Exploring the Spatiotemporal Patterns of Agricultural Land Abandonment in the Eastern Shore of Virginia

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ABSTRACT

Agriculture is the primary land use globally, covering approximately 40% of the Earth's land. Despite the growing demand for agricultural products and the limited availability of suitable land for farming expansion, there is an increasing trend of agricultural abandonment, especially in the US. In recent decades, coastal areas, particularly the Atlantic and Gulf coasts in the US, have been adversely impacted by challenges such as sea level rise, saltwater intrusion, and waterlogging as key consequences of climate change. Therefore, agricultural abandonment is becoming an evident reality in such regions. As agricultural land abandonment and its contributing factors reveal distinct regional variations in the primary elements shaping this intricate phenomenon, this thesis uses the United States Department of Agriculture CropScape Data Layer (USDA CDL) from 2008 to 2022 to explore the spatiotemporal patterns of agricultural land abandonment in the Eastern Shore of Virginia, a coastal area, to provide insights into when and where these abandonments occur. This study also analyzes the regional characteristics of ESVA, such as elevation, drainage quality, as well as proximity to salt-affected areas, to investigate the specific traits of such coastal areas contributing to land abandonment. Applying the introduced framework, significant abandonment was observed in the years 2009, 2010, and 2018, with estimated abandoned areas of approximately 1764, 1516, and 1530 acres respectively, representing 96% of all recorded abandoned areas between 2009 and 2019. Our analysis revealed that 24% of abandoned areas were located in low-lying regions, with 16% affected solely by drainage issues, 27% by adjacent salt-affected areas, and 53% by both factors. Conversely, 76% of abandoned areas were situated in high-elevation zones, with 14% facing drainage issues alone, 39% affected solely by adjacent salt-affected areas, and 27% experiencing the combined impact of both factors. Also, calculating the probability of agricultural abandonment highlighted that the most severe instances of abandonment occur when poor drainage coincides with proximity to salt-affected zones. Moreover, while low-lying regions generally exhibit higher abandonment probabilities overall, similar challenges increased abandonment probability significantly in high-elevation areas as well. Our findings underscore the complex interplay of economic, climatic, and demographic factors such as the Great Recession of 2008-2009, the Nor'Ida Storm in 2009, increasing agricultural expenses, demographic changes, and inadequate regulatory frameworks to counteract farmland conversion pressures in the state of Virginia in influencing land abandonment patterns in ESVA.

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CHAPTER 1
INTRODUCTION

1.1 Background

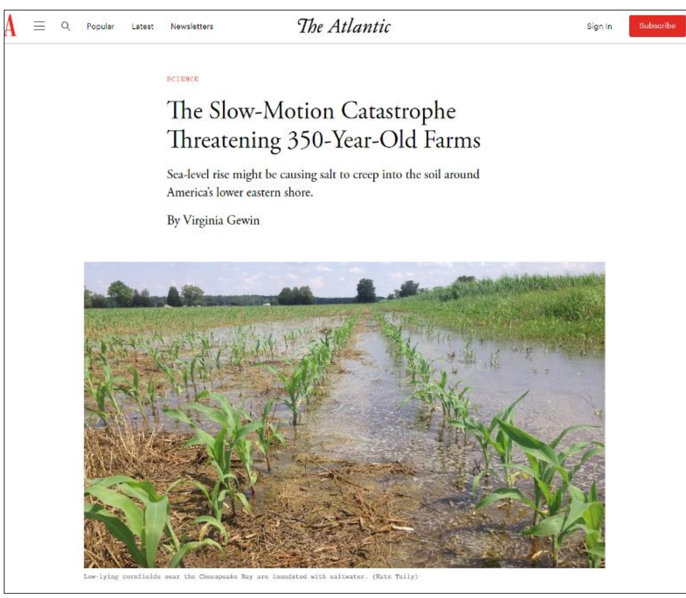
Agriculture is the primary land use globally, covering around 40% of the Earth's land. Despite the growing demand for agricultural products and the limited availability of suitable land for farming expansion, there is an increasing trend of agricultural abandonment, especially in developed countries (Levers et al., 2018). In recent decades, human activities and climate change have significantly impacted various ecosystems, particularly agricultural systems (Calzadilla et al., 2013; Cinner et al., 2022). Coastal areas, in particular, face challenges due to sea level rise, a key consequence of climate change. Along the Atlantic and Gulf coasts in the United States, farmers are increasingly grappling with saltwater intrusion, as a result of sea level rise (Lambrecht and Todd, 2020). Saltwater intrusion, characterized by the infiltration of saline water from the ocean into coastal lands, presents a significant concern, leading to soil contamination and rendering the lands unproductive (Lambrecht and Todd, 2020). As a result, agricultural abandonment is becoming an evident reality for many in these regions, emphasizing the pressing need for comprehensive solutions to sustain these vulnerable coastal communities (Gewin, 2018; Lambrecht and Todd, 2020)

Moreover, as coastal farmers contend with the repercussions of saltwater intrusion, it is crucial to acknowledge that sea level rise is just one among many factors contributing to the complex landscape of agricultural abandonment. The process of land abandonment is intricate and could be influenced by various social, economic, political, and environmental factors factors (Subedi et al., 2022). Factors impacting agricultural productivity, such as slope, elevation, soil quality, and distance to water sources are among the important environmental drivers of farmland abandonment (Wang et al., 2015). Also, factors like population change, labor, labor age, migration, technological advances, land revenue, and rent, as well as the density of settlements are frequently reported as important socioeconomic factors impacting agricultural land abandonment (Zhang et al., 2014). For example, in research conducted by Díaz et al, (2011), Prishchepov et al, (2013), and Zgłobic et al, (2020) it was highlighted that poor soil quality, high slope angles, and smaller farm size increase the probability of farmland abandonment significantly as in these cases, the lower average grain yields does not allow agricultural economic benefits outweigh the production costs. Furthermore, it was shown that the likelihood of abandonment rises with negative migration as well as increasing distances from nearby communities, and municipality centers as these factors affect transportation expenses and the availability of labor and infrastructure.

While agricultural land abandonment might have some positive impacts such as forest re-growth, improvement of carbon capture systems as well as recovery of ecosystem services, it may also come with significant downsides (Novara et al., 2017; Yu et al., 2017). For instance, cropland becomes less fertile for cultivation due to soil deterioration (Khanal and Watanabe, 2006). However, by disturbing the natural balance and driving out native plants and animals, invasive species exacerbate the situation even more (Rey Benayas et al., 2007; Leal et al., 2017). Furthermore, these neglected regions are more susceptible to wildfires, which could endanger local ecosystems and biodiversity (Levers et al., 2018). Meanwhile, the majority of these environmental issues affect local communities. Families that lose their jobs experience financial instability as a result of these hardships. In addition, these areas lose their monetary value as a result of declining property values, which limits their future prospects. Finally, the loss of traditional farming practices, once integral to community identity, deepens the sense of detachment from the land (Rey Benayas et al., 2007; Leal et al., 2017).

Although there has been a notable expansion of cultivated areas in numerous developing and tropical regions, the overall global extent of agricultural land has exhibited a downward trend since 2001 (Pearce, 2023). More specifically, arable land in the United States has diminished by approximately one-sixth over the past three decades primarily due to urbanization, excessive tillage, farming practices, as well as climatic crises (Vandenboss, 2021; Wilde, 2021; Pearce 2023). Coastal farms, as highlighted by different studies and news articles (Figure 1), are among the most vulnerable areas to agricultural land abandonment in the United States (Lambrecht and Todd, 2020; Sudol et al., 2023). This vulnerability is exemplified by the case of the Eastern Shore peninsula, where thousands of acres have been abandoned, spanning across Maryland, Delaware, and Virginia, between the ocean and the Chesapeake Bay (Gewin, 2018; Lambrecht and Todd, 2020; Sudol et al., 2023). On the other hand, it is important to mention that drivers of abandonment differ across different locations and time periods, with some being common globally and others specific to certain sites. Therefore, a comprehensive analysis of factors across various times and regions is necessary to ensure the development of policies that are both effective and aligned with the context of agricultural land management and abandonment in such vulnerable areas (Subedi et al., 2022).

Thousands of acres have been abandoned on the Eastern Shore peninsula that lies between the ocean and Chesapeake Bay, spanning three states. The long-farmed land was “the breadbasket of the revolution.”



While the farms have adapted to meet shifting demand, it is the unseen changes happening underfoot that may have a long-lasting impact. In the fields beyond the picturesque manor, six-foot-tall salt-tolerant weeds thrive. Nearby, a decaying corn cob lies in bare, bleached soil pocked with patches of blue-green algae. Last year’s dismal corn yield was this field’s last: The leasing farmer abandoned a 30-acre parcel. It’s amazing corn plants grew at all. “The soil salt content is six to seven parts per thousand. Corn, typically, won’t grow once salt is more than 0.8 parts per thousand,” says Keryn Gedan, a wetland ecologist.

Figure 1. News articles highlighting the agricultural land abandonment problem exacerbated by climate change in the Eastern Shore of Virginia (ESVA) (GewinGewin, 2018; Lambrecht and Todd, 2020)

1.2 Research Objectives

A review of the existing literature on agricultural land abandonment and its contributing factors reveals distinct regional variations in the primary elements shaping this intricate phenomenon. This underscores the necessity of a detailed evaluation of how these factors specifically impact different regions, a crucial step in crafting effective and tailored strategies to address the unique challenges posed by agricultural land abandonment. The primary objective of this thesis is to advance the study of agricultural land abandonment by exploring the spatiotemporal patterns of agricultural land abandonment in the Eastern Shore of Virginia (ESVA) to provide insights into when and where these abandonments occur. The ESVA is a low-lying coastal area with a sea level rise four times the global average, exacerbating challenges posed by saltwater intrusion (Lambrecht and Todd, 2020). This phenomenon causes soil contamination, rendering agricultural lands unproductive, resulting in agricultural abandonment in ESVA. The second objective is to offer an analysis of the regional localized-level characteristics of ESVA such as elevation, drainage quality as well as proximity to salt-affected areas influencing agricultural land abandonment, filling a gap in the literature by detailing the specific traits of such coastal areas contributing to land abandonment. Furthermore, by formulating potential hypotheses to explain agricultural land abandonment occurrences, this thesis provides a theoretical framework for understanding the reasons behind land abandonment. The collective contributions enhance the overall understanding of factors influencing land abandonment, offering researchers a holistic perspective. The following are our research questions:

1- What is the spatiotemporal pattern of agricultural land abandonment in the ESVA?

2- To what extent can exploring region-specific drivers of agricultural land abandonment improve our understanding of the detected abandonments?

1.3 Organization of Thesis

This thesis is organized as follows. Chapter 2 provides a literature review of agricultural land abandonment and its contributing factors. The contribution of this thesis is also highlighted in this chapter. Chapter 3 contains a comprehensive presentation of the methodology used to detect and classify agricultural land abandonment along with descriptions of key datasets used in this framework. The study area to which the methodology has been applied is also introduced in Chapter 3. Chapter 4 presents the results and discussion describing the spatiotemporal pattern of agricultural land abandonment in the ESVA from 2009 to 2019. Finally, chapter 5 contains conclusions outlining the key takeaways of this study, its limitations, and suggestions for future work.

CHAPTER 2
LITERATURE REVIEW

2.1 Overview

The literature review section of this thesis focuses on three themes. First, a review of studies focusing on agricultural land abandonment in the United States is provided (Section 2.2). This is followed by a review of studies developing algorithms to detect agricultural land abandonment (Section 2.3). The third theme focuses on studies that investigate the factors contributing to agricultural land abandonment (Section 2.4). Building upon the extensive literature review, Section 2.5 presents the contribution of this thesis.

