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Financial Assessment of Agricultural Lands at Risk to Coastal Salt Marsh Migration in Relation to Climate Change Induced Sea Level Rise in Dorchester County, Maryland

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Financial Assessment of Agricultural Lands at Risk to Coastal Salt Marsh Migration in Relation to Climate Change Induced Sea Level Rise in Dorchester County, Maryland

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Abstract

The increasing rate and effects of sea level rise is a major environmental concern in the Chesapeake Bay. This paper evaluates the impacts of rising sea level on coastal salt marshes and the surrounding agricultural lands at risk in Dorchester County, Maryland to build off existing environmental monitoring work performed by NOAA's Sentinel Site Program. The results of the spatial analysis were used to estimate monetary benefits to incentivize farmers to protect these marshes by making their land available for marsh migration to occur. Looking at three scenarios of sea level rise and marsh migration, grain crops (corn, soybeans, and sorghum) are most at risk to potential marsh migration and sea level rise. Areas along the west coast (Taylors Island), the centrally located tributaries, and the coasts of the northwestern tip will be most at risk. The spatial and financial results this analysis will be used in future conservation and climate change resiliency planning.

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Tables

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1.0 Introduction

The rate and effects of seal level rise is a major environmental concern in the Chesapeake Bay (Cronin, 2013). This rise is primarily a result of warmer ocean temperatures and melting glacial ice induced by changes in climate (Meehl et al., 2007). There are also geological factors in the Bay that might exacerbate the negative impacts of accelerated sea level rise such as groundwater withdrawal and land subsidence (Craft et al., 2008). Ecosystems and human populations along the coasts will be the first to experience these impacts. This is critical because over 18 million people live in the Chesapeake Bay proper with densely populated coastal areas exceeding 300,000 (Chesapeake Bay Program, 2016). Coastal lands are also ideal for human activities such as recreation, fishing, and agriculture. Given the Bay's valuable coastal resources, the population is expected to increase in the near future. Therefore, the impacts of higher sea levels will be highly variable, making it challenging for managers and scientists to quantify potential damage and develop solutions.

Sea level rise (SLR) threatens many of the Bay's coastal lands and some wetlands due to their low elevation and proximity to water in the intertidal zone. For example, salt water intrusion, increased flooding, and fluctuations in ocean currents (a hydrological factor that would circulate sediments and nutrients for wetland productivity), (Neubauer and Craft 2009; Delgado, 2013). Accelerated SLR not only threatens the ecosystem's ecological functioning, but also the species and coastal communities that depend on wetland ecosystem services. For example, coastal salt marshes have sustainable habitats and coastal vegetation for coastal species such as waterfowl, blue crabs, and fish (National Wildlife Federation, 2008). Additionally, wetlands provide critical economic benefits for coastal communities such as flood mitigation, storm protection, pollution reduction, and water filtration (Barbier et al., 2011). In the U.S., ecosystem services in coastal wetlands are valued at about $10,000 per hectare (Kirwan and Megonigal, 2013). As the rate of rising sea level continues to increase, the value of these services will likely decline.

However coastal wetlands, specifically tidal marshes, are resilient and can adapt to higher sea levels by vertical accretion and lateral transgression, which take place above and below ground. Vertical accretion is the process of wetland surface build up through accumulation of sediment substrates (Lynch et al. 2015). Above ground, “mineral sediment settles out of the water column and onto coastal wetland soils during periods of tidal flooding, so that deposition rates are highest in low elevation marshes that are inundated for long periods of time, and lowest in high elevation marshes that are more rarely flooded”. Plant shoots in the marsh “influence mineral sediment deposition by slowing water velocities and add organic matter to the soil surface. Below ground, the balance of plant root growth and decay directly adds organic matter to the soil profile, raising elevation by sub-surface expansion” (Kirwan and Megonigal, 2013). Researchers have found salt marshes maintained elevation in equilibrium with sea level via mineral sediment accumulation over 4000 years (Redfield, 1965,1972; Morris et al. 2002).

Additionally, Kirwan et al.’s research has demonstrated the growth of Spartina alterniflora, a dominant marsh grass, is positively correlated with interannual variations in sea level (2013). The unique feedback loops of increased plant productivity, sediment accumulation, and standing biomass allows marshes to migrate landward at higher elevations. However, human development and agricultural production are limiting factors in the available land that salt marsh migration will require (Feagin et al. 2010). Specifically in the Bay, there is a large presence of urban settings and infrastructure. Moreover, much of the land is privately owned and used for farming, which limits state governments and/or conservation groups from leading protection initiatives.

To increase land availability and allow salt marshes to migrate upslope, it is best that adjacent farmlands be proactively removed from production. Doing so will initially raise concerns for farmers regarding land ownership and their economic stability. Monetary incentives, in the form of one-time payments, can serve as a solution by protecting farmer's future profitability. Moreover, early adopters may benefit from funding availability while those that wait for yields to plummet may experience more competition and decreased funding.

2.0 Objective(s): The inherently spatial nature and variability of salt marshes, sea level, and human development makes GIS an ideal tool to examine the effects of sea level rise and ecosystem response. The objective of this project is twofold:

- To identify what areas of agricultural lands overlap (deemed at risk) with areas of potential wetland migration under different scenarios of projected sea level rise.
- To estimate payments to incentivize farmers to make their land available for coastal marsh migration and conservation.

3.0 Study area

Dorchester County, Maryland is the largest county along the eastern shore of the Chesapeake Bay. It is located within the Choptank River Complex, consisting of the Choptank River and its major tributaries (Little Choptank River, Nanticoke River, and Fishing Bay). The county's land area is 2,545.93 km^2 with a population of 32,578 (World Atlas, 2016). More than 50% of the county's land area is below 4.9 feet (1.493m) above sea level (Cole, 2008). It typically has a warm, humid temperate climate with average annual temperatures of 23.3C (73.9 F) and an average annual precipitation of 1,168.4 mm (46 in) (U.S. Climate Data, 2016). Many areas throughout the county are privately owned and/or heavily used for agricultural production, its primary economic driver along with commercial fishing.

I selected Dorchester County for this study to build on existing conservation efforts employed by the National Oceanic and Atmospheric Administration's Sentinel Site Cooperative. The cooperative consists of several ecosystem-based study sites in the Chesapeake Bay that measure the impacts of sea level rise. Additionally, the program works to improve partnerships with coastal managers, community liaisons, and decision makers to maximize effective data collection and modelling as well as to implement new methods and technologies (Wilkins, 2016). This is important given that Dorchester County is largely comprised of about 243 km^2 of marsh and wetland ecosystems, particularly along areas of lowest elevation (Chesapeake Bay Program, 2016).

4.0 Corporate Social Responsibility in Marsh Migration

Making land available for coastal marsh migration to occur in Dorchester will require farmers to be proactive in future planning and conservation efforts. Archie Carroll's pyramid of Corporate Social Responsibility (CSR) can guide farmers' steps in operating in an ecologically friendly way while understanding their roles in protecting salt marshes. CSR refers to corporate action beyond what is required by laws and regulations. In these actions, corporations or business owners improve their social responsibility while maintaining or even increasing their bottom line (Carroll, 1991).

The pyramid encompasses four components, each of which entails specific responsibilities for firms to execute. These components are economic, legal, philanthropic, and ethical (figure 1). Specifically, these components will aid in developing operational policies and practices that are efficient, moral, and profitable (Carroll, 2016). Aupperle et al. (1984), and other researchers, gave evidence on how each component is both valid and critical for decisions and actions beyond a firm's direct interest.

