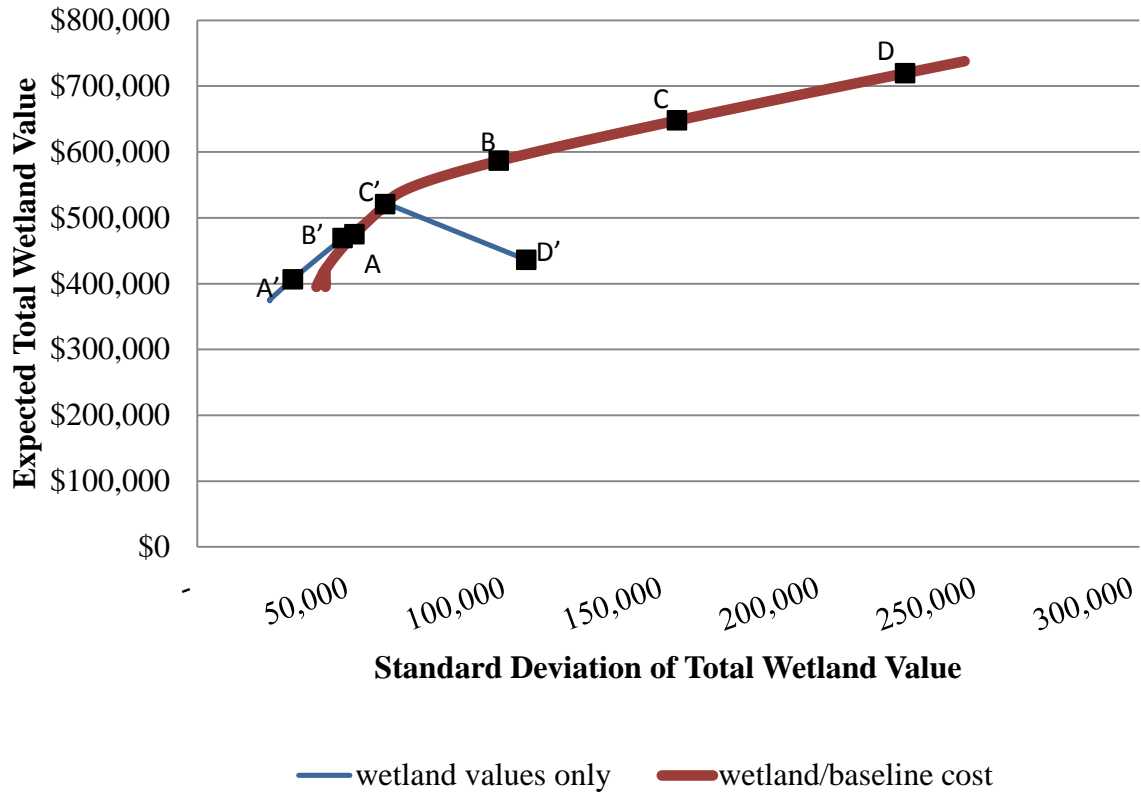Panel B: Benefit/Cost Analysis, Benefits Measured with Index

Figure 8: Risk and Returns in Total Wetland Value from Fixed-Cost Investment, Baseline

Note: Information about labeled points is given in Table 3.

Table 1: Wetland Values, Land Values, and Returns

A. CCI Wetland Quality Index Values				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	0.2902	0.1777	0.1244	0.1675
Central	0.7179	0.5872	0.2509	0.5032
Eastern	0.3172	0.5612	0.5837	0.6544

B. Wetland $ Values				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	$2,838	$2,269	$2,000	$2,218
Central	$5,000	$4,339	$2,640	$3,915
Eastern	$2,975	$4,208	$4,322	$4,679

C. Baseline Land Values $				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	$602	$602	$602	$602
Central	$695	$698	$698	$698
Eastern	$1,213	$1,213	$1,213	$1,213
means	$838	$838	$838	$838

D. Baseline Returns				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	4.72	3.77	3.32	3.69
Central	7.17	6.22	3.78	5.61
Eastern	2.45	3.47	3.56	3.86

E. Hypothetical Land Values with Positive Correlations with Wetland Values				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	$602	$379	$403	$370
Central	$698	$840	$616	$758
Eastern	$1,213	$1,416	$1,755	$1,575

F. Hypothetical Land Values with Negative Correlations with Wetland Vaues				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	$602	$825	$801	$833
Central	$698	$556	$779	$637
Eastern	$1,213	$1,010	$671	$851

G. Hypothetical Returns with Positive Correlations with Wetland Values				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	4.72	5.99	4.96	5.99
Central	7.17	5.17	4.28	5.17
Eastern	2.45	2.97	2.46	2.97

H. Hypothetical Returns with Negative Correlations with Wetland Values				
Subregion	Historical	+2 degrees	+4 degrees	+4 and +precip
Western	4.72	2.75	2.50	2.66
Central	7.17	7.81	3.39	6.14
Eastern	2.45	4.17	6.44	5.50

Table 2: Expected Returns and Variance/Covariance Matrices

Scenario	Subregion	E[return]	cov[x,Western]	cov[x,Central]	cov[x,Eastern]
Baseline land value forecasts	Western	3.87	0.26	0.56	-0.25
	Central	5.70	0.56	1.53	-0.43
	Eastern	3.34	-0.25	-0.43	0.28
Positive correlation	Western	5.41	0.34	-0.25	0.15
	Central	5.45	-0.25	1.12	-0.08
	Eastern	2.71	0.15	-0.08	0.07
Negative correlation	Western	3.16	0.82	0.68	-1.21
	Central	6.13	0.68	2.85	-2.00
	Eastern	4.64	-1.21	-2.00	2.25
Wetland values only	Western	$1,552	266,156	657,096	-497,265
	Central	$4,289	657,096	2,062,819	-1,003,951
	Eastern	$4,410	-497,265	-1,003,951	1,146,403

Table 3: Products of Fixed-Budget Expenditures with Benefit/Cost and Benefit-Only Diversification

	Portfolio Weights (W, C, E)	Expected # of Acres Purchased	Standard Deviation of Total Wetland Value	Expected Total Wetland Value
Wetland Values/Baseline Cost				
A	(.20, .25, .55)	1,041,054	50,130	474,983
B	(.00, .63, .37)	1,127,849	96,081	586,538
C	(.00, .80, .20)	1,251,480	152,784	647,781
D	(.00, .96, .04)	1,396,504	225,464	719,622
Wetland Values Only				
A'	(.54, .07, .39)	1,180,951	30,406	406,619
B'	(.27, .24, .49)	1,082,497	46,303	468,955
C'	(.01, .40, .59)	1,001,223	59,921	520,413
D'	(.00, .00, 1.0)	824,399	104,773	436,218

Note: Specified points correspond to points labeled in Figure 8.