2.2 Agricultural Land Abandonment in the United States

In the United States, agriculture is one of the most important industries. A historical analysis conducted by Yu and Lu, (2017) reveals from 1850 to 2016, the nation's cropland increased by around 104 million hectares overall, reaching a peak of 127 million hectares in 1920. Despite considerable expansions, agricultural land abandonment in the United States remains a pressing concern that is prevalent throughout the nation, particularly in regions experiencing climatic, demographic, and economic changes (Baxter and Calvert., 2017; Zheng et al., 2023). In a recent study conducted by Xie et al. (2024), 30-m resolution Landsat images as well as the United States Department of Agriculture (USDA) Cropland Data Layer (CDL) along with a classification method were used to detect agricultural land abandonment in the United States from 1986 to 2018. They reported that from 1986 to 2018, 12.3 million hectares of croplands were abandoned across the United States, with areas of greatest change over the Atlantic Coast, Ogallala Aquifer, the southern Mississippi Alluvial Plain, northern Montana, North Dakota, and eastern Washington state. It was also highlighted that the average annual abandoned area nationwide, estimated from 1986 to 2018, amounted to 0.51 million hectares per year. Moreover, while the Atlantic Coast has been identified as one of the regions with the greatest rate of land abandonment in the above study, the recent climate change has also adversely impacted coastal agriculture in the US (Lambrecht and Todd, 2020; Sudol et al., 2023). As a result of climate change, environmental stressors like frequent/intensified floods, sea level rise, and saltwater intrusion threaten coastal agriculture (Gewin, 2018; O'Donnell et al., 2024). This leads to the abandonment of agricultural land due to soil salinization and waterlogging, rendering it unsuitable for traditional farming practices (Gewin, 2018; Lambrecht and Todd, 2020;). Therefore, due to the severity of agricultural land abandonment in the United States especially in coastal areas, and the region-specific nature of this problem, it becomes imperative to conduct regional studies that consider unique regional characteristics such as climatic patterns, demographic trends, economic dynamics, and ecological factors. (Gedan et al., 2019). The framework proposed in this thesis is supposed to explore the spatiotemporal patterns of agricultural land abandonment in the ESVA and investigate the region-specific contributing factors leading to such abandonments.

2.3 Agricultural Land Abandonment Detection Algorithm

Agricultural land abandonment poses significant challenges as a land-use change. Accurate mapping of both the location and timing of abandonment is essential for understanding its environmental and social outcomes. Recognizing the importance of agricultural land abandonment, researchers have focused on developing algorithms to detect the spatiotemporal patterns of these abandonments. These methods can generally be categorized as remote sensing-based algorithms, traditional data-driven algorithms, or a hybrid approach combining both. In one study, Wang et al. (2024) used Landsat and Sentinel long-term images together with a random forest machine learning algorithm to detect abandoned farmland in the Huangshui Basin from 2002 to 2020. First, using Google Earth Engine, a time series of satellite-based images was created to train and validate the developed land use classification model. Then, using a sliding window algorithm, abandoned pixels were detected using the time series of classified land use maps. The results revealed that the area of agricultural abandonment in the Huangshui Basin increased in that period. Yin et al, (2018) used 30-m Landsat images time series along with the spatial and temporal segmentation approach and random forest machine learning algorithm to accurately detect agricultural land abandonment in the Caucasus. First, they created farmland image objects using satellite-based images and a multi-resolution segmentation approach. Then, the probability of each object being farmland was estimated using Landsat images and a random forest machine-learning model. Finally, using the agricultural land probability time series, they found out that their proposed methodology was able to separate agricultural abandonment from active agricultural lands, fallow land, and re-cultivation. Zumkehr and Campbell, (2013) used high-resolution cropland inventories for the entire U.S. as well as land-use models to develop a historical cropland data layer from 1850 to 2000. According to the developed cropland data layer, the area of abandoned agriculture for each cell was defined as the difference between the maximum historical cropland area and the cropland area of the most recent time step. Using the developed methodology, they reported 68 million hectares of agricultural land abandonment in the conterminous United States from 1850 to 2000. A review of remote sensing-based algorithms designed to identify agricultural land abandonment underscores a common reliance on extensive data, which may not always be readily available across all regions. Conversely, an evaluation of data-driven algorithms reveals the presence of unrealistic assumptions, contributing to increased uncertainty in detecting abandoned areas. Hence, this study proposes a practical data-driven approach leveraging the USDA CDL, ensuring adaptability across diverse regions with access solely to a time series of pixel-level land use maps. Furthermore, specific hypotheses are formulated to verify that identified abandoned areas were indeed agricultural pixels and that they remain abandoned post-detection, a crucial consideration often overlooked in prior research efforts.

2.4 Factors Contributing to Agricultural Land Abandonment

Detecting spatiotemporal patterns of agricultural land abandonment and evaluating the various factors influencing this intricate process are both necessary to ensure the development of policies that are not only effective but also aligned with the context of agricultural land abandonment. In other words, by systematically assessing economic, social, environmental, and policy-related drivers, policymakers can tailor interventions to address the root causes and mitigate the impacts of land abandonment, ensuring that policies are relevant, feasible, and capable of generating positive outcomes within diverse socio-economic, cultural, and environmental contexts. Eklund et al. (2024) used satellite-derived land use classification data as well as survey and interview data on migration patterns to evaluate the impacts of biophysical, political, or socio-economic factors on farmland abandonment in Syria from 2000 to 2011. Their findings indicated a significant reduction in cultivated areas during the 2008-2009 drought, with no notable increases observed after drought years. The study also highlighted migration occurring in both normal and drought years, revealing that the majority of migrants abandoned their lands after departing Syria. Sang and Xin (2023) used high-resolution remotely sensed products to analyze the spatial pattern of reclaimed and abandoned areas on the Qinghai-Tibet Plateau from 2000 to 2020. Using correlation analysis, they explored the impacts of climatic factors, socioeconomic factors, and location conditions on both the reclaimed and abandoned areas. Their findings pointed to socioeconomic factors as the key drivers leading to transformations observed in cultivated areas.

Faye et al. (2023) used a combination of remote sensing and survey data to study the transitions in agricultural land use within the Thiès region from 2000 to 2020. Using a linear regression model, they delved into potential driving factors and identified population growth, farmers' labor force, and wind erosion as fundamental elements contributing to agricultural land abandonment in this specific region. Osawa et al. (2016) employed a comprehensive approach, integrating natural and social factors alongside the random forest machine-learning method, to analyze the potential drivers contributing to agricultural land abandonment in Japan. Their findings highlighted regional disparities in the primary factors contributing to this phenomenon, emphasizing the importance of thoroughly assessing the impact of potential factors within each specific region to formulate effective and relevant strategies. Gellrich and Zimmermann (2007) used mountain-wide land-use change data to evaluate agricultural abandonment trends in the Swiss mountains from 1980 to 1990. Using a rigorous approach, they applied both a maximum-likelihood-based spatial lag model and a spatial error model to study the impacts of geophysical and socio-economic factors on agricultural abandonment. Their findings revealed that areas characterized by shallow soils, steep slopes, and under-developed road infrastructure showed higher instances of land abandonment. Interestingly, while certain regions demonstrated a correlation between strong labor markets and increased abandonment rates, this was not observed across all Swiss mountainous areas. The reviewed studies emphasize the distinct impact of each driver on various regions, underscoring the crucial need for conducting region-specific analyses on agricultural land abandonment. On the other hand, while previous studies have primarily focused on low-resolution regional characteristics to explore reasons behind land abandonment, a need for a more high-resolution analysis to explore the precise effects of each factor at a localized level is evident. Therefore, this thesis uses region-specific localized-level characteristics, namely elevation, drainage quality, and salt-affected areas' land cover, to study the potential reasons for detected abandonment in the ESVA.

2.5 Contribution of the Thesis

A review of the existing literature on agricultural land abandonment and its contributing factors reveals distinct regional variations in the primary elements shaping this intricate phenomenon (Eklund et al., 2024; Sang and Xin, 2023; Gellrich and Zimmermann, 2007). Moreover, a need for a more high-resolution analysis to explore the precise effects of region-specific localized-level characteristics is also evident. Therefore, this thesis proposes a framework based on a data-driven approach to detect spatiotemporal patterns of agricultural land abandonment and use region-specific localized-level characteristics to explore contributing factors leading to such abandonments. Since land abandonment in the United States, especially in coastal areas, is experiencing an increasing trend, this framework is applied to the ESVA with an area of 494211 acres, one of the most affected coastal areas in the United States (Baxter and Calvert, 2017; Lambrecht and Todd, 2020; Zheng et al., 2023). It has been frequently reported that thousands of acres in this specific region are being abandoned as a result of direct and indirect climate-induced challenges (Gewin, 2018; Lambrecht and Todd, 2020). However, no study has been conducted to address this assertion. This thesis aims to use the proposed framework to explore the spatiotemporal patterns of agricultural land abandonment in the ESVA. Additionally, by exploring regional potential characteristics of the ESVA impacting abandonments in such coastal areas, it provides insights into land abandonment and enhances the overall understanding of this intricate phenomenon, offering researchers and policymakers a holistic perspective.

CHAPTER 3
Methodology

3.1 Overview

In this chapter, the methodology proposed for detecting agricultural land abandonment and exploring its potential region-specific contributing factors is discussed. First, the datasets used in this framework are described in Section 3.2, 'Data.' Then, the data-driven pixel-level approach proposed to detect agricultural land abandonment is introduced in Section 3.3, 'Agricultural Land Abandonment Detection.' Next, ESVA region-specific characteristics used to spatially classify detected abandonment are discussed in Section 3.4, 'Agricultural Land Abandonment Classification.' Finally, the ESVA is introduced in Section 3.5, ‘ Eastern Shore of Virginia.’ Figure 2 provides an overview of the described methodology and datasets.

3.2. Data

To evaluate agricultural land abandonment in the ESVA, several datasets spanning from 2008 to 2022 were compiled using different sources: United States Department of Agriculture (USDA) Cropland Data Layer (CDL), United States Geological Survey (USGS) Digital Elevation Model (DEM), and Soil Survey Geographic Database (SSURGO), and road shapefiles from DATA.GOV.

The USDA Cropland Data Layer which provides detailed pixel-level information at a resolution of 30m by 30m for crop-specific land cover is used to detect abandoned areas (USDA, National Agricultural Statistics Services, CDL, 2023). This dataset has been widely used by different studies to explore crop rotation (Li et al., 2012; Long et al., 2014; Sahajpal et al., 2014) or land use change, more specifically agricultural land recultivation or abandonment (Wright and Wimberly, 2013; Johnston, 2013; Lark et al., 2015). This data is created annually using satellite images and on-the-ground agricultural verification, offering a thorough and yearly snapshot of land use changes throughout the entire United States. More specifically, the classification of the CDL relies on diverse satellite imagery sources such as Resources at 1- Advanced Wide Field Sensor (AWiFS), -2 Linear Imaging Self Scanning (LISS), 3-Landsat-5 Thematic Mapper (TM), 4-Landsat-7 Enhanced TM Plus (ETM+), 5-Landsat-8 Optical Land Imager (OLI), 6-Sentinel-2 A/B, and 7-Deimos-1 and UK-2 (Lark et al., 2021).