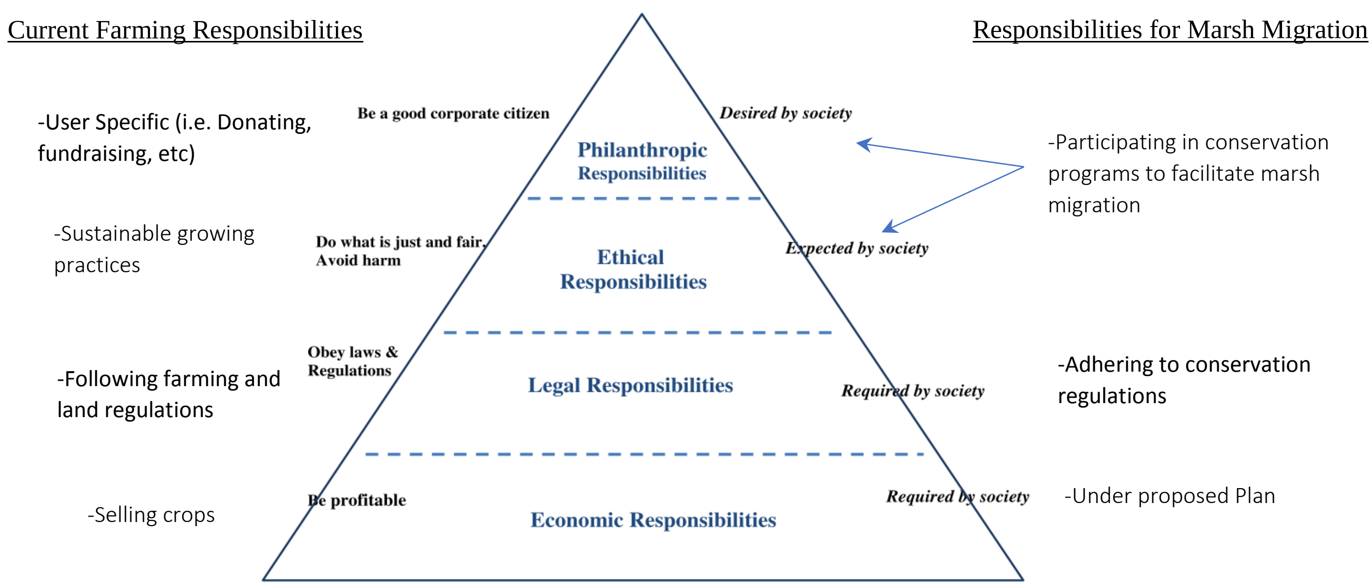

Fig. 1 Carroll's pyramid of CSR

Figure 1*: Current activities versus potential marsh migration program activities for Farmers in Dorchester County, MD. Each activity aligns with Carroll's pyramid of Corporate Social Responsibility to ensure they fulfill the economic, legal, ethical, and philanthropic activities.*

4.1 Economic Responsibilities

According to the economic component, a business organization's principle role in providing goods and services is to be profitable (Carroll, 1991). This component is the foundation of the CSR framework because all other business responsibilities are dependent on the firm's economic responsibility. Farmers are local business owners who provide raw materials to the county's population. By forfeiting their lands for upslope marsh migration to occur, they would be forfeiting future profitability. However, the estimated payments, calculated in this analysis, for transitioning their land are roughly equivalent to farmers' future profitability if they were to keep crops on their lands. This alleviates concerns that farmers might have about surrendering their future profits. From another perspective, if farmers keep their land for production, their crops are vulnerable to salt water intrusion and inundation from future SLR. Consequently, the costs due to crop damage would hinder farmers' ability to be profitable anyway.

4.2 Legal Responsibilities

Businesses are expected to structure their operations to comply with laws, standards, and regulations promulgated by federal state and local governments (Carroll, 1991). Many of these laws often reflect public interests and stakeholder concerns regarding environmental protection. Government programs and assistance mandated by Congress can support farmers in transitioning their land for marsh migration and simplify their efforts in meeting their legal responsibilities.

4.3 Ethical Responsibilities

To fulfill their ethical responsibility, farmers should consider the potential ethical consequences to the county population of hindering marsh migration. Salt marshes provide value to both the population's economy and well-being. If farmers remain a barrier to marsh migration and marshes do not have the space to adapt to SLR, vital ecosystem services would no longer be available. This could threaten the economic health and well-being of the population. Carroll

(1991) explains that a firm's practices should embody ethical norms of fairness and justice that are codified into law, but are expectations of what consumers, communities, employees, and shareholders regard as fair. By taking initiative in facilitating coastal salt marsh migration, farmers will fulfill their ethical responsibilities. Furthermore, the payments calculated in this analysis would also help farmers achieve their goals without compromising ethical norms in the county.

4.4 Philanthropic

Philanthropic responsibilities include actions that meet society's expectation for businesses to be good corporate citizens (Carroll, 1991). Farmers achieve corporate citizenship by actively partaking in conservation efforts for marsh migration that promote the health and quality of marshes in Dorchester. This would include supporting conservation programs, learning more about the marsh migration phenomenon, and increasing the county's overall resiliency to future SLR. Furthermore, the estimated payments for ceasing production on their land could serve as another resource to carry out philanthropic activities.

5.0 Data

This study uses spatially aggregated data from three sources: a county polygon boundary layer from the State of Maryland, land cover data showing marsh migration and sea level rise from NOAA Office for Coastal Management as well as National Cropland data obtained from the U.S. Department of Agriculture's National Agriculture Statistics Service CropScape (see table 1).

The data from NOAA provides a preliminary look at the scale of potential sea level rise and coastal flooding impacts. The water levels in the scenarios represent inundation during the highest high tides (NOAA-SLR, 2017). The impact is based on subtracting how much accretion will occur at each time period from the amount of sea level rise impact (Harold, 2017). Each scenario in this study was based on a 2 mm/year accretion rate, which was selected based on Leonardi et al.'s previous research as a reasonable rate for vertical accretion (2016).

Table 1

Data Layer	**Data Type**	**Resolution**	**Units**	**Description**	**Source**
Projected Marsh Migration and Sea Level Rise	Raster	10	M	Includes landcover categories of the county. Depicts the potential inundation of coastal areas resulting from projected 1 to 6ft rise in sea level	Dept. of Commerce-NOAA, NOS, OCM https://www.coast.noaa.gov/slr
2010 Cropland Cover	Raster (tiff)	30	M	Cropland data for Dorchester county	https://nassgeodata.gmu.edu/CropScape/

6.0 Methodology

6.1 Sea level rise/Marsh Migration

All data conversion and spatial analyses were performed in Clark University's Geospatial Monitoring and Modeling software, TerrSet. Three sea level-marsh migration scenarios were analyzed: 1 foot (low rise), 3 feet (mid rise), and 4 feet (extreme rise). These scenarios were chosen for this study based on current observations and prediction of water levels (Sweet et al. 2017). The impacts on crops in each scenario were evaluated at time scales of 50 years and 100 years to see the effects and variability of scale.

I first converted sea level-marsh migration data from image format to TerrSet raster format using the GDAL conversion utility tool. Additionally, I projected the data for each scenario into Maryland State Plane Coordinate System Zone 1 to match that of the Dorchester County boundary. The sea level-marsh migration data was in 10 meter resolution. I changed the resolution of the cropland layer to match by reclassifying the values of the minimum and maximum x and y coordinates to units of 10 for the county, subtracted the minimum and maximum and divided by 10 to get the columns and rows. The two marsh categories analyzed were brackish and estuarine marshes because of their adaptability to increases in sea level. I reclassified the land cover data to isolate only estuarine and brackish marshes by assigning a new value of 1 to the former and 2 to the latter. I completed the same procedure for each sea level rise scenario. The data representing sea level-marsh migration at 1 foot of SLR in 50 years was used as the basis for comparison because, in this scenario, the rate of accretion offsets the height of the sea, resulting in no impact (Harold, 2017).

