AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Socially Optimal Strategies for Ecological Restoration under Climate Change

Koel Ghosh
James S. Shortle
Pennsylvania State University
Carl Hershner
Virginia Institute of Marine Science
Contact: koelg@psu.edu

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, July 1-4, 2004

Copyright 2004 by Koel Ghosh, James S. Shortle, and Carl Hershner. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on all such copies.

Introduction

Ecological Restoration is defined as a process of assisting the recovery of a damaged, degraded, or destroyed ecosystem (SER 2002). The potential of restoration was first realized in context of the wetlands conservation program. Although conservation efforts are at the heart of the "no net policy" of wetlands, the unavoidability of some losses made it necessary to adopt restoration programs that contribute to "no net loss" (Heimlich 2003). Federal policies have over the past two decades increasingly realized the role of restoration in environmental conservation. Restoration has emerged as an important environmental practice in aiding recovery of damaged habitats, watersheds, and estuaries. There are numerous community based and federal restoration projects in the United States, i.e. the USEPA's Office of Water inventory of ecological restoration projects within the Mid Atlantic Integrated Assessment (MAIA) Region list 188 terrestrial and aquatic that are conducted by federal, state, local governments, and non governmental organizations(EPA 2004). The Chesapeake Bay program and the Florida Everglades are two of America's premier watershed restoration programs.

Ecological conservation and restoration projects are achieved at the expense of high economic costs. Total federal expenditures on resource conservation and environmental programs were estimated to be $5.9 billion in fiscal year 1998(Heimlich 2003). It has been determined that the full costs of restoring an hectare of sea grass is $940000 in 1996 dollars (Fonseca, Kentworthy et al. 2001) while that of per acre of salt marsh restoration costs can range anywhere between $900 to $90,000 in 1997 dollars (Louis Berger and Associates 1997)

Given the huge expenditures involved in the pursuit of environmental conservation and restoration projects, efficiency and design issues of conservation and restoration programs and spatial allocation of conservation funds have come under scrutiny (Wu and Boggess 1999; Wu and Skelton-Groth 2002).

Restoration targets are usually set on the basis of current on site, productivity related criteria like water quality or soil erosion rates. Resource managers rarely identify stressors beyond their control that could potentially affect the success of the conservation or restoration programs. One such stressor is climate change. Projected climate change in this century is expected to significantly impact ecosystems and biodiversity. Analysis of biological trends observed in diverse species and geographic regions match trends predicted under climate change with a very high level of confidence as laid down by the IPCC (Parmesan and Yohe 2003). Climate change will affect fundamental ecological processes and the spatial distribution of terrestrial and aquatic species (Malcolm and Pitelka 2000; LeRoy Poff, Brinson et al. 2002).