Data processing and classification occur at the state level, resulting in a nationwide CDL mosaic with up to 155 crop classes and 23 non-cropland covers, although most states typically have a smaller subset of applicable classes (Lark et al., 2021). Through the use of independent validation data sets created from the National Land Cover Database (NLCD) (non-agricultural categories) and the Farm Service Agency Common Land Unit (FSA CLU) data (agricultural categories), the accuracy of the USDA CDL is assessed. For the main crop-specific land cover categories, generally, the user's/producer's accuracy ranges from 85% to 95% (USDA, National Agricultural Statistics Services, CDL, 2023)

The 1-meter DEM, obtained from the USGS website (USGA, The National Map - Data Delivery, 2023), was used to identify the low-lying areas within the ESVA region, contributing a critical spatial dimension to our assessment. The topographic bare-earth surface is represented by the elevations in this DEM. Only high-resolution light detection and ranging (lidar) source data with a resolution of one meter or greater are exclusively used to create USGS standard 1-meter DEMs. (USGA, The National Map - Data Delivery, 2023)

To further enhance our understanding of potential drivers for land abandonment, soil drainage data was acquired from the SSURGO website to detect poor drainage areas (USDA, Web Soil Service, 2023). This dataset categorizes soil drainage into distinct classes, including 1-

Excessively drained, 2-Somewhat excessively drained, 3-Well drained, 4-Moderately well-drained, 5-Somewhat poorly drained, 6-Poorly drained, 7-Very poorly drained, and 8-Subaqueous Soils. The definition of each soil drainage class is provided in Table 1. This classification enabled the detection of areas experiencing drainage issues, providing valuable insights into conditions that might contribute to agricultural land abandonment on the ESVA.

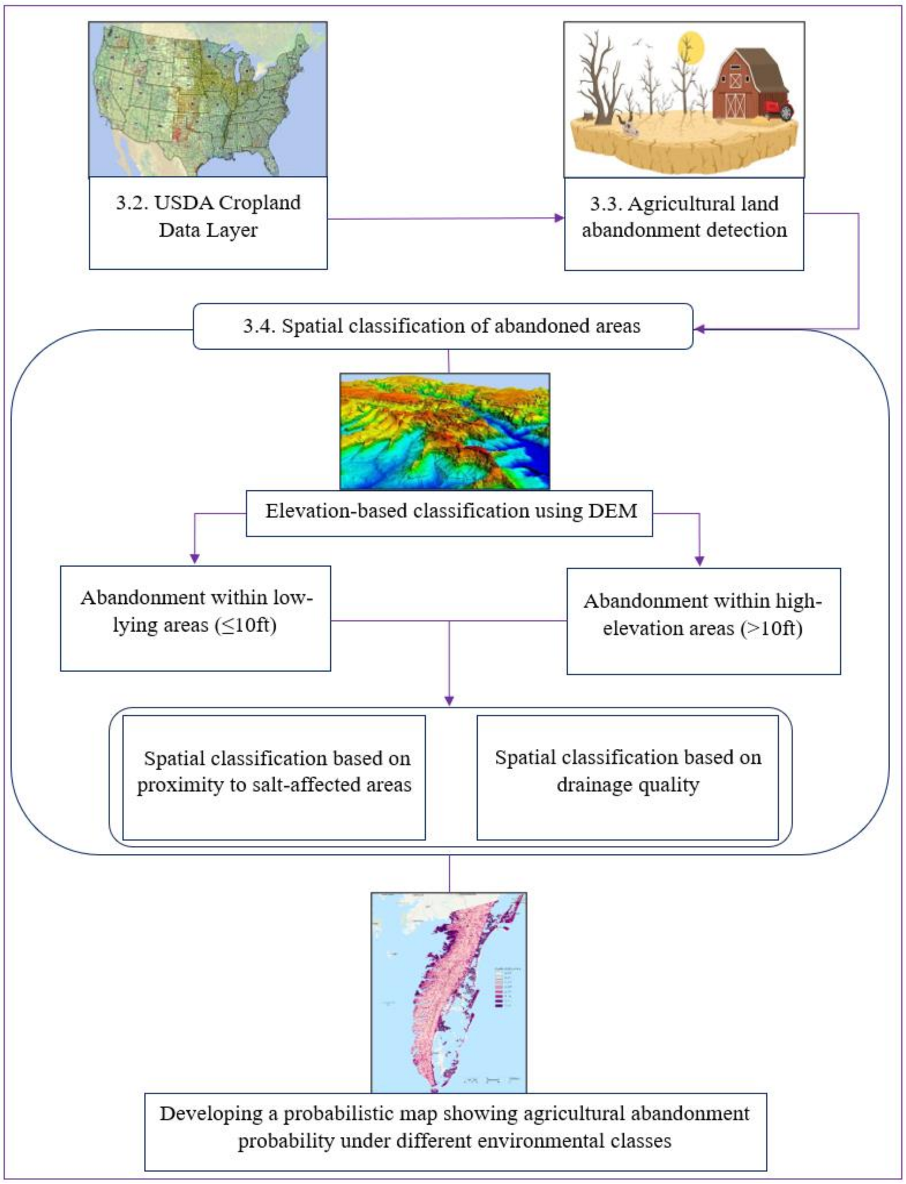


Figure 2. A flowchart of the proposed methodology. Step 3.2 outlines the data used for agricultural land abandonment detection in Section 3.3. Additionally, Section 3.4 describes the characteristics-based spatial classification process

Table 1- Different soil drainage class definitions (USDA, Web Soil Service, 2023)

Soil drainage class	Definition
Excessively drained	Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have very high hydraulic conductivity or are very shallow.
Somewhat excessively drained	Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have high saturated hydraulic conductivity or are very shallow.
Well drained	Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.
Moderately well drained	Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m, periodically receive high rainfall, or both.
Somewhat poorly drained	Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.
Poorly drained	Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity of nearly continuous rainfall, or of a combination of these.
Very poorly drained	Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.
Subaqueous Soils	Free water is above the soil surface. Internal free water occurrence is permanent, and there is a positive water potential at the soil surface for more than 21 hoursof each day. The soils have a peraquic soil moisture regime.

Also, salt patches and marsh land cover for 2017 were adapted from Mondal et al. (Mondal et al., 2023). Mondal et al, (2023) used the National Agriculture Imagery Program (NAIP) as well as moderate-resolution Landsat together with a random forest classification algorithm to produce land use/cover maps across the Delmarva Peninsula. With a user's accuracy of 90.61% for salt patches in 2017, and 86.25% for marshland in the same year, this dataset facilitated identifying areas affected by salt, contributing crucial insights into the impact of saltwater intrusion on the Eastern Shore of Virginia's agricultural land.

Finally, to explore the potential relationship between road infrastructure and urban expansion, road shapefiles for both Accomack and Northampton Counties were obtained from the DATA.GOV website (U.S. Census Bureau, Department of Commerce, 2021).

3.3. Agricultural Land Abandonment Detection

In our study, as shown in Table 2, different CDL land use classes are classified into different generalized categories: Primary Cropland, Idle Cropland, Forest, Shrubland, Bare Land, Developed Areas, Wetland, and Grassland. Subsequently, Primary Cropland is defined as Major land use, as these are the strategic/main crops being cultivated in ESVA, and the area of other crops/vegetables is negligible compared to this group of land uses. Also, everything else is categorized as Non-major land use. To detect the abandoned areas, USDA CDL pixel-level crop-specific data is used from 2008 to 2022. Therefore, a pixel is defined as abandoned when starting in 2008 with major land use (Primary cropland), it transitions to non-major land use at a certain point (year) and continues to remain a non-major land use until the end of the analysis period (i.e., 2022). For a more detailed understanding of major and non-major land use categories, along with their corresponding classifications, please refer to Table 2.

Table 2- Major and non-major land use categories and definitions

Land Use Type	Category	CDL Land Use Classes
Major land use	Primary cropland	Soybeans, Corn, Winter Wheat, Cotton, and their double crops (i.e. Dbl Crop Corn/Soybeans*, Dbl Crop Barley/Soybeans, etc.)
Non-major land use**	Idle cropland	Fallow/Idle Cropland
	Forest	Mixed Forest, Deciduous Forest, Evergreen Forest, Christmas Trees
	Shrubland	Shrubland
	Bare land	Barren, Open Water, Aquaculture
	Developed areas	Developed/Low Intensity, Developed/Open Space, Developed/High Intensity, Developed/Med Intensity
	Wetland	Herbaceous Wetlands, Woody Wetlands
	Grassland	Grassland/Pasture

* The term "Dbl Crop A/B" refers to the agricultural practice of cultivating crops A and B on the same land during a growing season or in a crop rotation strategy.

** It is important to highlight that we opted to exclude a category of non-major land uses referred to as "Other Crops and Vegetables." This decision was to avoid confusion between this category and the primary cropland, and based on the fact that there was not a significant transition from primary cropland to this specific category.

Also, Figure 3 schematically illustrates how the presented agricultural land abandonment detection method works:

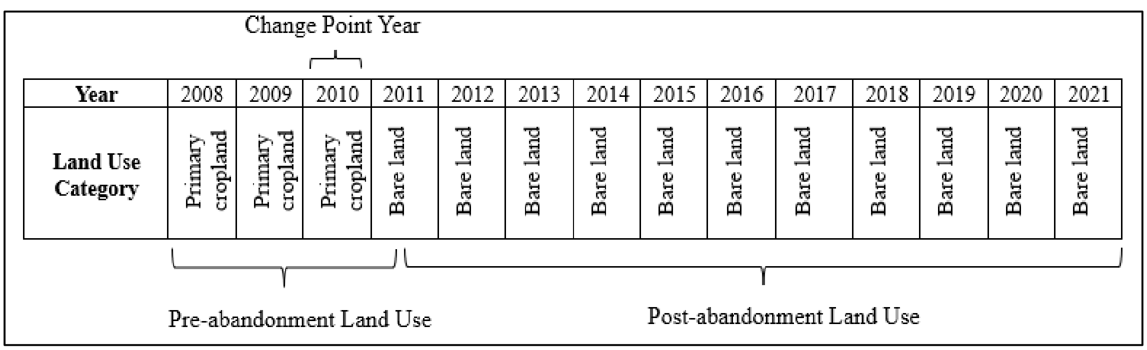


Figure 3. A schematic of the proposed method to identify agricultural land abandonment. The depicted trajectory illustrates one possible scenario (Primary cropland to Bare land). Considering all provided categories of Non-major land use, alternative trajectories may include primary cropland to wetland, primary cropland to developed areas, etc.

Where Pre-abandonment Land Use refers to the land use category that has been most frequently observed before the change point year, Post-abandonment land use refers to the land use category that has been most frequently observed after the change point year, and Change Point Year denotes the year when a pixel undergoes a transition from major land use to non-major land use. In the example provided in Figure 3, Pre-abandonment Land Use, Post-abandonment land use, and Change Point Year are Primary Cropland, Bare Land, and 2010.

It should also be noted that while our dataset covers the period from 2008 to 2022, we opted to exclusively consider areas with a change point year falling between 2009 and 2019. This decision ensures that for a pixel detected with a change point in 2009, there are at least two consecutive years of major land use before 2009. Conversely, for a pixel detected with a change point year of 2019, we can confirm a minimum of three consecutive years of non-major land use after 2019.