6.2 Agricultural/Croplands in Dorchester County

I derived my crop layer in the following way. In CropScape, I used the "define the area of interest" feature to highlight Dorchester County and then selected the "area of interest statistics" feature, with the "Display Crops Only" button checked. Selecting all values with their respective categories, I exported the selected crops as a layer for mapping. The crop data layer for 2010 was used instead of the most recent 2016 data because the spatial distribution of crop cover in 2016 was significantly less than 2010, which would not best illustrate the potential impacts of marsh migration on crops. This data was also converted into TerrSet raster format using the GDAL Conversion Utility tool and projected to Maryland State Plane Coordinate System Zone 1 for consistency.

6.3 Analysis

For each marsh migration and sea level rise scenario, I created a Boolean image using the Assign and Editor tools where a value of 1 was assigned to areas of wetland presence and a value of 0 indicating no wetlands present. A Boolean image is a Binary image that contains only values of 0, indicating a pixel does not contain the desired condition, and a value of 1 where the pixel(s) do meet the desired condition. I overlayed the Boolean image of wetlands with the Cropland layer using the Overlay tool. The overlay math operation for each scenario was First * Second. To determine the results, I used the Area tool selecting Tabular output format on the result to calculate the amount of each category of crop in hectares that would be affected (see figure 3).

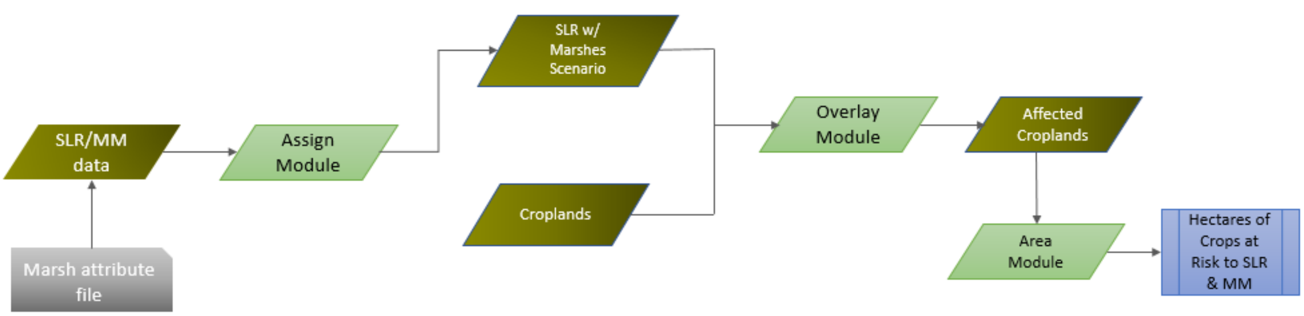

***Figure 3**: Methodology of steps performed for determining crops at risk to marsh migration in each scenario of projected SLR forward 50 years and 100 years. These steps were completed in TerrSet.*

6.4 Calculating Financial Incentives for Farmers

I determined monetary benefits to incentivize farmers to make land available for marsh migration and conservation efforts. The idea for this incentive plan is modeled after the U.S. Department of Agriculture's Conservation Reserve Program (CRP) administered by the Farm Service Agency. The CRP is a land conservation program where farmers voluntarily remove environmentally sensitive land from agricultural production and plant certain species to improve the land's environmental quality in exchange for annual rental payments, (USDA-FSA, 2016).

I used the present valuation method to calculate a one-time payment for farmers based on the current, annual yield values for the crops at risk to marsh migration and SLR. The present valuation method, or present value, is the current value or worth of a future stream of cash flows discounted at a specific rate over time (see figure 4). Future cash flow values are based on previous crop prices and costs in Maryland outlined in the University of Maryland's 2016 Field Crop Budgets. For simplification, I utilized a nominal discount rate of 2.1%, which is a government discount rate that includes inflation assumptions relevant for planning (USDA-NRCS, 2016). The value of t as the period will be the timeframe of the predicted sea level rise at the two time scales of interest (50 years and 100 years). Due to the nature of the environmental and economic conditions that cause fluctuations in crop production and profit, assumptions were made and will be later addressed in the limitations section of this paper.

$$\boldsymbol{PV = \frac{C}{r}\left[1 - \frac{1}{(1+r)^t}\right]}$$

Where:
PV = present value
C = cash flow for crop (based on 2016 UMD Crop Budget)
r = discount rate
t = time (in years)

Figure 4: Present valuation formula used for estimating payments as monetary incentives for farmers.

7.0 Results

7.1 Marsh Migration

The spatial distribution of brackish and estuarine marshes in Dorchester County significantly changed under each scenario of SLR projected at the two different time scales (see figure 5). Looking at the scenarios projected forward 50 years, marshes potentially will migrate and spread across the southern half of the county. Compared to the present wetland cover in figure 5a, the open area east of Taylors Island Wildlife Management will be completely inundated at both 3 feet and 4 feet SLR. Similarly, the extent of marsh cover increases along the county's entire east coast at 3 feet and 4 feet of sea level. Scenario 3 of extreme rise (figure 5c) has the most marsh cover compared to the current conditions (figure 5a) and the midrise scenario (figure 5b).

Looking at the scenarios projected out 100 years (figure 5 d-f), the extent of salt marsh cover shifts from the southern half of the county to the central and northwestern part. In the midrise scenario, there is less coverage along the southern part of the county compared to the coverage in current conditions, but extends further west. Marsh presence also increases just outside of the northern county boundary in Nanticoke River and Choptank River. Marsh cover in the extreme rise projection (4 feet) differs from both the current cover and the midrise scenario as the extent is smaller and concentrated in the northwest tip of the county. This could be due to the southern areas would be completely flooded or inundated where salt marshes would not be able to thrive.