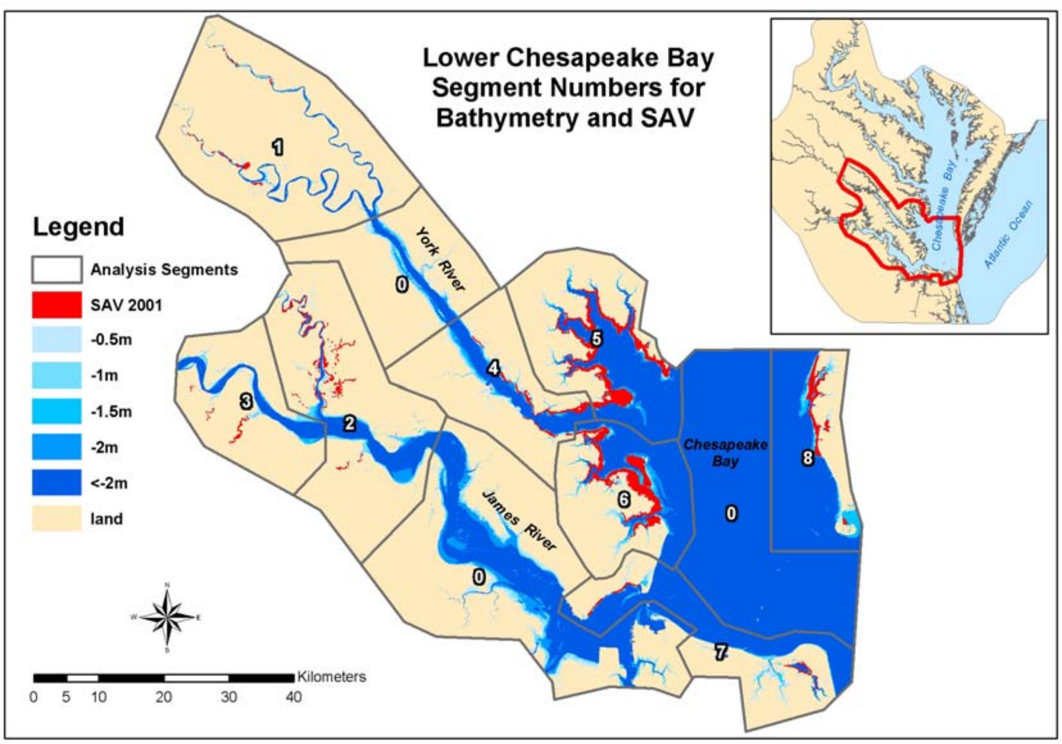
The spatial aspect has implications for restoration policy analysis and design. Site-specific biotic conditions affect species ability to reproduce, a crucial determinant of successful restoration, thereby making the returns to investments in restoration site-specific. The success of restoration projects will be affected by the choice of site. Climate change, by altering the geographic distribution of the biotic conditions, will impact species survival. The uncertainty surrounding climate change translates into uncertainty regarding the location of the optimal sites for restoration. The spatial uncertainty emerges as a key source of uncertainty in dealing with ecological restoration projects.

No work has yet examined the implications of climate change for the efficiency of current conservation program designs or for investments in ecological preservation and restoration. It is important to combine climate change with environmental management to offer appropriate guidance to authorities tasked with environmental conservation and restoration duties, especially those in charge of ecosystems, like marine ecosystems, that are limited in ability to adapt.

In this paper, we examine the effect of climate change on restoration projects. The study concentrates on the design of optimal strategies for habitat restoration under climate change in an aquatic environment using the lower Chesapeake Bay's Submerged Aquatic Vegetation (SAV) restoration program as a case study. The paper presents a methodological framework that determines optimal restoration strategies that takes into account the SAV dynamics, the benefits and costs of restoration, and the uncertainties about climate change.

Case Study

SAV's are ecologically important for the aquatic environment of the Chesapeake Bay. They are important natural resources that provide food and habitat for waterfowl, fish and invertebrates and mitigate shoreline erosion. The habitat services is highly valued for the shell fish population chief among which is the blue crab, symbolic of life and culture in the Chesapeake Bay, which uses the SAV as nursery beds. They are also important for water quality, a concern in the Chesapeake Bay, as they produce oxygen, filter and trap sediments, and remove excess nutrients that can fire up unwanted algal growth. SAV abundance in the Chesapeake Bay regions was historically recorded to exceed 200,000 acres but by 1978 aerial surveys conducted by Virginia Marine Resources Commission documented only 41,000 acres (Moore and Orth 1997). Declining water quality of the Bay characterized by high sediment and nutrient level were held primarily responsible in general. These prompted several diverse bay management and interest groups into planning and implementing SAV restoration programs throughout the bay. Bay scientists believe that 'long time resurgence of underwater bay grasses is critical to the overall Bay restoration effort'(Chesapeake Bay Program 2003). Consequently SAV restoration is a top priority with the Chesapeake Bay Authority and a great deal of interest and urgency is placed on the development of best science to assist the return of SAV to historically known levels.



Map 1: The case study site-Hampton Roads area, Virginia.

Within the Hampton Roads area in Virginia, the case study site, it is the Virginia Marine Resource Commission that is tasked with restoration efforts. Map 1 shows the case study area, with the red areas on the map indicating existing SAV as of 2001. The SAV in this lower bay region is predominantly eelgrass (Zostera Marina) and they occur at water depths of 0.5 to 2 meters. The habitat requirements for SAV are listed as (1) temperature, (2) light penetration, (3) water currents and wave action, (4) bottom sediment, and (5) **water depth** (range: below low tide line to about 2 meters in depth).