3.4. Agricultural Land Abandonment Classification

After detecting the abandoned areas, environmental-based classification factors namely elevation, drainage quality, and proximity to salt-affected areas are used to spatially classify abandoned pixels. The decision to exclusively focus on environmental-based contributing factors is driven by both the significant impact these factors have on agricultural sustainability and the availability of reliable data. Considering the fact that agricultural land abandonment, specifically in coastal areas, occurs in both low-lying and high-elevation areas, abandoned areas are classified based on their elevation. According to Blunk et al. (2020), we distinguish between the low-lying and high-elevation areas by setting a threshold of 10 feet above sea level (Blunk et al., 2020). Areas below this are considered low-lying, while those above are categorized as high-elevation. Based on interviews conducted with experts and the literature review, it was concluded that the ESVA, being a low-lying area prone to frequent storms and floods, experiences land abandonment due to poor drainage. Therefore, abandonment within poor drainage areas accounts for another group. Moreover, it is reported that proximity to salt-affected areas plays a crucial role in prompting agricultural land abandonment (Mondal et al., 2023). As advised by Mondal et al. (2023), farmlands situated within 200 meters of salt-affected regions are particularly vulnerable, with the most notable impacts occurring within a 50-meter buffer zone surrounding these areas. Therefore, a 50m buffer has been used around the salt patch and marsh land cover data to detect such an abandonment.

3.5. Eastern Shore of Virginia

The Eastern Shore of Virginia (ESVA) is a unique coastal region situated along the Atlantic Ocean to the east of Chesapeake Bay. Encompassing Accomack and Northampton counties, this peninsula extends approximately 110 km in length and has a varying width of 7 to 15 km for the land portion (excluding lagoons), covering an overall area of around 2,000 km^2 (494211 acres). Bounded by the Atlantic Ocean to the east, the Chesapeake Bay to the south and west, and the State of Maryland to the north, the Eastern Shore exhibits a diverse landscape dominated by marshes along the coast, interspersed with a combination of agriculture and forest in the central region (Sanford and Pope, 2010). About a third to half of the ESVA is made up of a network of broad tidal lagoons and low-barrier islands that are close to the Atlantic Ocean (McFarlandand Beach, 2019). On the other hand, the peninsula's western and central regions are comparatively well-drained and have higher land surface (McFarlandand Beach, 2019). It should be mentioned that ESVA is heavily dependent on groundwater and that the only fresh surface water in this area is found in a few small streams. Two counties, Accomack to the north and Northampton to the south, form the ESVA. Agriculture is a pivotal component of the Eastern Shore's economy, contributing significantly to employment, economic output, and land usage. In 2022, the value of agricultural production in Accomack reached 326 million dollars, while in Northampton it was 109 million dollars (2022 Census of Agriculture reports Virginia's top producing counties). Moving to the agricultural landscape, corn, soybean, and winter wheat dominate as the major crops in the ESVA. (McFarlandand Beach, 2019). However, the ESVA is confronted with significant challenges arising from climate change, including sea level rise and saltwater intrusion, with sea level rise rates four times higher than the global average, posing an imminent threat to its agricultural ecosystem (Sudol et al., 2023). Saltwater intrusion has rendered acres of agricultural lands unproductive, resulting in agricultural land abandonment. Beyond impacting soil quality, it has disrupted traditional farming practices, leading to economic hardships for farmers in the region (Lambrecht and Todd, 2020). Additionally, due to these challenges, the ESVA experienced a notable 243% increase in the extent of salt patches between 2011 and 2017. Despite the alarming growth rate, it is important to note that the actual area occupied by these identified salt patches in 2017 remained relatively small, totaling approximately 1.22 km^2 (301.5 acres) (Mondal et al., 2023).

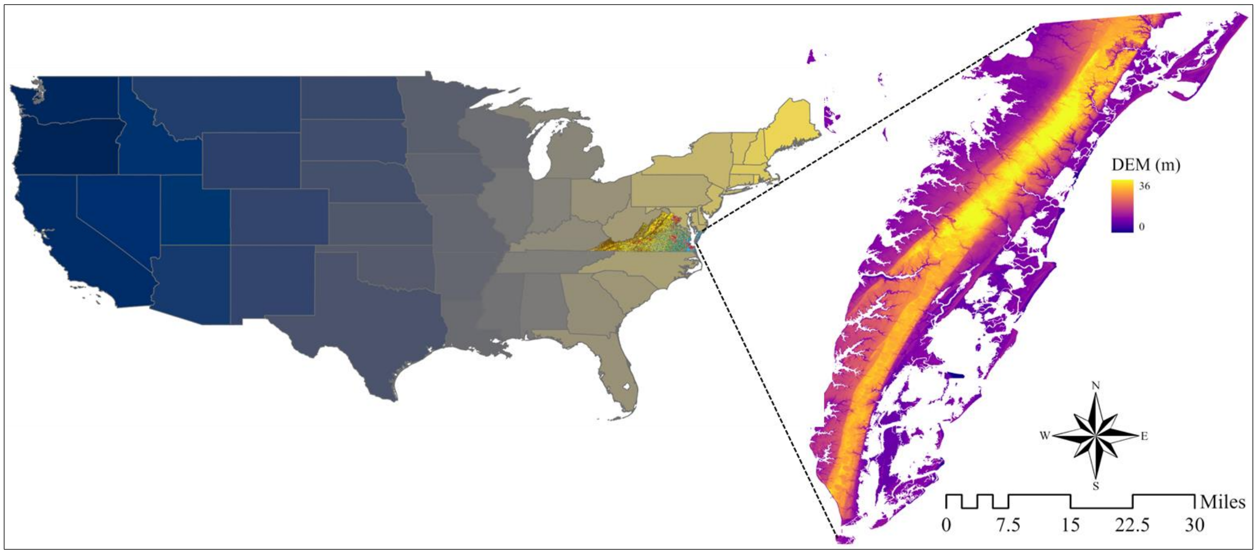


Figure 4. Location of the Eastern Shore of Virginia and its Digital Elevation Model (The color scheme on the US map reflects a west-to-east gradient, with darker shades of blue indicating states in the western region and lighter shades, such as yellow, representing states in the eastern region)

CHAPTER 4
RESULTS AND DISCUSSION

4.1. Overview

This chapter provides the results of detected agricultural land abandonment on the Eastern Shore of Virginia. Through 4.2 Temporal Analysis of Agricultural Land Abandonment, 4.3 Spatial Analysis of Agricultural Land Abandonment, and 4.4 Probability of Agricultural Abandonment within Different Classes, spatiotemporal results are introduced. Afterward, the 4.5 Discussion section delves deeper into the derived results, providing thorough scrutiny.

4.2. Temporal Analysis of Agricultural Land Abandonment

Figure 5 displays the annual estimates of abandoned agricultural land on the ESVA from 2009 to 2019.

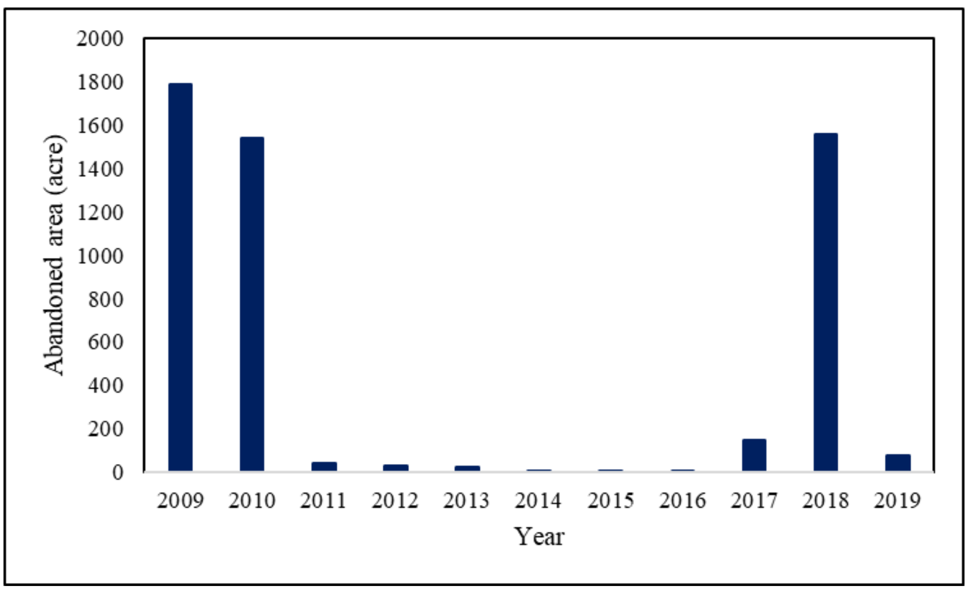


Figure 5. Area of abandoned agricultural lands in the ESVA from 2009 to 2019

Significant abandonment was observed primarily in the years 2009, 2010, and 2018, with estimated abandoned areas of approximately 1764, 1516, and 1530 acres respectively, as illustrated in Figure 5. In contrast, abandonment in other years was negligible. Various factors could have contributed to these abandonments. The Great Recession in 2008-2009 and the Nor'Ida Storm in 2009 could be potential reasons for the abandonments in 2009 and 2010. In other words, the real GDP fell by 8.5% in the fourth quarter of 2008, which had a negative impact on agricultural exports (Coppola, 2022). Also, as shown in Figures 6, and 7, 86% and 79% of the abandoned areas in 2009 and 2010 were converted to Wetlands. This suggests that the Nor'Ida Storm and subsequent waterlogging likely played a crucial role in this outcome. Moreover, Figure 8 shows that 68% of the abandoned areas in 2018 were converted to developed areas. A combination of increasing agricultural expenses, shifting demographic trends, and inadequate regulatory frameworks in Virginia may have led to the abandonment in 2018 which is more deeply discussed in the discussion section (Nosowitz, 2018; Levers, et al., 2018; USDA, Economic Research Service, 2024; Economic Research, FRED, 2024; THE STATE OF THE STATES, Virginia Conservation Network, 2024). Despite the substantial abandonment in the years 2009, 2010, and 2018, it should also be highlighted that it only represents 1.25%, 1.17%, and 1.14% of total agricultural areas in those respective years.