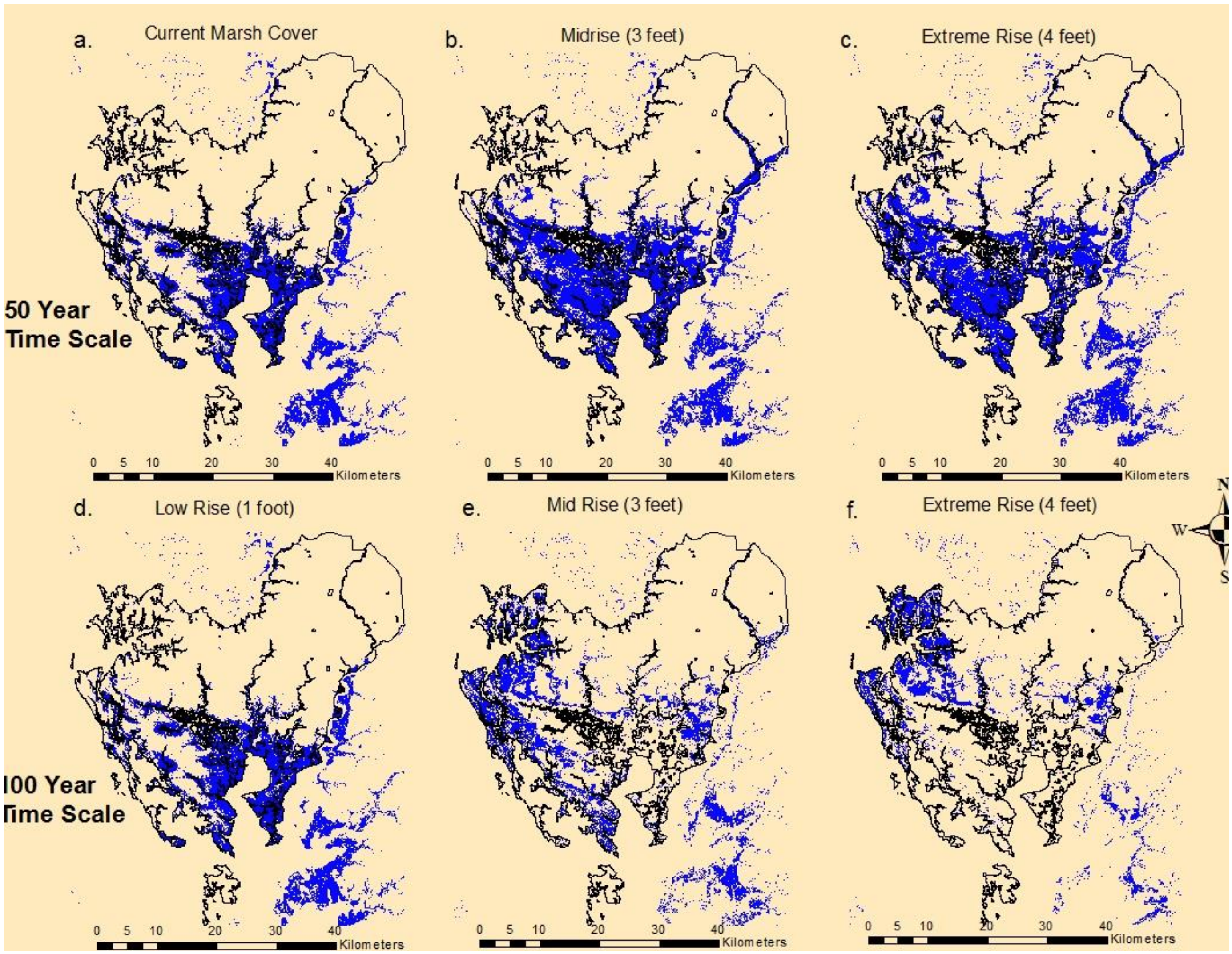

Figure 5*: Spatial distribution of potential marsh migration in relation to 1foot, 3 feet, 4 feet of SLR projected out 50 years (top row) and 100 years (bottom row).*

7.2 Crops at risk to Marsh Migration

The original cropland layer has 42 different categories of crop and cropland types for Dorchester County. For each scenario, the analysis revealed that almost all the categories would be at risk to marsh migration in relation to projected SLR. However, many of them are a very small percentage that can be considered negligible for this paper. I focused on the seven crop categories that were found in the analysis to be most affected across all scenarios for simplification. These categories were soybeans, corn, grass pasture, sorghum, fallow/idle land, double crop (winter wheat/soybeans) and other hay/non alfalfa. The remaining negligible crops were categorized into the "all other crops" category (see figure 6).

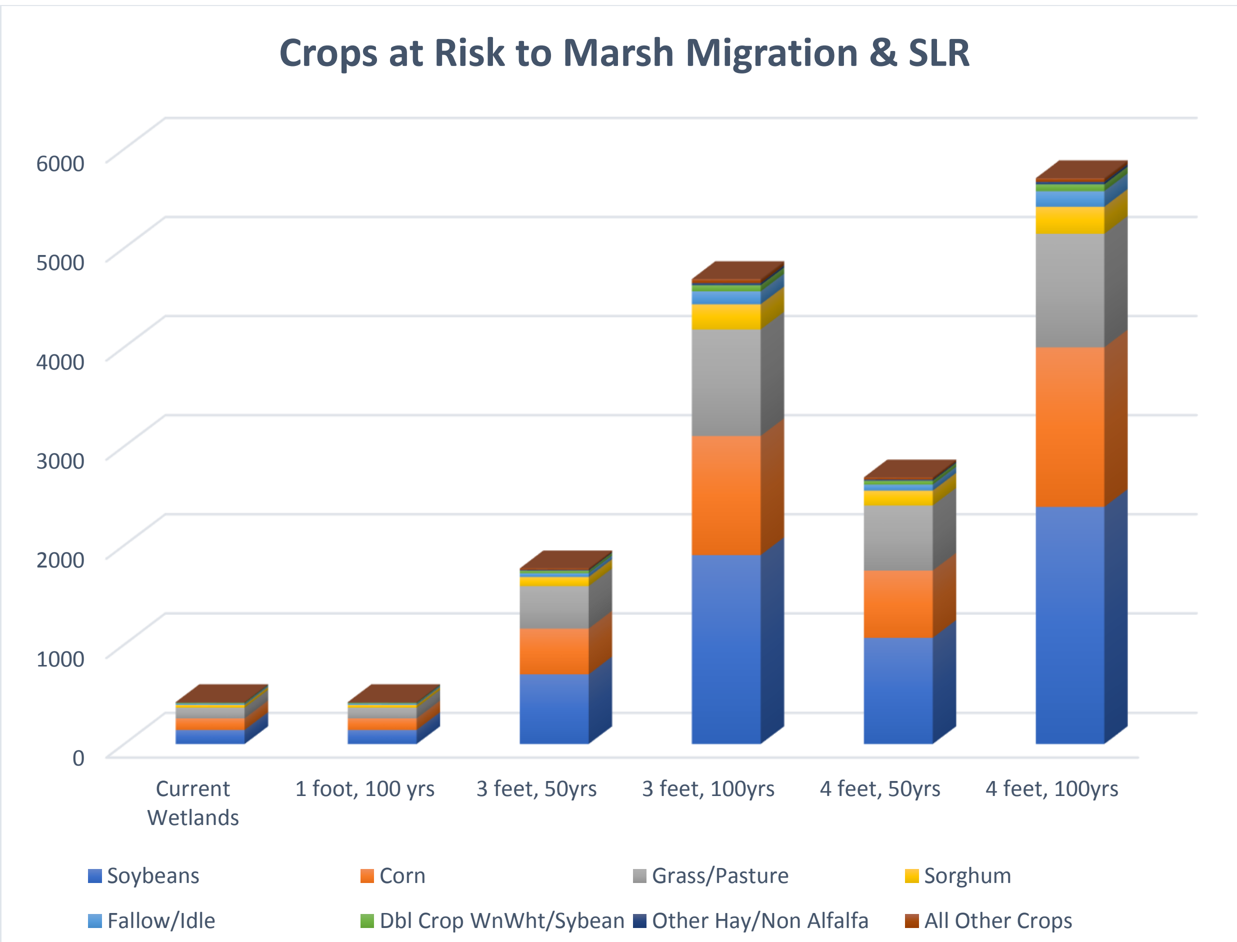

Figure 6*: Results of 7 major crop categories at risk (in hectares) to marsh migration and SLR projected forward 50 years and 100 years. Large hectares of crops at risk occur in the midrise and extreme rise scenario at the 100 year time scale.*

7.3 Scenario Results

7.3.1 Scenario 1-Low Rise Results

The analysis showed 421.49 hectares of crops in Dorchester County would be at risk to a 1 foot increase in SLR projected forward 100 years. In the analysis, soybeans are most at risk with about 142 hectares while other hay/non alfalfa are the least at risk with only 4 hectares at risk. Figure 7 depicts very small clusters of crops at risk primarily along the coastlines of the county. Along the northern coasts adjacent to the Choptank River, a very small cluster of crops (mostly soybeans and grass/pasture) will potentially affected. Similarly, a stretch of crops at risk are present in Taylors Island on the west coast (figure 7b). Other small clusters of crops at risk were found along the tributaries centrally located inland.