One of the most well understood and studied impacts of climate change is sea level rise. An increase in the sea level implies that the water depth, an important habitat criterion for SAV, will increase at the current restoration sites by the amount of increase in sea level. Provided the other habitat criterions are met, this means that most suitable habitat conditions will emerge at sites where the appropriate water depth occurs post the sea level rise. The current restoration sites will cease to be optimal for restoration because of the change in water depth at these sites. With rising sea level the 'ideal' restoration sites will be migrating to shallower waters. Figure 1 illustrates how changing sea level might results in SAV relocating to shallower depth. The C indicates current sea level while the F indicates the future sea level. The SAV relocate to places where the water depth is appropriate.

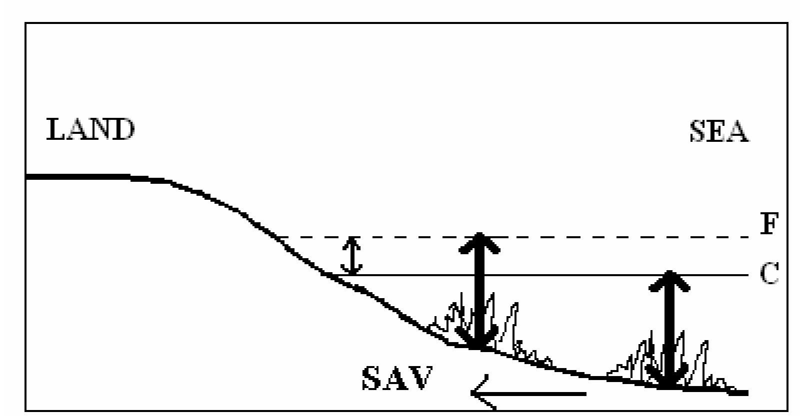


Figure 1: Migration of SAV in accordance with changing water depth.

The maximum abundance of current SAV occurs at the 0.5 meters water depth. As the sea level rises and the sea moves inland, the SAV has restricted opportunities of moving onto land, primarily because it cannot grow on land. Therefore there is the risk of losing a substantial part of SAV that currently exists at the 0.5 meters water depth. One opportunity of conserving the existing SAV lies in the tidal marshes along the coast. The tidal marshes, on account of their biotic similarity with SAV habitat, have the potential for being sites for the SAV to migrate into. The tidal marshlands are protected under current Wetlands Protection Program in Virginia. The wetlands protection ensures availability of the tidal marshes as a future SAV site.

The potential migration of SAV in response to sea level rise has policy implications for SAV restoration program in the lower bay area. Originally the Bay authorities targeted complete restoration of areas where SAV had been known to exist. However reassessing the real potential for SAV growth in areas showing historic growth beds as per the Chesapeake 2000 agreement, the Chesapeake Bay program adopted a new goal to restore 185000 acres in the Bay and the tidal tributaries by 2010 (Chesapeake Bay

Program 2003). The new goal, although lower than the historic 200000, does not discriminate between depth zones. Under existing policy, the resource manager will continue to restore SAV at current sites. As the water depth changes at these sites with rising sea level, the success of SAV restoration in all current depth zones will be impacted negatively, the deeper zones more than the shallower. A failure in anticipating climate change induced sea level rise and in adapting restoration targets at the sites accordingly will result in inefficient spatial allocation of SAV restoration effort inversely affecting the net benefits of restoration.

SAV Restoration Model

An intertemporal spatial model is used to capture the essential elements of the restoration problem. The earliest year for which sea level rise projections for the Mid Atlantic Region is available is the year 2030 (MARA, 2001). We therefore consider a 30 years time horizon, divided into two time periods (t =1,2) of 10 and 20 years respectively.

The model considers three sites indexed by j, where $j = \{s, d, e\}$, the s, d, and e representing sites that shallow(s), deep (d), and emergent (e) respectively. The sites d and e are current restoration sites while e represents the tidal wetlands that will become available only in t=2, post sea level rise. The current sites are differentiated in water depth. s represents restorations regions in the Bay that are less than a meter deep and the d stands for Bay restoration areas of water depth ranging from 1 meters to 2 meters.

We assume that all restoration occurs in the first period i.e. in t=1. It is difficult to determine the lifetime of SAV restoration projects. The Chesapeake Bay program set its restoration goal to be achieved by the year 2010. Taking cue from that, we model that all restoration effort is implemented at the onset period 1 and they are completely restored by the end of 2010 (period 1) at no incremental effort. There is no restoration in the second period.