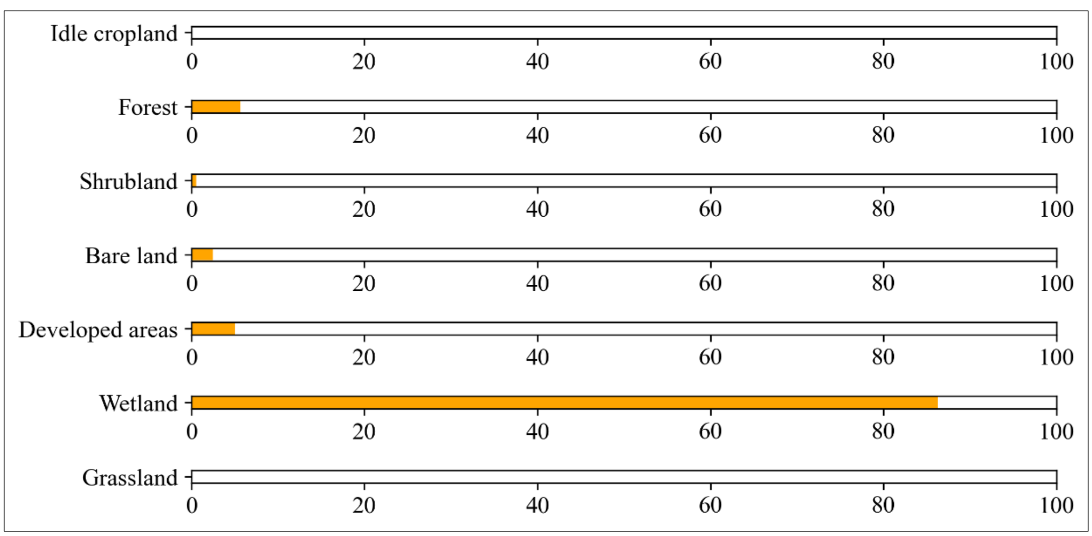


Figure 6. Percentage distribution of different post-abandonment land use categories in the ESVA in 2009

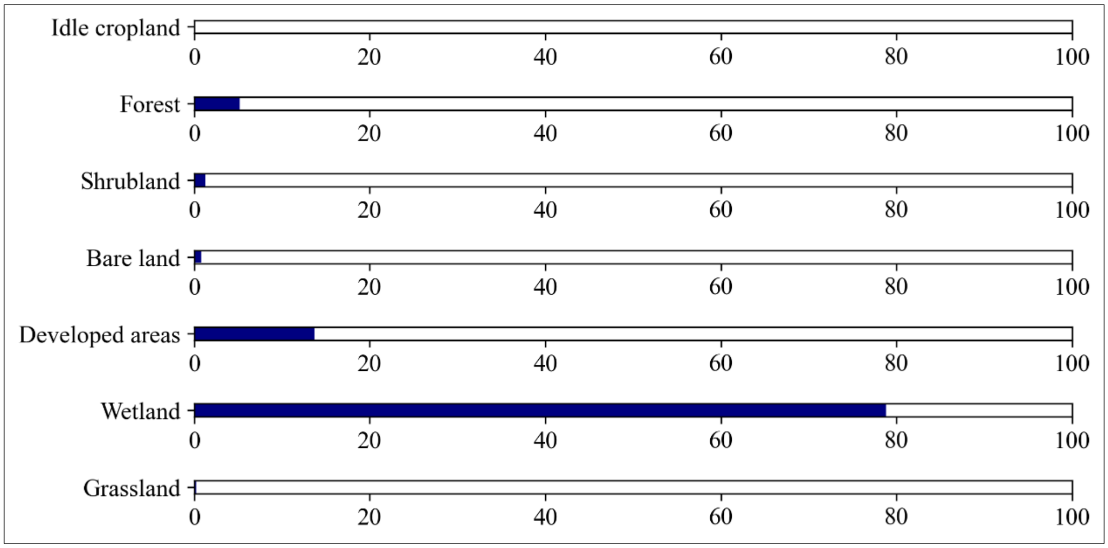


Figure 7. Percentage distribution of different post-abandonment land use categories in the ESVA in 2010

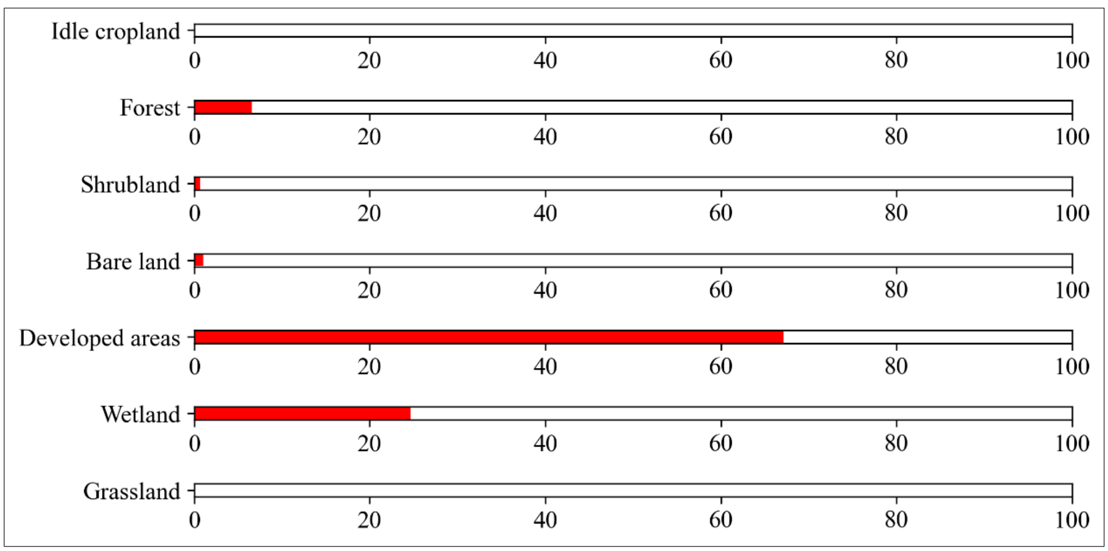


Figure 8. Percentage distribution of different post-abandonment land use categories in the ESVA in 2018

4.3. Spatial Analysis of Agricultural Land Abandonment

The spatial distribution of abandoned areas in ESVA from 2009 to 2019 is depicted in Figure 9. Furthermore, Table 3 categorizes the abandoned areas in ESVA from 2009 to 2019 according to elevation, drainage quality, and exposure to salt-affected areas. Results show that 24% of all abandoned areas were situated in low-lying regions. Among these, 16% faced solely drainage issues, 27% were affected solely by adjacent salt-affected areas, while 53% experienced the combined impact of drainage issues and proximity to salt-affected areas. Conversely, a significant majority of 76% of abandoned areas were located in high-elevation zones. Among these, 14% faced solely drainage issues, 39% were affected solely by adjacent salt-affected areas, while 27% experienced the combined impact of drainage issues and proximity to salt-affected areas.

Table 3- The area and percentage of agricultural abandonment on the ESVA within different classes from 2009 to 2019

Class	Abandoned area (acres)	Percentage of abandonment relative to the agricultural areas	Percentage of abandonment relative to total land areas
All abandonments located in low-lying areas	1209	4.94	0.67
Abandoned areas located in low-lying areas with poor drainage outside salt-affected zones	175	3.05	0.59
Abandoned areas located in low-lying areas within a 50-meter buffer of salt-affected areas without poor drainage issue	329	5.11	0.64
Abandoned areas located in low-lying areas with poor drainage issues within a 50-meter buffer of salt-affected areas	638	7.97	0.83
All abandonments located in high-elevation areas	3802	3.44	1.79
Abandoned areas located in high-elevation areas with poor drainage outside salt-affected zones	547	2.67	1.04
Abandoned areas located in high-elevation areas within a 50-meter buffer of salt-affected areas without poor drainage issue	1478	4.85	3.36
Abandoned areas located in high-elevation areas with poor drainage issues within a 50-meter buffer of salt-affected areas	1041	7.51	6.04
Total	5011	1.6	1.27

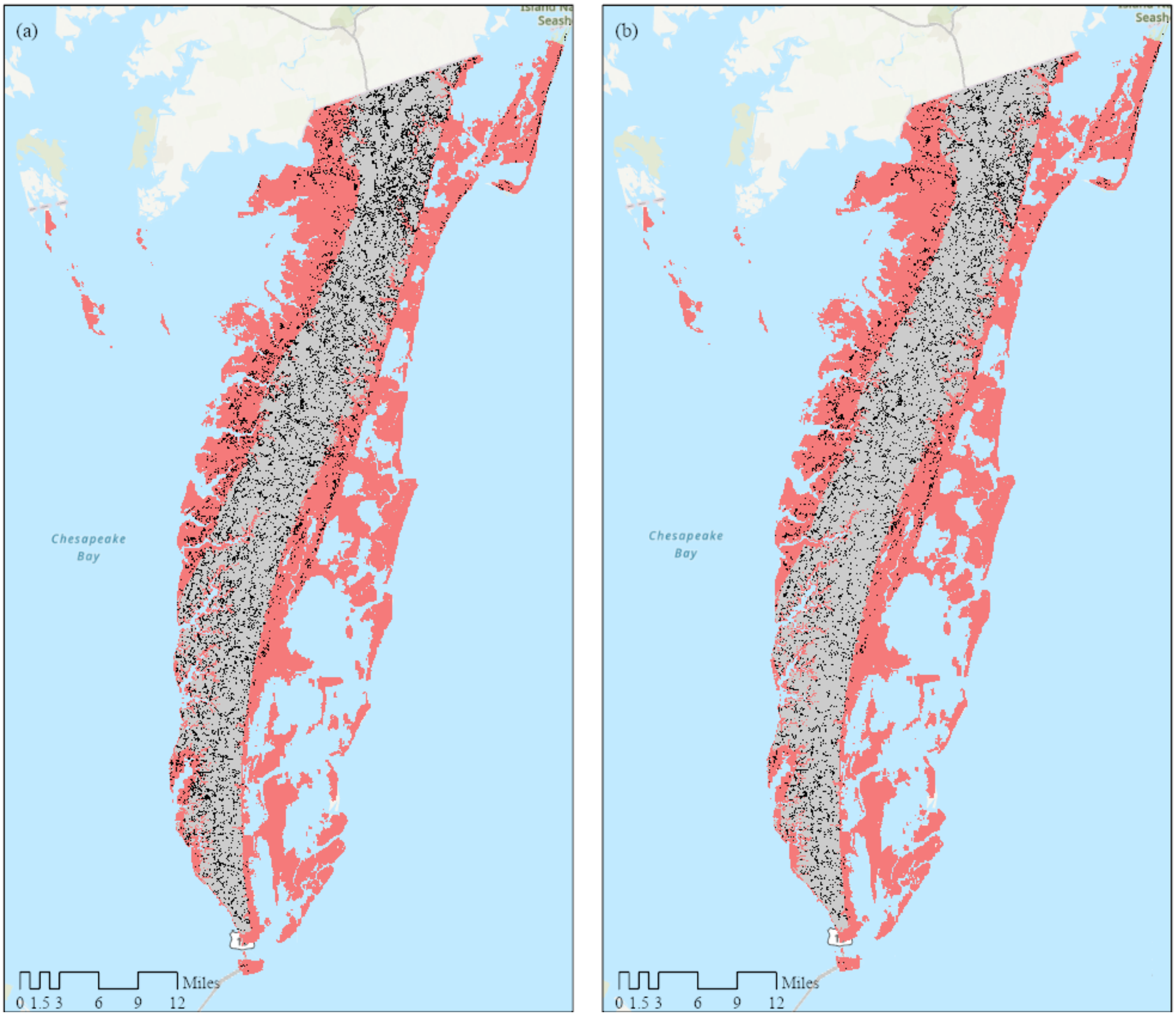


Figure 9. Abandoned areas in the ESVA from 2009 to 2019 with pink showing low-lying areas and gray showing high-elevation areas. a) All abandoned pixels. B) Abandoned pixels with drainage issues in low-lying areas and within a 50-buffer of salt-affected areas in high-elevation areas

To further explore the spatial distribution of agricultural land abandonment in the ESVA, as shown in Figure 9, abandoned areas in low-lying regions show a clustering on the west side of the ESVA, aligning with the prevalence of low-lying areas in Accomack County. Moreover, the majority of abandoned areas, attributed to drainage issues, are found in Accomack County. While abandoned areas do not follow a distinct pattern, there is a slightly higher density of abandonments in the northern part of Accomack County. Out of the total 5011 acres detected from 2009 to 2019, Accomack County accounts for nearly 72%, with Northampton County making up the remaining 28%. In other words, 3532 acres in Accomack County account for approximately 4.7% of its annual average agricultural areas from 2009 to 2019, while 1479 acres in Northampton County account for 2.6% of its annual average agricultural areas during the same period. Within the subset of 1209 acres situated in low-lying areas, 85% are located in Accomack County, representing roughly 6% of its annual average agricultural areas situated in low-lying regions from 2009 to 2019. Conversely, 15% are in Northampton County, accounting for approximately 0.2% of its annual average agricultural areas located in low-lying areas during the same period. This breakdown highlights the significant impact of Accomack County on abandonment trends, especially in low-lying areas.