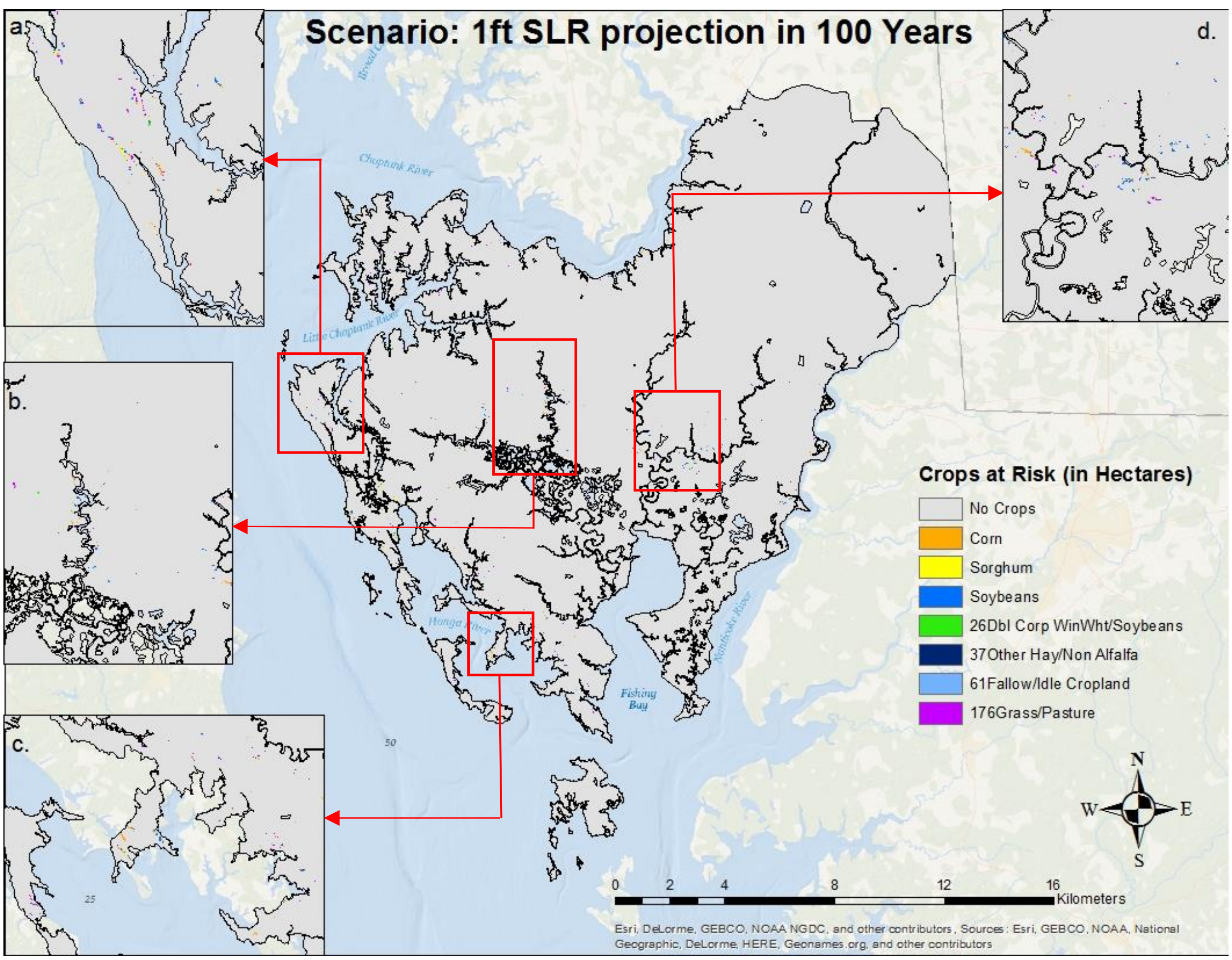

Figure 8*: Crops (in hectares) at risk to 1 foot SLR projection forward 100 years in Dorchester County, MD.*

7.3.2 Present Value Estimate for Scenario 1

About $8,000,000 US (8,292,689.45) is a present value-based estimate that could support farmers in areas at risk to 1 foot of SLR projected out 100 years as well as future planning for marsh migration (see calculations below). This estimate considers the current annual cash flow for grain crops (soybeans, corn, and double crop (winter wheat/soybeans).

$PV = \frac{C}{r}\left[1 - \frac{1}{(1+r)^t}\right]$ 1ft SLR, 100 years

Soybeans = 141.98 hectares (350.84 acres) at risk

C = $231.30 x 350.84 acres = $81,148.30

r = 2.1%

t = 100 years

$PV = \frac{81,148.30}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$ → $**3,380,605.00US**

Corn = 116.54 hectares (287.98 acres) at risk

C = $374.45 x 287.98 acres = $107,834.77

r = 2.1%

t = 100 years

$PV = \frac{107,834.77}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$ → **$4,492,352.49**

Double Crop-Winter Wheat/Soybean = 8.478709 hectares (20.95 acres) at risk

C = $480.89 x 287.98 acres = $10,075.28

r = 2.1%

t = 100 years

$PV = \frac{10,075.28}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$ → **$419,731.96US**

Total PV $_{scenario1}$**=$8,292,689.45**

7.3.3 Scenario 2-Midrise results

1,767.85 hectares of crops are potentially at risk to 3 feet of SLR projected forward 50 years. These potentially affected crops are centrally located inland rather than the coasts of the county (figure 8). 700.76 hectares of soybeans and 460.21 hectares of corn are most at risk while 8.43 hectares of other hay/non alfalfa lands are the least at risk. Several crop categories would be affected along the centrally located tributaries (figure 8a). Additionally, hectares of grass/pasture land and sorghum at risk are mostly present in the southwestern part of the county (figure 8c). Looking to the east, relatively larger areas of soybeans will be at risk (figure 8e) while crops are sparsely scattered along the county's east coast.

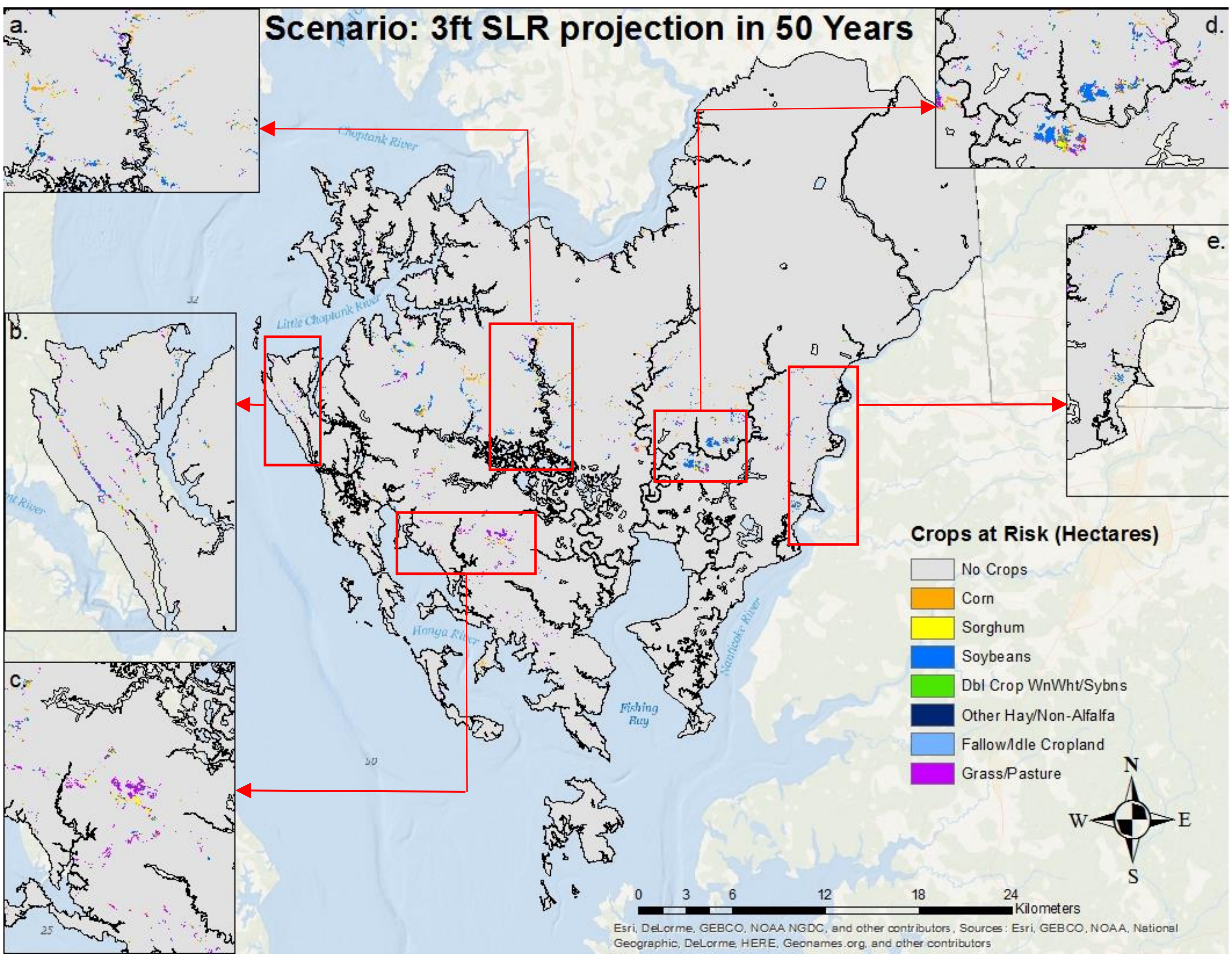

***Figure 8**: Midrise scenario of crops (in hectares) at risk to 3 feet SLR projection forward 50 years in Dorchester County, MD.*