Restoration effort refers only to transplantation of the SAV seedlings. Seed planting holds the promise of large scale restoration but is currently not feasible as a restoration practice as it performs well only in low energy areas of minimum disturbance(Fonseca, Kentworthy et al. 2001).

The objective is to decide how much to restore at the current sites given that sea level rise will (1) affect the restoration success in the current sites and (2) wipe out the stock of restored SAV at current sites and create opportunities for SAV in the emergent site in the future.

Each site has an initial stock of SAV[1], denoted by S^j and is constrained in the suitable area available for restoration, denoted by A^j. Let S_0, ($S_o = \sum_{j=s,d} S^j$) be the initial stock of existing SAV at the beginning of period 1. The total stock of SAV at the end of period 1 will be the sum of the existing SAV and the SAV that is restored in period 1. Equation (1) shows the stock of SAV at the end of period 1

$$(1) \quad S_1 = S_0 + \sum_{j=s,d} r^j x^j$$

r^j is the restoration success ratio at a given site, $0< r^j <1$. r^j is the area of SAV that is gained if a unit area of restoration was undertaken. The decision variable is x^j, the number of units of area that is subjected to restoration effort.

The effect of the changing water depth is felt in the second period, t=2. Equation (2) gives the stock of SAV that remains at the end of the second period.

[1] The coverage area of SAV is used as a metric for measuring the stock of SAV throughout the analysis. No consideration is taken of the density shoots or of biomass in determining the SAV abundance.

(2) $S_2 = (1-\alpha)S_1 + S^e$

SAV is lost at the current sites, *s* and *d*. α is the proportion of SAV that is lost at the current sites due to sea level rise, $0 < \alpha < 1$. The value of α varies proportionately with the water depth change under consideration. The proportion of SAV retained in period 2 at the current sites is therefore given by (1- α). Biological understanding of the similarity of the SAV habitat and tidal marshes indicate that SAV from period 1 that migrates into the emergent area colonizes the entire portion of the tidal marshlands that becomes sub aqueous. This implies that any area of the tidal marshlands that become sub aqueous translates into that area of SAV. Let S^e denote the sub aqueous area of the emergent area in period 2. The migrant surviving SAV adds to the total SAV stock at the end of the second period.

Uncertainty regarding the magnitude of sea level rise is captured using three scenarios of sea level rise, *w*, $w \in W = \{l, m, h\}$ where *l*, *m*, and *h* represents low, medium, and high scenarios of sea level rise. Each scenario occurs with probability *p(w).*

Equation (3) and (4) report the SAV dynamics across the two time periods under each scenario w. These equations report the same dynamics of SAV as equations (1) and (2) excepting for the fact that under the former set of equations the values of the parameters r^j , α, and S^e depend on the scenario *w* under consideration. The stock of SAV at the end of period 2 will therefore depend on the sea level rise scenario considered.

(3) $S_1(w) = S_0 + \sum_{j=s,d} r^j(w)x^j$

(4) $S_2(w) = (-\alpha(w))S_1(w) + S^e(w)$

Benefits of SAV for each period, B_t accrues at the end of each period and is a function of the total amount of SAV in the relevant period i.e. $B_t = f(S_t)$. Let c denote the constant per unit cost of restoration and d_1 and d_2 discounting parameters for the two periods.

The optimization problem under the baseline model without climate change is to maximize the net benefits of SAV restoration and is given by

$$\underset{x_s, x_d}{Max} \qquad d_1 B(S_1) + d_2 B(S_2) - c(\sum_{j=s,d} x^j)$$

subject to constraints

(5) $\qquad x^j \leq A^j$

(6) $\qquad x^j \geq 0 \qquad$ for $j=s,d$.

Equation (5) states the constraint that the area to be restored at site j cannot exceed the amount of suitable restoration area A^j available at site j. Equation 6 states the usual non-negativity constraints.