As the temporal analysis of abandoned areas revealed, a significant number of abandonments occurred in the years 2009, 2010, and 2018. Specifically, in 2009, 35% of all abandonments in ESVA occurred, totaling 1764 acres. Table 4 categorizes the abandoned pixels in ESVA from 2009 according to elevation, drainage quality, and exposure to salt-affected areas. Results show that 31% of all abandoned areas were situated in low-lying regions. Among these, 14% faced solely drainage issues, 24% were affected solely by adjacent salt-affected areas, while 58% experienced the combined impact of drainage issues and proximity to salt-affected areas. Conversely, a significant majority of 69% of abandoned areas were located in high-elevation zones. Among these, 18% faced solely drainage issues, 35% were affected solely by adjacent salt-affected areas, while 31% experienced the combined impact of drainage issues and proximity to salt-affected areas.

Table 4- The area and percentage of agricultural abandonment on the ESVA within different classes in 2009

Class	**Abandoned area (acres)**	**Percentage of abandonment relative to the agricultural areas**	**Percentage of abandonment relative to land areas**
All abandonments located in low-lying areas	554	2.05	0.31
Abandoned areas located in low-lying areas with poor drainage outside salt-affected zones	77	1.27	0.26
Abandoned areas located in low-lying areas within a 50-meter buffer of salt-affected areas without poor drainage issue	135	1.92	0.26
Abandoned areas located in low-lying areas with poor drainage within a 50-meter buffer of salt-affected areas	323	3.14	0.42
All abandonments located in high-elevation areas	1210	1.06	0.57
Abandoned areas located in high-elevation areas with poor drainage outside salt-affected zones	221	1.03	0.42
Abandoned areas located in high-elevation areas within a 50-meter buffer of salt-affected areas without poor drainage issue	421	1.31	0.96
Abandoned areas located in high-elevation areas with poor drainage within a 50-meter buffer of salt-affected areas	369	2.52	2.14
Total	1764	1.25	0.45

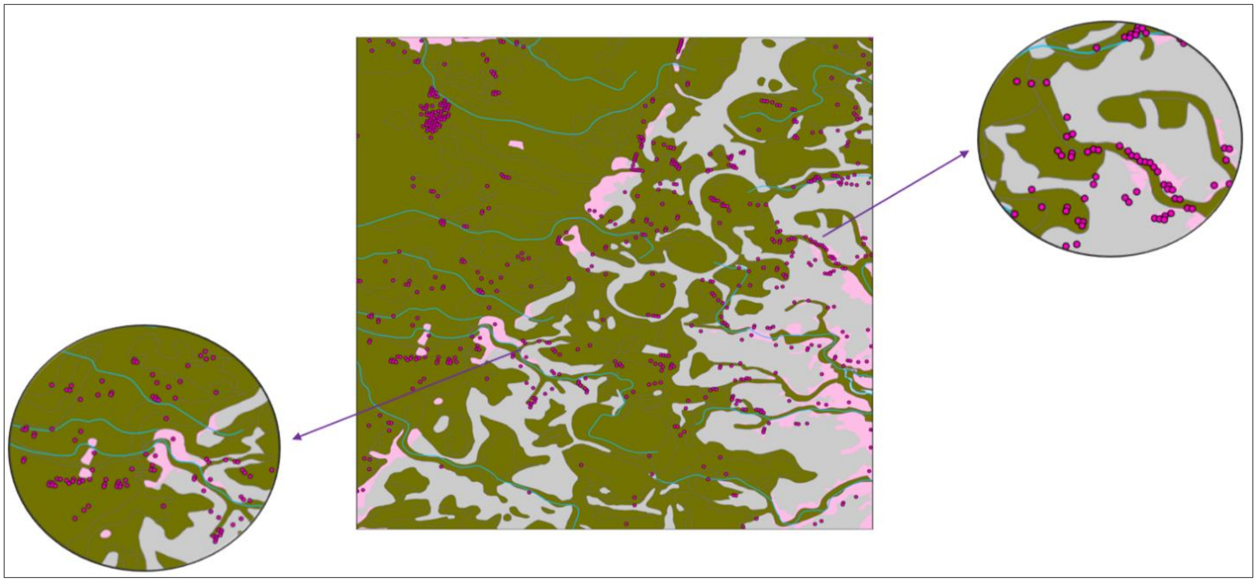


Figure 10. A zoomed-in example of abandoned areas (pink circles represent abandoned pixels) in the ESVA in 2009; pink areas are low-lying regions, gray areas are high-elevation regions, and green areas are regions with poor drainage issues

Also, 30% of all abandonments in ESVA occurred in 2010, amounting to a total of 1516 acres. According to Table 5, results show that 26% of all abandoned areas were situated in low-lying regions. Among these, 14% faced solely drainage issues, 29% were affected solely by adjacent salt-affected areas, while 53% experienced the combined impact of drainage issues and proximity to salt-affected areas. Conversely, a significant majority of 74% of abandoned areas were located in high-elevation zones. Among these, 13% faced solely drainage issues, 40% were affected solely by adjacent salt-affected areas, while 30% experienced the combined impact of drainage issues and proximity to salt-affected areas.

Table 5- The area and percentage of agricultural abandonment on the ESVA within different classes in 2010

Class	**Abandoned area (acres)**	**Percentage of abandonment relative to the agricultural areas**	**Percentage of abandonment relative to land areas**
All abandonments located in low-lying areas	390	1.75	0.22
Abandoned areas located in low-lying areas with poor drainage outside salt-affected zones	55	1.02	0.18
Abandoned areas located in low-lying areas within a 50-meter buffer of salt-affected areas without poor drainage issue	113	1.9	0.22
Abandoned areas located in low-lying areas with poor drainage within a 50-meter buffer of salt-affected areas	205	3.16	0.27
All abandonments located in high-elevation areas	1126	1.05	0.53
Abandoned areas located in high-elevation areas with poor drainage outside salt-affected zones	143	0.7	0.27
Abandoned areas located in high-elevation areas within a 50-meter buffer of salt-affected areas without poor drainage issue	456	1.54	1.04
Abandoned areas located in high-elevation areas with poor drainage within a 50-meter buffer of salt-affected areas	342	2.6	1.98
Total	1516	1.17	0.39

Finally, it should be noted that 31% of all abandonments in ESVA occurred in 2018, amounting to a total of 1530 acres. According to Table 6, results show that 16% of all abandoned areas were situated in low-lying regions. Among these, 16% faced solely drainage issues, 31% were affected solely by adjacent salt-affected areas, while 42% experienced the combined impact of drainage issues and proximity to salt-affected areas. Conversely, a significant majority of 84% of abandoned areas were located in high-elevation zones. Among these, 11% faced solely drainage issues, 43% were affected solely by adjacent salt-affected areas, while 24% experienced the combined impact of drainage issues and proximity to salt-affected areas.

Table 6- The area and percentage of agricultural abandonment on the ESVA within different classification groups in 2018

Class	**Abandoned area (acres)**	**Percentage of abandonment relative to the agricultural areas**	**Percentage of abandonment relative to land areas**
All abandonments located in low-lying areas	248	1.03	0.14
Abandoned areas located in low-lying areas with poor drainage outside salt-affected zones	39	0.68	0.13
Abandoned areas located in low-lying areas within a 50-meter buffer of salt-affected areas without poor drainage issue	78	1.23	0.15
Abandoned areas located in low-lying areas with poor drainage within a 50-meter buffer of salt-affected areas	103	1.42	0.13
All abandonments located in high-elevation areas	1281	1.16	0.6
Abandoned areas located in high-elevation areas with poor drainage outside salt-affected zones	139	0.71	0.27
Abandoned areas located in high-elevation areas within a 50-meter buffer of salt-affected areas without poor drainage issue	546	1.84	1.24
Abandoned areas located in high-elevation areas with poor drainage within a 50-meter buffer of salt-affected areas	312	2.26	1.81
Total	1530	1.14	0.93

Figure 11. A zoomed-in example of abandoned areas in ESVA in 2018 impacted by salt-affected areas (orange circles represent abandoned pixels)

In light of the discernible linear pattern observed in the distribution of abandoned areas in both Accomack and Northampton Counties in 2018, as shown in Figure 12, spatial analysis employing a 50-meter buffer around roads was conducted to elucidate the intricate relationship between infrastructure and abandonment. Since a significant number of abandoned areas in 2018 have been transformed into developed areas, our analysis revealed that approximately 89%, 81%, and 75% of abandoned areas that were converted to development in the years 2018, 2010, and 2009, respectively, fall within this buffer zone in Accomack and Northampton counties. This result highlights the proximity of development to roadways, suggesting a possible relationship between road infrastructure and urban expansion.

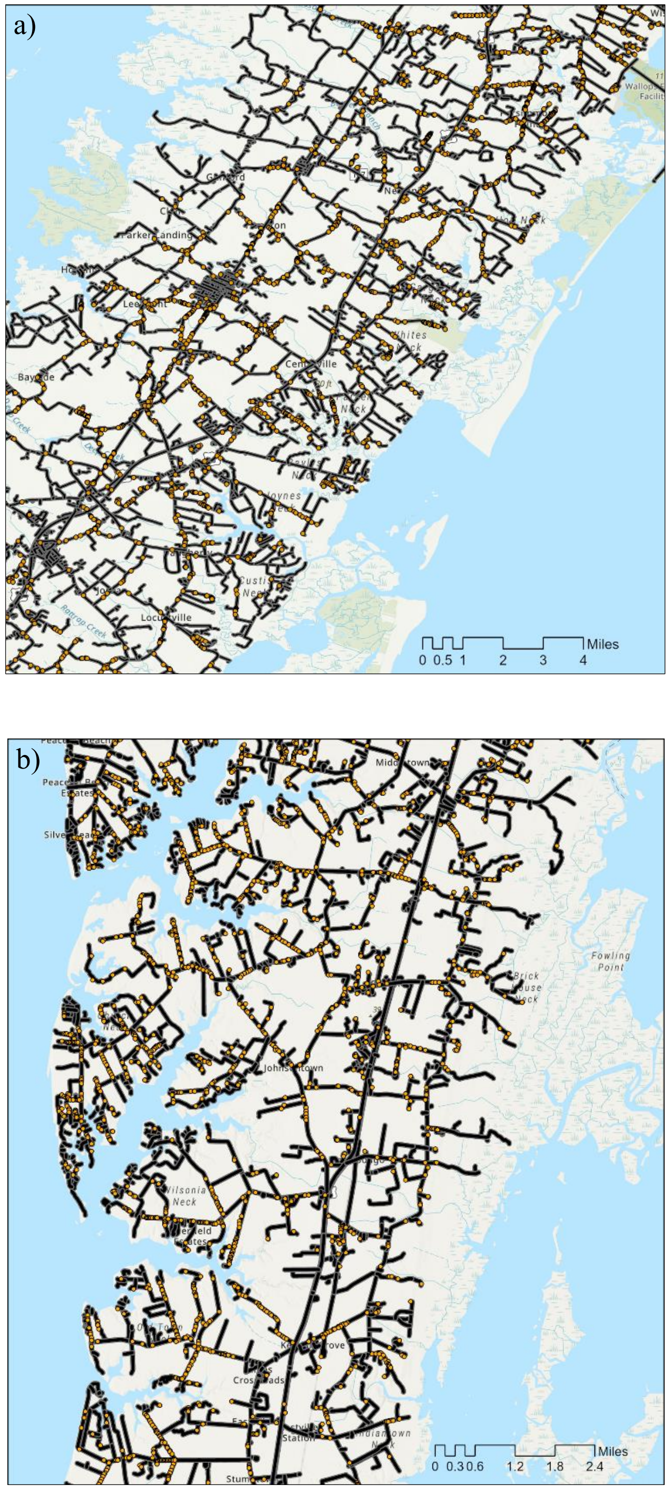


Figure 12. Abandoned areas in 2018 within a 50-buffer of roadways. a) Accomack b) Northampton

Table 7- Percentage of development within a 50 m buffer of roadway in the ESVA

Year	Developed area (acres)	Area of development within a 50 m Road buffer (acres)	Percentage of development within a 50 m buffer relative to land areas within the same buffer
2009	94.05	70	0.08
2010	220.725	180	0.21
2018	1043.325	930	1.10

4.4. Probability of Agricultural Abandonment within Different Classes

The analysis of abandonment probability in the ESVA reveals varying degrees of risk across different environmental classes. Using data on the area of agricultural abandonment as well as annual average agricultural areas from 2009 to 2019, Figure 13 presents the agricultural abandonment probabilities based on different classes outlined in Table 8.