The spatial distribution of crops at risk to displacement by 3 feet of SLR in 100 years is significantly different. At this scale, 4,688.05 hectares of crops are vulnerable to marsh migration, with soybeans (1,902.19) and corn (1,201.06) still having the most hectares at risk. The total hectares potentially affected at this time scale has almost tripled compared to 3 feet of rise at 50 years. Large areas of grass/pasture lands, corn, and sorghum are located in the northwestern tip (figure 8.2a). The extent of these crops range down to the central West half of the county. Similar to the crops at risk to 1 foot SLR forward 100 years, crops along the west coast and Taylors Island will potentially be displaced (figure 8.2b). However, this stretch of crops is mostly soybeans, corn, and sorghum.

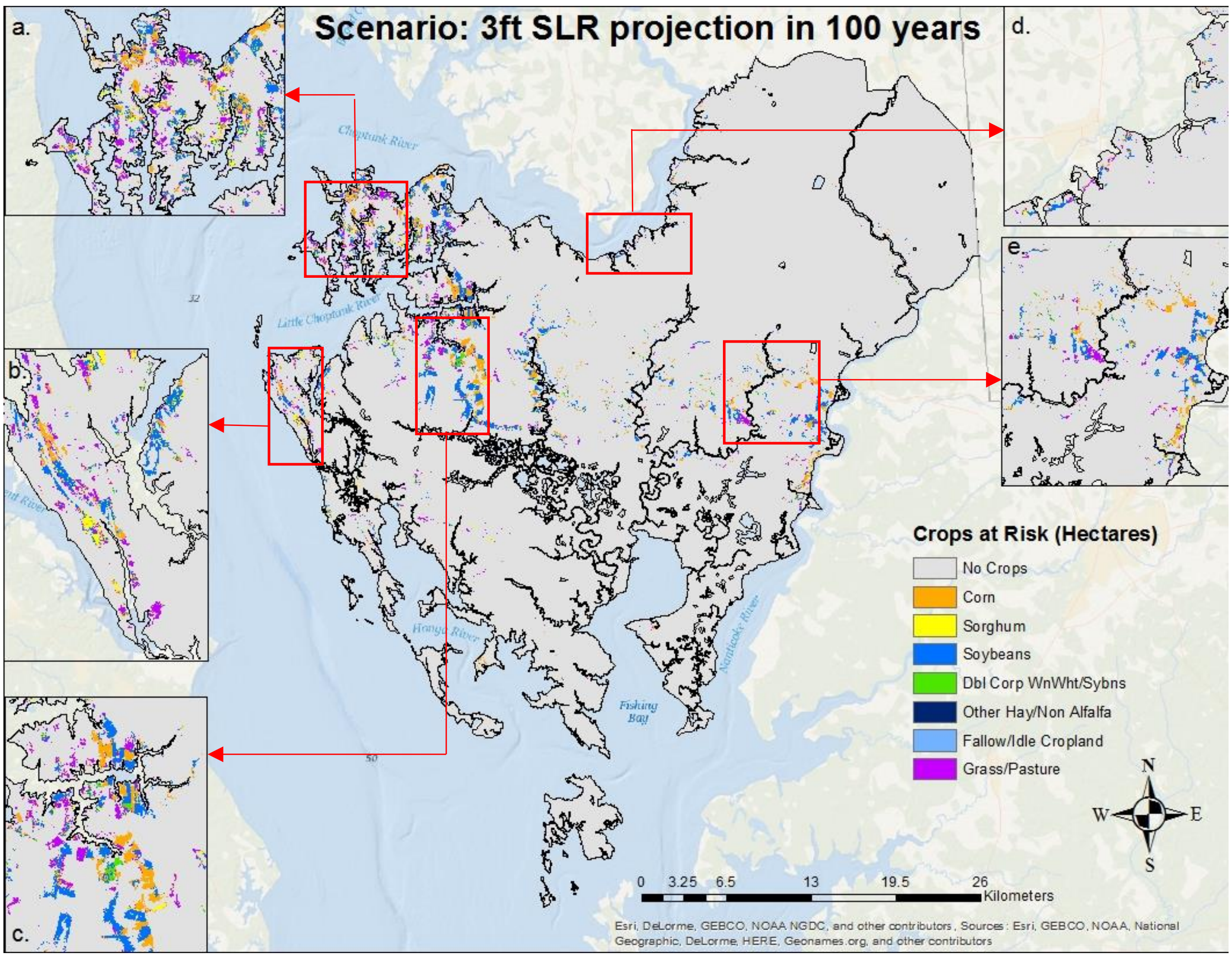

Figure 8.2: Midrise scenario of crops (in hectares) at risk to 3 feet SLR projection forward 100 years in Dorchester County, MD.

7.3.4 Present Value Estimate for Scenario 2

About $26,000,000 US ($26,382,930.03) is a present value-based estimate that could support farmers in areas potentially impacted by 3 feet of SLR projected forward 50 years (see calculations below). This estimate also considers the most recent annual cash flow for grain crops (soybeans, corn, and double crop (winter wheat/soybeans). For the same SLR projected forward 100 years, farmers could receive a present value based estimate of about $98,000,000.00 ($98,007,360.28).

$PV = \frac{C}{r}\left[1 - \frac{1}{(1+r)^t}\right]$ 3ft SLR, 50 years

Soybeans = 700.76 hectares (1,731.62 acres) at risk
C = $231.30 x 1,731.62 acres = $400,523.99
r = 2.1%
t = 50 years
$PV = \frac{400{,}523.99}{0.021}\left[1 - \frac{1}{(1+2.1)^{50}}\right]$ → **$12,325,393.33 US**

Corn = 460.21 hectares (1137.20 acres) at risk
C = $374.45 x 1,137.20 acres = $425,825.21
r = 2.1%
t = 50 years
$PV = \frac{425{,}825.21}{0.021}\left[1 - \frac{1}{(1+0.021)^{50}}\right]$ → **$13,103,992.11 US**

Double Crop-Winter Wheat/Soybean = 26.08 hectares (64.44 acres) at risk
C = $480.89 x 64.44 acres = $30,986.23
r = 2.1%
t = 50 years
$PV = \frac{30{,}986.23}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$ → **$953,544.60 US**

Total PV** $_{scenario2}$ **=$26,382,930.03

$PV = \frac{C}{r}\left[1 - \frac{1}{(1+r)^t}\right]$ for 3ft SLR, 100 years

Soybeans = 1902.19 hectares (4700.41 acres) at risk
C = $231.30 x 4700.41 acres = $1,087,204.29
r = 2.1%

t = 100 years

$PV = \frac{1,087,204.29}{0.021}\left[1 - \frac{1}{(1+2.1)^{100}}\right]$ → **$45,292,488.63 US**

Corn = 1201.06 hectares (2967.87 acres) at risk

C = $374.45 x 2967.87 acres = $1,111,319.78

r = 2.1%

t = 100 years

$PV = \frac{1,111,319.78}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$ → **$46,297,130.23 US**

Double Crop-Winter Wheat/Soybean = 129.64 hectares (320.35 acres) at risk

C = $480.89 x 320.35 acres = $154,051.95

r = 2.1%

t = 100 years

$PV = \frac{154,051.95}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$ → **$6,417,741.42 US**

Total PV $_{scenario2}$= $98,007,360.28

7.3.5 Scenario 3 extreme rise results

At the 50 year time scale, 2,686.15 hectares of crops will potentially be displaced by marsh migration and 4 feet of SLR. Like the previous scenarios, soybeans (1,068) and corn (677.94) have the most hectares at risk. The spatial extent of crops potentially affected is similar to crops potentially affected given 3 feet of SLR. However, unlike the midrise scenario, clusters of grass/pasture land are present in the northwestern time of the county facing the little Choptank River (figure 9a). Relatively larger clusters of grass/pasture lands at risk are located in the southwestern region of the county. There are also crops potentially affected that are located along the major tributaries (figure 9d). The extent of crops at risk in Taylors Island is also slightly larger (figure 9b). Like the previous scenario, some crops at risk are on the East coast. Overall, the largest amount of hectares of crops at risk are scattered across the county.