The optimization problem under the model with climate change differs from the baseline model in its specification of the objective function. The problem in the climate change model is to maximize the expected net benefits and is given by

$$\underset{x_s, x_d}{Max} \qquad \sum_w p(w)\{d_1 B(S_1(w)) + d_2 B(S_2(w)) - c(\sum_{j=s,d} x^j)\}$$

subject to the additional constraints

(7) $\qquad 0 \leq p(w) \leq 1, \forall w \in W$

(8) $\qquad \sum_w p(w) = 1$

Data and Model Calibration

Virginia Institute of Marine Science (VIMS) obtained bathymetry information from the Chesapeake Bay Program. The information was then used to create bathymetry bands at incremental depth of 0.5 meters from the coastline all the way to the 2 meters water depth. The 1.5 meters line was interpolated from existing information using the program (Contour Gridder) run using Arcview Software. Coverage information of current (2001) SAV and historic SAV (1971-2001) was obtained from VIMS. The Wetlands Research Program at VIMS had completed the Tidal Marsh Inventory data in 1992. The above coverages were unioned together using GIS software ArcInfo. A frequency was run to determine areas of existing SAV, wetlands, and suitable SAV restoration regions within each bathymetry bands. The information was then compiled on an Excel spreadsheet that lists the area in square meters within each bathymetry band, the acreage of historic SAV and current SAV within the bands and the acreage of the total wetlands available.

The National Oceanic and Atmospheric Administration (NOAA)'s National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) collects and distribute observations and predictions of water levels and currents (http://tidesandcurrents.noaa.gov/). The rate of mean sea level rise or fall has been determined for 117 long-term water level stations at CO-OPS. Data from 1935 to 1999 for Sewells Point, Hampton Roads establish a mean sea level (MSL) trend of 0.412 millimeters per year. Trend lines using past twenty-five years data from Chesapeake Bay Bridge Tunnel indicate the highest MSL of 7.01 millimeters per year for the region. These two MSL trends were used as guiding information in determining the scenarios of sea level rise. The 0.412 millimeters MSL obtained from historic data was fixed as the lower bound of annual sea level rise. This served as the magnitude of sea level rise under the low sea level rise scenario. The 7.01 millimeters MSL was used as the magnitude of medium sea level rise. The high sea level rise scenario was obtained by doubling the magnitude of sea level rise under the medium sea level rise scenarios. Table 1 lists the three sea level rise scenarios considered, the magnitude of sea level rise considered under these scenarios, and the total sea level rise expected by the year 2030 under each of the scenarios. The baseline model was run with scenario l being the background scenario of sea level rise.

Table 1: Sea level rise under the three scenarios considered

Scenarios (*w*)	Mean Sea Level (mm/year)	Sea Level Rise by 2030(m)
Low (*l*)	0.42	0.1
Medium (*m*)	7.01	0.2
High (*h*)	14.02	0.4

The technology for restoration is currently not well developed. Experimental settings using current restoration technology reveal a very low ratio of restoration success. In addition SAV thrives better in shallow water depth. Combining this information, we assume 0.5 (50 percent) as the current maximum value of restoration success ratio for the shallow site. The restoration success ratio at the deep site is assumed to be 0.4. The restoration success ratio that is used in the climate change model for the scenarios is adjusted according to the magnitude of sea level rise considered within that scenario.

Information on the costs of restoration remains elusive. The two major costs that are identified in sea grass restoration projects are the planting costs and the monitoring costs. Consistent estimates of planting costs are difficult to obtain. Fonseca et.al report the distribution of the restoration costs among the various tasks based on recent restorations plans that have been litigated in the Federal Court(Fonseca, Kentworthy et al. 2001). Planting costs constitute 18.5% of the total costs of restoration with monitoring costs dominating with 58.7% of the costs. Planting costs are incurred at a single point of time whereas monitoring is a labor-intensive multi year project. To avoid issues of discounting the monitoring costs over the lifetime of a restoration project, we consider only planting costs in our analysis. For a 1.55 acre area, the planting costs are reported as $64,846 in US 1996 dollars. Adjusted for inflation, they work out to be 10, 000 US dollars per thousand square meters of SAV restored.

A discount rate of 0.3 is used in the analysis and the benefits accruing at the end of 15 and 30 years are discounted back to their Net Present values. The initial assignment of the probabilities across the three scenarios ranked the probability of medium sea level rise scenario at the highest with the low scenario getting the least probability.