In this map, agricultural areas grappling with the combined effect of poor drainage as well as proximity to salt-affected areas exhibit the highest probabilities of abandonment, reaching 7.97% in low-lying areas and 7.51% in high-elevation areas. Further, low-lying agricultural areas within a 50-meter buffer of salt-affected areas have an abandonment probability of 5.11%, while high-elevation agricultural areas within the same buffer exhibit a probability of 4.85%. Notably, agricultural areas in both low-lying and high-elevation affected solely by poor drainage show abandonment probabilities of 3.05% and 2.67%, respectively.

Building upon the presented results, when considering the impact of individual factors, proximity to salt-affected areas appears to play a more significant role than poor drainage alone. This is evident in the substantial increase in abandonment probabilities compared to the base scenario, where neither poor drainage nor proximity to salt-affected areas is present. In these base scenarios, the probability of abandonment decreases significantly to 1.56% in low-lying areas and 1.61% in high-elevation areas.

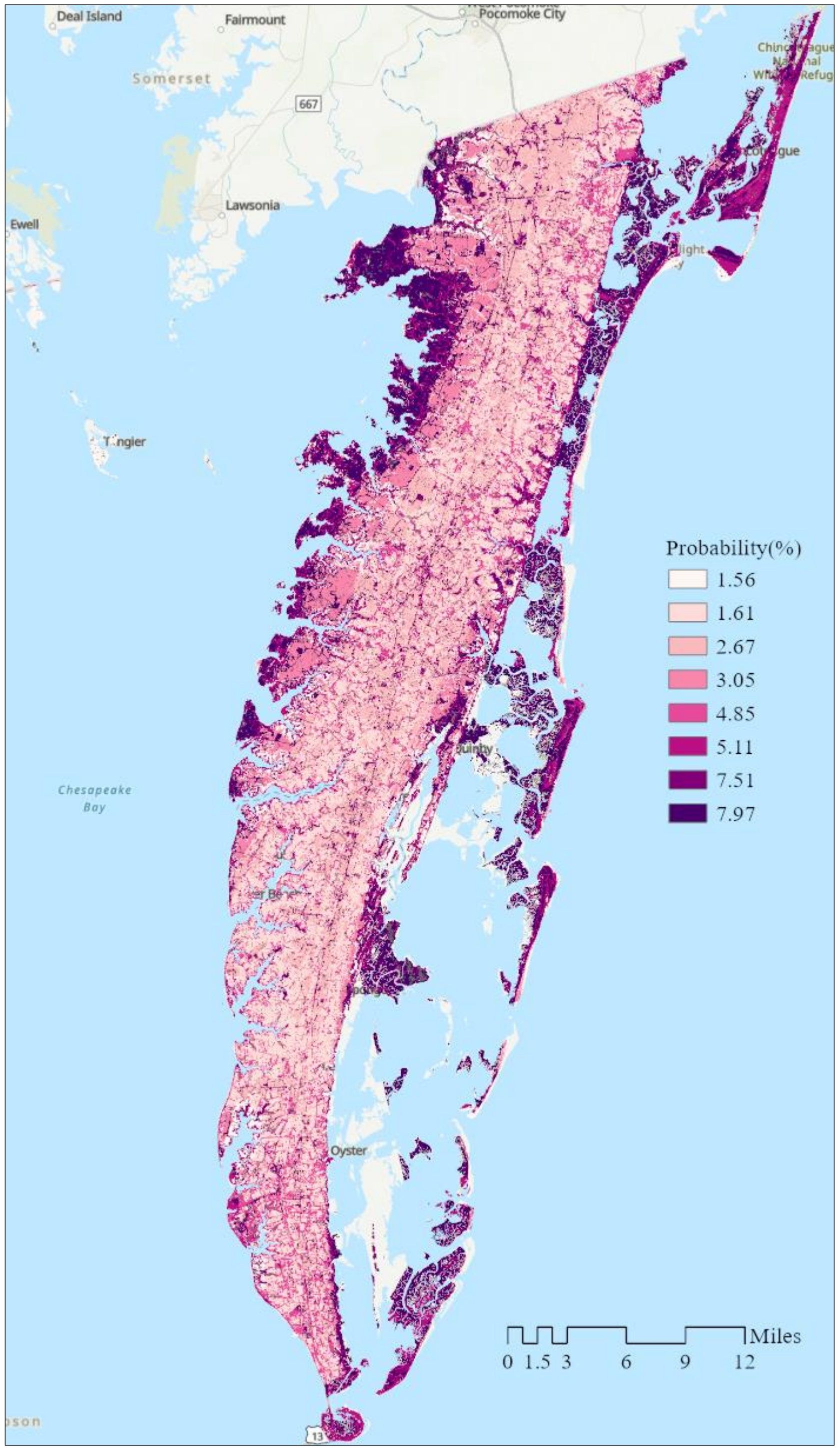


Figure 13. Map of ESVA showing the probability of agricultural abandonment within different classes

Table 8. Probability of agricultural abandonment within different classes

Class	Probability of abandonment (%)
All abandonments located in low-lying areas	1.56
Abandoned areas located in low-lying areas with poor drainage outside salt-affected zones	3.05
Abandoned areas located in low-lying areas within a 50-meter buffer of salt-affected areas without poor drainage issue	5.11
Abandoned areas located in low-lying areas with poor drainage within a 50-meter buffer of salt-affected areas	7.97
All abandonments located in high-elevation areas	1.61
Abandoned areas located in high-elevation areas with poor drainage outside salt-affected zones	2.67
Abandoned areas located in high-elevation areas within a 50-meter buffer of salt-affected areas without poor drainage issue	4.85
Abandoned areas located in high-elevation areas with poor drainage within a 50-meter buffer of salt-affected areas	7.51
Total	1.6

4.5. Discussion

While evaluating the spatiotemporal pattern of land abandonment is one aim of this study, the primary focus rested on exploring the potential reasons for such abandonment and crafting potential hypotheses to explain occurrences of agricultural land abandonment. This study is focused on the agricultural land abandonment within coastal regions significantly impacted by climate change. Therefore, the projected increase in flood occurrences is expected to exacerbate vulnerability, especially in coastal low-lying areas. Moreover, regions grappling with drainage problems in such circumstances are expected to face more vulnerability compared to areas without such challenges. On the other hand, reports highlight that rising sea levels are causing saltwater intrusion as well as water logging, resulting in the degradation of thousands of acres of agricultural land (Lambrecht and Todd, 2020). Additionally, surge overwash, a phenomenon characterized by inundation in coastal areas during intense storm surges or tidal waves often compounds this situation. Within unconfined aquifers, surge overwash has the potential to forcefully infiltrate saltwater into these porous and permeable groundwater systems, thereby jeopardizing their previously freshwater-dependent nature. Likewise, elevated land surfaces, while less directly vulnerable to inundation, remain susceptible to the effects of surge overwash, as the salt-laden water can seep into the soil (Wang et al., 2015). This dual impact underscores the complex interplay between rising sea levels, surge overwash, and their combined effect on saltwater intrusion, which profoundly affects agricultural land in the ESVA. Within this context, the proximity to salt-affected areas emerges as a significant factor influencing land abandonment, especially in high-elevation areas less prone to flooding. Thus, by applying the classification rationale introduced in this study, we effectively explained the majority of the abandonment observed between 2009 and 2019. As previously mentioned, abandoned areas in 2009, 2010, and 2018 comprised 96% of all abandonments recorded from 2009 to 2019. In contrast, abandonment in other years was negligible by comparison. Additionally, whereas the predominant outcome for abandoned areas in 2009 and 2010 was their transition into wetlands, by 2018, a notable shift occurred, with most abandoned areas being converted into developed areas.

There could be multiple potential reasons for these abandonments, however, for those observed in 2009 and 2010, factors such as the Great Recession of 2008-2009 and the Nor'Ida Storm in 2009 could have played significant roles. The Great Recession, the most prolonged economic downturn since World War II and the deepest before the COVID-19 Recession, likely exerted a substantial influence on these abandonments (Coppola, 2022). During the fourth quarter of 2008, there was a notable 8.5% decline in Real GDP, which had severe repercussions on agricultural exports (Coppola, 2022). Furthermore, considering that the majority of abandonments in 2009 and 2010 were converted to wetlands, it can be inferred that this outcome may be attributed to the impact of the storm and subsequent waterlogging. Regarding abandonments in 2018, it has been widely reported that agricultural costs have risen significantly in recent years (USDA, Economic Research Service, 2024). Moreover, alongside the surge in agricultural costs, the US government's cheap food policy may have diminished the profitability of farming compared to previous years. Consequently, younger generations may be less inclined to inherit their ancestors' farms and may opt to sell their lands instead (Nosowitz, 2018). Besides these factors, it is essential to acknowledge demographic shifts in the ESVA as another contributing factor to land abandonment. Data on migration in ESVA indicates a substantial shift, with net migration increasing by nearly 100% from 2009 to 2020 (Economic Research, FRED, 2024). The significant increase in migration is expected to lead to higher probabilities of abandonment, especially when contrasted with regions showing a robust positive migration balance (Levers, et al., 2018). On the other hand, some news articles highlight the notable rate at which farmland is being converted into development in the state of Virginia, noting a deficiency in effective policies to counteract this loss of agricultural land (THE STATE OF THE STATES, Virginia Conservation Network, 2024). Therefore, all of these factors collectively contributed to the significant developments that occurred in 2018.

To also discuss the impact of region-specific localized-level contributing factors, abandonment probabilities were calculated under different classes. Results highlight that over the course of a decade (2009-2019), variations in abandonment probabilities are evident, particularly between low-lying and high-elevation areas. Notably, low-lying regions experienced a higher abandonment rate of 4.94% compared to 3.44% in high-elevation areas, suggesting a potentially greater vulnerability to land use changes in lower-lying terrain. Further analysis reveals intricate patterns within these categories. For instance, in low-lying areas solely impacted by poor drainage, the abandonment probability is 3.05. Conversely, the sole proximity to salt-affected areas appears to exacerbate abandonment, with probability spiking to 5.11%. This trend intensifies when coupled with poor drainage, as evidenced by the staggering 7.97% abandonment probability in similar low-lying areas. In contrast, high-elevation regions demonstrate comparatively lower abandonment probabilities, even in the presence of salt-affected areas or poor drainage. However, within these contexts, the influence of environmental factors remains discernible. For high-elevation areas solely impacted by salt-affected areas, the abandonment probability increases to 4.85%. Moreover, when compounded with poor drainage, the abandonment probability escalates further to 7.51%, indicating the simultaneous impact of salt-affected areas and poor drainage on land use decisions. These findings underscore the complex interplay between topography, drainage conditions, and soil salinity in shaping land use dynamics, warranting targeted interventions to mitigate agricultural land abandonment and promote sustainable management practices.