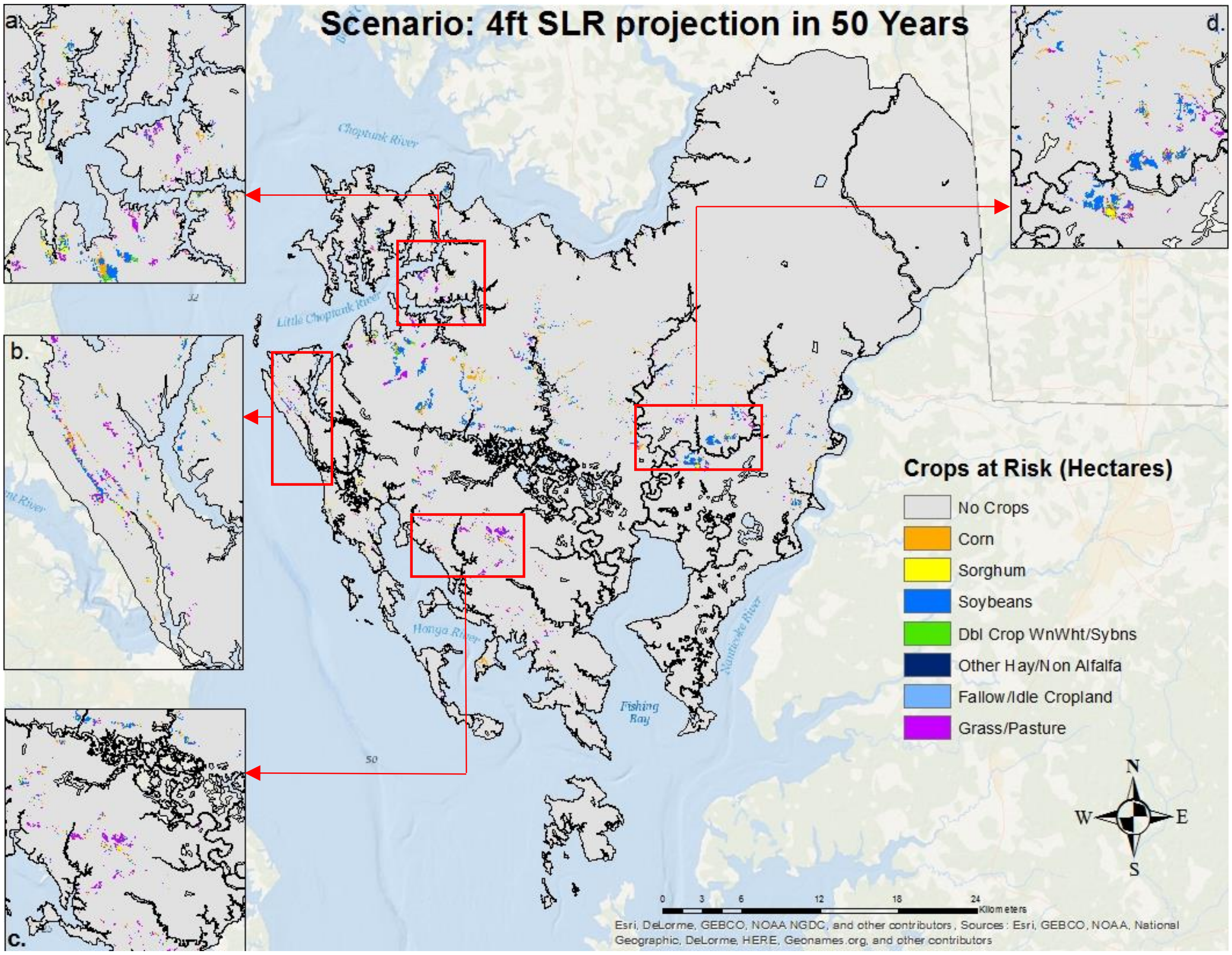

Figure 9*: Extreme rise scenario of crops (in hectares) at risk to 4 feet SLR projection forward 50 years in Dorchester County, MD.*

Looking at the 100 year time scale, 5,706.00 hectares of crops will potentially be displaced by a 4 feet rise in sea level. Soybeans (2388.08) and corn (1,610.30) are still the crops with the most hectares, as shown in the previous scenarios, while other hay/non alfalfa have the least hectares affected (25.00). There is a large presence of crops at risk in the northwestern tip of the county opening to the Little Choptank River (figure 9.2a). The stretch of crops at risk along the far west coast in Taylors Island looks very similar to the crops at risk in the midrise 100 year scenario. Additionally, the extent of crops scattered across the center of the county have increased in both size and spatial distribution (figure 9.2).