Assumptions had to be made about the area of the tidal marshlands that would be sub aqueous under the three scenarios. The lack of contour information relevant for tidal wetlands prevents us from knowing precisely what proportion of it will become submerged under sea level rise. Beginning with the assumption that 5 percent of the total wetlands area will become submerged under a 0.5 meters of sea level rise, we compute correspondingly weighed amounts of sub aqueous wetlands for the three sea level rise scenarios.

The fact that SAV is very beneficial for the Bay, contributing to high primary and secondary productivities, is well established and documented. However, very few studies exist that conduct economic valuation of the marketable and the non-marketable services provided by the SAV. Although many papers exist in the literature that value estuarine resources and quality improvements in the estuarine, only two papers (to the knowledge of the authors) directly address the economics concerning SAV. The first by Kahn and Kemp employs an empirical methodology to derive a lower bound of the marginal damage function for reductions in the level of SAV in the Chesapeake Bay(Kahn and Kemp 1985). The other work, more recent, employs simulation methods to derive the economic benefits of SAV restoration for the Virginia hard shell blue crab fishery (Anderson 1989). We model the benefits to the crab fishery in our analysis.

In the absence of better information, we specify a quadratic functional form for the benefit function of SAV. Assuming that the benefits of a given stock of SAV occur in each period till infinity, the true benefit for a given stock of SAV would include infinite discounting of the benefits to the current period. Equation (9) lists the discounted quadratic benefit function B(S), where *S* is the stock of the SAV and *d* is the discount factor.

(9) $$B(S) = d(aS + bS^2)$$

The marginal benefit corresponding to the quadratic specification is given by Equation (10).

(10) $$MB(S) = d(a + 2bS)$$

The elasticity of marginal benefit (ε) at a given level of S (say $\hat{s}$) is given the formula $\varepsilon = 2bd\hat{s} / MB(\hat{s})$. For given SAV stock, the value of the marginal benefit at that stock level (obtained from the Anderson paper), and assumptions of the value of elasticity the formula is used to calibrate the values of the parameter b in the quadratic specification. Once b is known, a can be determined.

The calibration of the model using different starting values of elasticity reveals that lower is the rate at which the marginal benefit of an incremental unit of SAV decreases, more optimal would it is to restore more.

Results

The non-linear optimization problem was run separately for the baseline model and for the model with climate change. The probabilities assigned to the later model are 0.2, 0.5, and 0.3 for the scenarios *l, m, h* respectively. Table 2 reports the optimal restoration choices at the two sites under the baseline and climate change models for different specification of elasticity. The results align with intuition. It is always optimal to restore the shallow site first, irrespective of which model one considers, as the restoration success ratio is higher for the shallow site under both models. This is the result of the way we have set up the model. Restoration in the deep site is optimal when the shallow site has been restored to its maximum capacity. The maximum capacity for restoration is indicated in bold fonts in the table.

With climate change, it optimal to restore less at both sites compared to the baseline model. Intuitively, one would restore less in the current period at any site if there were a risk of restored SAV getting wiped out in the future period. Optimal decision-making under climate change requires less restoration at the deeper sites.

Table 2: Optimal restoration targets (in 1000 square meters) under the baseline model and the climate change model

Elasticity (-)	Baseline		Climate Change	
	Shallow	Deep	Shallow	Deep
1.0	9012	0	6586	0
0.95	12883	0	10774	0
0.75	**23688**	1444	**23688**	0
0.68	**23688**	**7258**	**23688**	7013
0.5	**23688**	**7258**	**23688**	**7258**

Sensitivity analysis

Table 3 shows the results of sensitivity analysis of the probability specification for the three scenarios under climate change model. The table reports the results for value of elasticity, -0.95 and -0.68. At the higher value of -0.95, it is optimal to restore the shallow site but not the deep site. Under this specification of elasticity, we can see clearly how restoration choices at the shallow site change in response to different specifications of probabilities. At -0.68, restoration choices are positive for the deep site and variation in the optimal restoration choice for the deep site in response to alternative specifications of the probability distribution can be seen.