Additionally, Figure 14 presents the percentage of abandonment attributed to various classes in each year, relative to the total abandonment attributed to that class from 2009 to 2019. For instance, in the case of the bar representing 2009 in the categories of low-lying areas with poor drainage issues, the value of 44% signifies that 44% of all areas abandoned due to being in low-lying with poor drainage issues from 2009 to 2019 happened specifically in 2009. As illustrated, the majority of abandonment attributed to being in low-lying areas or areas with both low-lying and poor drainage occurred in 2009 and 2010, which aligns with the occurrence of floods during those years. Additionally, it is notable that 2018 stands out as the year with the highest occurrence of abandonment in high-elevation areas as well as within a 50 m road buffer compared to other years, which correlates with the significant development activities observed during that year.

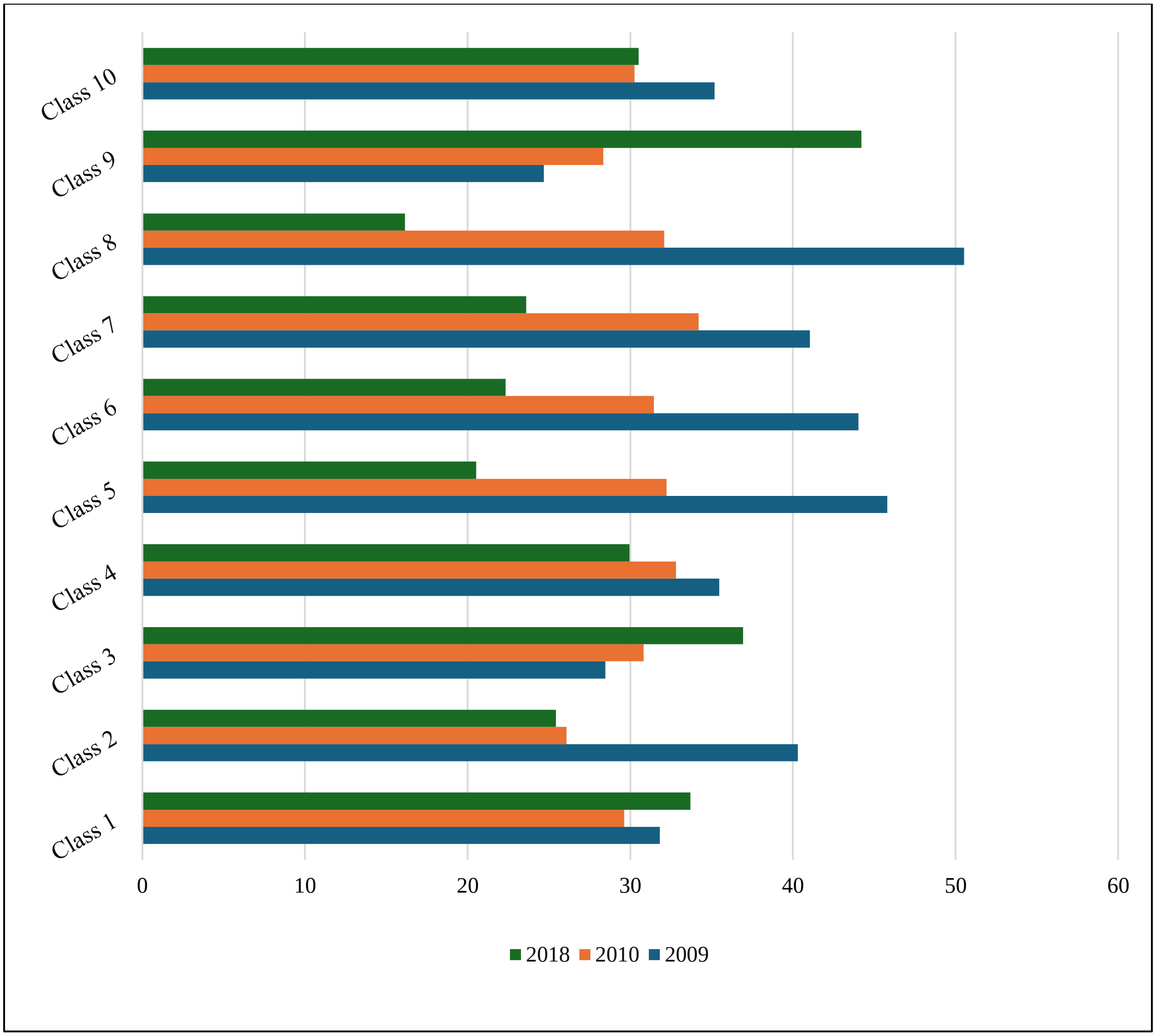


Figure 14. General overview of ESVA's' land abandonment, showing the percentage of abandonment attributed to various classes in each year, relative to the total abandonment attributed to that class from 2009 to 2019 (Class 1: High-elevation areas, Class 2: High-elevation areas with poor drainage, Class 3: High-elevation areas within a 50-meter buffer of salt-affected areas, Class 4: High-elevation areas with poor drainage within a 50-meter buffer of salt-affected areas, Class 5: Low-lying areas, Class 6: Low-lying areas with poor drainage, Class 7: Low-lying areas within a 50-meter buffer of salt-affected areas, Class 8: Low-lying areas with poor drainage within a 50-meter buffer of salt-affected areas, Class 9: Abandonment within a 50 m road buffer, Class 10: Total)

CHAPTER 5
CONCLUSIONS AND FUTURE WORK

5.1 Overview

This chapter presents the key takeaways and conclusions from this thesis. In Section 5.2, the study objectives are restated and explanations of how they were achieved are given. Finally, the results for the study area are summarized. Section 5.3 contains the limitations of this work, and Section 5.4 provides suggestions for addressing them in future work.

5.2 Conclusions

In light of increasing agricultural land abandonment worldwide, exacerbated notably by the impacts of climate change, the necessity for proactive frameworks to assess this phenomenon becomes paramount. The Atlantic Coast was identified as one of the regions experiencing the highest rates of land abandonment in the United States, underscoring the adverse effects of climate change on coastal agriculture in the country. Due to the significant implications of climate change on coastal regions, including phenomena like sea level rise, saltwater intrusion, and water logging, the Eastern Shore of Virginia (ESVA) has emerged as an example of a susceptible area, having witnessed the loss of thousands of acres of its agricultural lands.

Hence, one of the main objectives of this thesis was to discern the spatiotemporal pattern of agricultural land abandonment in the ESVA. Furthermore, the other objective was to explore the potential drivers behind agricultural land abandonment in this region to enhance comprehension of such occurrences. To achieve these goals, USDA CDL data spanning from 2008 to 2022 was employed to identify abandonments from 2009 to 2019.

Remarkably, the concentration of abandonments in 2009, 2010, and 2018, which collectively represent 96% of all recorded instances between 2009 and 2019, underscores discernible patterns meriting thorough examination. The economic downturn experienced during the Great Recession of 2008-2009, compounded by the impacts of the Nor'Ida' Storm in 2009, emerged as potential factors influencing the observed instances of abandonment in 2009 and 2010. The protracted economic downturn led to a substantial decline in real GDP, exerting severe repercussions on agricultural exports, thereby likely playing a role in the observed shifts in land use patterns. Moreover, the prevalence of conversion to wetlands indicates a correlation with abandonment induced by storms. Conversely, the year 2018 witnessed a notable surge in abandonment, attributed to a combination of escalating agricultural expenses, shifting demographic trends, and inadequate regulatory frameworks to counteract farmland conversion pressures in the state of Virginia.

Furthermore, spatial classification of abandoned areas was conducted using DEM, soil drainage data, and marsh and salt patch land cover data. Our analysis revealed that from 2009 to 2019, 24% of all abandoned areas were situated in low-lying regions. Among these, 16% faced solely drainage issues, 27% were affected solely by adjacent salt-affected areas, while 53% experienced the combined impact of drainage issues and proximity to salt-affected areas. Conversely, a significant majority of 76% of abandoned areas were located in high-elevation zones. Among these, 14% faced solely drainage issues, 39% were affected solely by adjacent salt-affected areas, while 27% experienced the combined impact of drainage issues and proximity to salt-affected areas.

Also, considering the area of agricultural abandonment as well as the total area of agricultural lands within different classification groups, the calculated abandonment probabilities revealed that in both high-elevation and low-lying areas, the most severe instances of abandonment occur when poor drainage coincides with proximity to salt-affected zones. Moreover, while low-lying regions generally exhibit higher abandonment probabilities overall, similar challenges increased abandonment significantly in high-elevation areas as well.

Our findings underscore the complex interplay of economic, climatic, and demographic factors in influencing land abandonment patterns. Tailored strategies must be formulated to address these multifaceted challenges, highlighting the urgency of implementing policies for sustainable land use in vulnerable coastal regions such as the Eastern Shore of Virginia (ESVA).

This research offers valuable insights for policymakers, researchers, and practitioners striving to develop effective and region-specific solutions.

5.3 Limitations

This study is subject to some noteworthy limitations. Agricultural land abandonment is recognized as a complex phenomenon influenced by a myriad of social, economic, political, and environmental factors. Nevertheless, this study primarily concentrated on environmental factors for spatial classification and explanation of recorded abandonment. Furthermore, owing to data limitations, the analysis in this study used salt patches and marsh land cover data from 2017. Highlighting the rapid rise in salt patches and marshland areas, it is recommended that for more precise detection of abandoned areas affected by salt-affected areas, a more recent dataset should be employed. Also, in this study, we only considered horizontal proximity to salt-affected areas, despite recognizing that both horizontal and vertical proximity can impact abandonment. This limitation underscores the need for future research to explore the effects of vertical proximity in addition to horizontal proximity on agricultural land abandonment

5.4 Future Work

Future work objectives have been outlined to address the limitations of this study and improve the resources that have been introduced. The overarching goal of this thesis is to explore the spatiotemporal pattern of agricultural land abandonment in the ESVA and analyze the regional characteristics of ESVA to fill this gap in the literature by detailing the specific traits of such coastal areas contributing to land abandonment. This requires the development of a more comprehensive agricultural land abandonment framework, which, in addition to environmental-based factors, also incorporates socio-economic and political factors for spatial classification.

Such an approach would facilitate the formulation of more informative and comprehensive potential scenarios for the detected abandonment, thereby enhancing the utility of the framework for stakeholders and policymakers.

However, achieving this requires active engagement with both the community and experts. To be more specific, designing questionnaires for local people to fill out could help identify the most significant regional characteristics impacting agricultural land abandonment in the area. By incorporating community input through questionnaires, the introduced framework could be further enhanced to comprehensively capture all aspects of agricultural abandonment and its contributing factors. Furthermore, it is recommended that future studies integrate this analysis with a land use classification analysis to ensure access to the most up-to-date information on salt-affected areas, thereby enhancing the accuracy of the results produced.

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