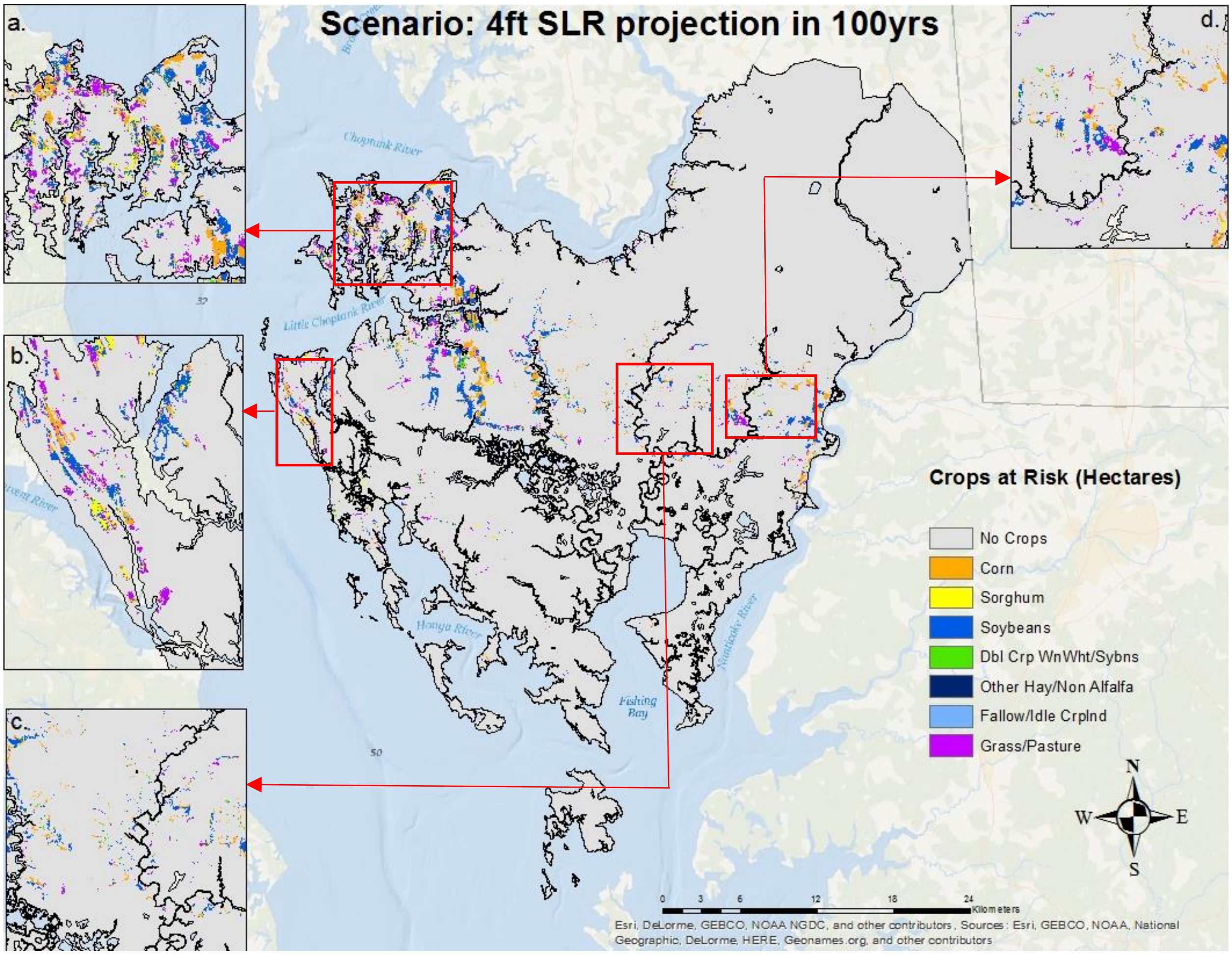

Figure 9.2*: Extreme rise scenario of crops (in hectares) at risk to 4 feet SLR projection forward 100 years in Dorchester County, MD.*

7.3.6 Present Value Estimate for Scenario 3

In this scenario, about $40,000,000.00 US ($40,319,254.79) is a present value-based estimate that could support farmers in areas at risk to 3 feet of SLR projected forward 50 years (see calculations below). Like the previous scenarios, this estimate considers the most recent annual cash flow for grain crops (soybeans, corn, and double crop (winter wheat/soybeans). For the same SLR projected out 100 years, farmers could receive a present value based estimate of about $126,000,000 ($126,758,607.86).

$PV = \frac{C}{r}\left[1 - \frac{1}{(1+r)^t}\right]$ for 4 feet SLR, 50 years

Soybeans = 1067.99 hectares (2639.05 acres) at risk
C = $231.30 x 2639.05 acres = $610,412.34
r = 2.1%
t = 50 years
$PV = \frac{610{,}412.34}{0.021}\left[1 - \frac{1}{(1+2.1)^{50}}\right]$ → **$18,784,323.61 US**

Corn = 677.94 hectares (1675.22 acres) at risk
C = $374.45 x 1675.22 acres = $627,284.53
r = 2.1%
t = 50 years
$PV = \frac{627{,}284.53}{0.021}\left[1 - \frac{1}{(1+0.021)^{50}}\right]$ → **$19,303,534.41 US**

Double Crop-Winter Wheat/Soybean = 61.02 hectares (150.78 acres) at risk
C = $480.89 x 150.78 acres = $72,511.11
r = 2.1%
t = 50 years
$PV = \frac{72{,}511.11}{0.021}\left[1 - \frac{1}{(1+0.021)^{50}}\right]$ → **$2,231,396.77 US**

Total PV $_{scenario3}$= $40,319,254.79

$PV = \frac{C}{r}\left[1 - \frac{1}{(1+r)^t}\right]$ for 4 feet SLR, 100 years

Soybeans = 2388.08 hectares (5901.06 acres) at risk
C = $231.30 x 5901.06 acres = $1,364,914.33
r = 2.1%

t = 100 years

$$PV = \frac{1,364,914.33}{0.021}\left[1 - \frac{1}{(1+2.1)^{100}}\right]$$ → **$56,861,775.97 US**

Corn = 1610.30 hectares (3979.14 acres) at risk
C = $374.45 x 3979.14 acres = $1,489,990.41
r = 2.1%
t = 100 years

$$PV = \frac{1,489,990.41}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$$ → **$62,072,394.42 US**

Double Crop-Winter Wheat/Soybean = 158.06 hectares (390.56 acres) at risk
C = $480.89 x 390.56 acres = $187,818.38
r = 2.1%
t = 100 years

$$PV = \frac{187,818.38}{0.021}\left[1 - \frac{1}{(1+0.021)^{100}}\right]$$ → **$7,824,437.47 US**

Total $PV_{scenario3}$= $126,758,607.86

8.0 Limitations and Future Work

There were several assumptions due to uncertainties made in this analysis. For example, the estuarine and brackish wetlands analyzed were all assumed to have a constant 2mm/yr wetland accretion rate in each scenario. However, the adaptability of coast salt marshes is often linked to varying sediment dynamics. Leonardi et al (2016) found salt marsh accretion is spatially variable as it depends on the exchange of sediments between salt marshes, tidal channels, and tidal flats. The rate of SLR was also assumed to be constant.

This was because the landcover-marsh migration data only considered water levels as they would appear during the highest high tides. However, the rate of SLR can vary in location and with seasonality (Fitzpatrick, 2013). For example, relative mean sea level during the summer growing season affects productivity by determining both flood frequency and soil salinity (Morris et al 2002). Future work would consider the rate of SLR in each scenario and how variation influence salt marshes' rate of accretion. Research needs to understand not only the spatial distribution, but also the overlap of multiple stressors on coastal salt marshes that can occur simultaneously (Crain et al. 2009).

There were also assumptions made for the crop yield values based on environmental, economic, and anthropogenic uncertainties. For instance, this study assumed future cash flows for crop will be constant. However, the value of crops often fluctuates based on changes in weather conditions, advances in technology, and market conditions. In calculating the payment estimates, assumptions were made because data was not available for the remaining four non-grain crop categories. Consequently, this does not provide much insight for farmers with non-grain crops and underestimates the value of the estimated payments. Future work would include the crop yield values for all crop categories affected to better support farmers in transitioning their lands. Future research can also identify a combination of potential funding sources to supply payments to farmers.

9.0 Conclusions

Grain crops such as corn, soybeans, and sorghum are most at risk to displacement by marsh migration in relation to sea level rise (SLR) in Dorchester County, Maryland. Crops in areas along the west coast (Taylors Island), the centrally located tributaries, and the coasts of the northwestern tip will be at risk to all three scenarios of SLR. Based on the results, these areas should be prioritized for conservationists and local governments to collaborate with farmers and make land available for marsh migration. These areas could also be starting points for outreach efforts to support community dialogue and engage groups such as the Eastern Shore Land Conservancy, Natural Resource Conservation Service, and many others. This analysis also showed the effects of temporal variability, as the results in each scenario varied between the two projected time scales. More crops potentially affected occurred at the 100 year time scale compared to the 50 year scale, which is a significant indication that SLR impacts will worsen as time goes on.

The present valuation method is a reasonable approach for determining appropriate payment to support farmers in transitioning their land. I estimated that paying farmers in Dorchester County to make their lands available for coastal salt marsh migration will cost roughly $8,000,000 under the low rise scenario (projected forward 100 years), $26,000,000 (3 feet SLR projected out 50 years) and $98,000,000 (3 feet SLR projected out 100 years) under the midrise scenario, and $40,000,000 (4 feet SLR projected out 50 years) and $126,000,000 (4 feet SLR projected out 100 years) under the extreme rise scenario. These investments will not only protect the quality of salt marshes, but also maintain the county's economic well-being based on the marshes' ecosystem services. Additionally, Carroll's pyramid of Corporate Social Responsibility can encourage farmers to be proactive in facilitating marsh migration while both achieving their economic responsibilities and considering society at large.

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