A represents the case of ‘maximum’ climate change while F represents the case of ‘no’ or ‘very little’ climate change. Optimization results establish maximum restoration at both sites under case F and the least restoration at either site under Case A. F represents the case where all the three scenarios are equally probable. Commensurate with intuition the restoration choices at both sites drop relative to 'no climate change' case F. Cases A to D show the optimal solution for different probability weighing between the medium and higher sea level rise scenarios. The higher is the probability weight given to the high sea level rise scenario in any case, lower is the restoration choice at both sites for that case. The loss in the SAV stock will be more under the higher sea level rise scenario and correspondingly it would be optimal to restore less under that state.

Table 3: Sensitivity analysis results for the probability specification for the climate change model

Case				Elasticity			
	Probabilities			0.95		0.68	
	l	m	h	Shallow	Deep	Shallow	Deep
A	0.2	0.3	0.5	9002	0	Full	3915
B	0.2	0.4	0.4	9943	0	’’	5543
C	0.2	0.5	0.3	10774	0	’’	7013
D	0.2	0.6	0.2	11511	0	’’	**7258**
E	**0.33**	**0.33**	**0.33**	9450	0	’’	4572
F	0.5	0.3	0.2	9531	0	’’	**7258**

Conclusions

The simulation results clearly indicate that restoration choices under the baseline model are sub optimal under the climate change model. This has important policy implications for the SAV restoration program in the Chesapeake Bay. A restoration target that requires restored SAV at all site known to have historical abundance, as is currently being pursued in the Bay, is not the optimal restoration strategy when one considers climate change. Results suggest that current restoration policies are beneficial with current climate. The same restoration activities maybe sub optimal when one takes climate change into account. Adaptive restoration strategy would favor more restoration in the shallow regions of the Bay relative to the deeper region of the Bay.

Reference

Anderson, E. E. (1989). "Economic Benefits of Habitat Restoration: Seagrass and the Virginia Hard-Shell Blue Crab Fishery." North American Journal of Fisheries Management **9**: 140-149.

Chesapeake Bay Program (2003). 2002 Chesapeake Bay SAV Abundance and New BaywideRestoration Goal. **2004**. www.chesapeakebay.net

Environmental Protection Agency (2004). River Corridor and Wetland Restoration. **2004**. http://www.epa.gov/owow/wetlands/restore/

Fonseca, M. S., W. J. Kentworthy, et al. (2001). Seagrasses. Handbook of Ecological Restoration.

Heimlich, R. (2003). Agricultural Resources and Environmental Indicators, 2003. Agriculture Handbook No. (AH722), Economic Research Service, U.S. Department of Agriculture.

Kahn, J. R. and W. M. Kemp (1985). "Economic Losses Associated with the Degradation of an Ecosystem: The case of Submerged Aquatic Vegetation in the Chesapeake Bay." Journal of Environmental Economics and Management **12**: 246-263.

LeRoy Poff, N., M. M. Brinson, et al. (2002). Aquatic ecosystems & Global climate change, Pew Center on Global Climate Change.

Louis Berger and Associates. (1997). Costs for wetland creation and restoration projects in the glaciated Northeast. U.S. Environmental Protection Agency, Region 1, Boston, Massachusetts.

MARA (2001). Preparing for aChanging Climate: The Potential Consequences of Climate Variability and Change.Chapter 7. Coatal Zones. , Mid-Atlantic Foundations.

Malcolm, J. and L. Pitelka (2000). Ecosystems and Climate Change: A Review of Potential Impacts on Terrestrial Ecosystems and Biodiversity, The Pew Center for Climate Change.

Moore, K. A. and R. J. Orth (1997). Evidence of widespread destruction of submerged aquatic vegetation (SAV) from clam dredging in Chincoteague Bay, Virginia, Report to the Virginia Marine Resources Commission**:** 6.

Parmesan, C. and G. Yohe (2003). "A globally coherent fingerprint of climate change impacts across natural systems." Nature **421**(2).

Society for Ecological Restoration Science & Policy Working Group (2002). "The SER primer on Ecological Restoration.".

Wu, J. and W. G. Boggess (1999). "The Optimal Allocation of Conservation Funds." Journal of Environmental Economics and Management **38**: 302-321.

Wu, J. and K. Skelton-Groth (2002). "Targeting conservation efforts in presence of threshold effects and ecosystem linkages." Ecological Economics **42**: 313-331.