An Interdisciplinary Model of the Natural-Human System on the Eastern Shore of Virginia (1880 and 1920): The Implications of Selected Technology and Socio-Economic Factors on System Dynamics

Thomas Anthony Szuba, Jr.
Charlottesville, Virginia

M.Ed., University of California at Berkeley, 1990
B.A., Yale University, 1989

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Abstract

This investigation of the natural-human system begins with a review of human history, is advanced by stable isotope data, and explored in depth through detailed systems modeling. More specifically, it examines people as a critical component of the natural system on the Eastern Shore of Virginia during a period of intense technological, social, and environmental change (1880 - 1920) and compares system dynamics before and after the arrival of the New York, Philadelphia and Norfolk Railroad in 1884, which connected the people, agricultural harvests, and fishing products of the Eastern Shore to large northeastern markets. The Natural-Human System - Eastern Shore of Virginia (NHS-ESVA) model is parameterized with a large body of historical data from the U.S. Census and other historical resources, as well as more traditional biogeophyical perspectives on system dynamics. As such, it simulates energy balances, human population dynamics, terrestrial land use and agricultural harvests, estuarine productivity and fishing harvests, critical technological and economic components influencing farming and fishing activities, and the links between terrestrial and estuarine systems. Simulations of the 1880 system show a farming enterprise that generated enough calories to feed the human population, but which operated at a financial loss and required financial support from fishing activities. In contrast, the 1920 simulations (after the railroad connection to national markets) revealed a system in which farming activities drove an increase in profits by an order of magnitude relative to 1880. Fishing profits in 1920 declined in relative importance due to overfishing, market prices, and the loss of habitat in the Chesapeake Bay because of then-unknown linkages between terrestrial and estuarine systems (i.e., farming practices causing increased erosion, runoff, and nutrient loads, intensified salinity gradients, eutrophication, and benthic anoxia). Carbon and nitrogen isotopes corroborate evidence from historical research and model simulations. This work is presented

as an example of interdisciplinary research, in which ecology, isotope geochemistry, history, and economics are incorporated. It has broad implications related to our understanding of coupled natural-human systems, links between terrestrial and estuarine systems, and, perhaps most importantly, as an example of the potential significance of interdisciplinary approaches to complex systems analysis.

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I would also like to extend my thanks to the many colleagues who helped me through the years. I first knew Hank Shugart, Steve Macko, and Bob Swap as teachers, but they soon turned into collaborators, eventually became mentors, and I now know them as friends. My academic pursuits would not have been possible without them. Similarly, Fred Diehl always had time to encourage my interests—from my first meeting with him before entering graduate school through my dissertation defense. Brooks Miles Barnes of the Eastern Shore Public Library introduced me to Eastern Shore history (and food) and was always available as a resource when questions arose. I would also like to recognize the support of Lyndele von Schill and Cindy Allen who often helped me to navigate the administrative side of graduate work. Neighbor and friend Deirdre Engel helped with data preparation and undergraduate Mark Gross contributed greatly to isotope analysis. Finally, work colleagues Beth Young and Ghedam Bairu went beyond the call of duty with their support and flexibility during critical periods in my academic program.

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Chapter 1. Study Introduction and Background

When we try to pick out anything by itself we find that it is bound fast by a thousand invisible cords that cannot be broken, to everything in the universe.

— John Muir, 1869

Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect.

—Chief Seattle, 1854

Introduction

This is an investigation of the complexity of the natural-human system. More specifically, it examines people as a critical component of the natural system on the Eastern Shore of Virginia, a geographically isolated neck of land at the southern tip of the crescent-shaped Delmarva Peninsula, laying entirely within the North American Atlantic Coastal Plain between the Chesapeake Bay to the west and the Atlantic Ocean to the east (approximately 37° 30’ N latitude and longitude 75° 45’ W) (Figure 1.1).

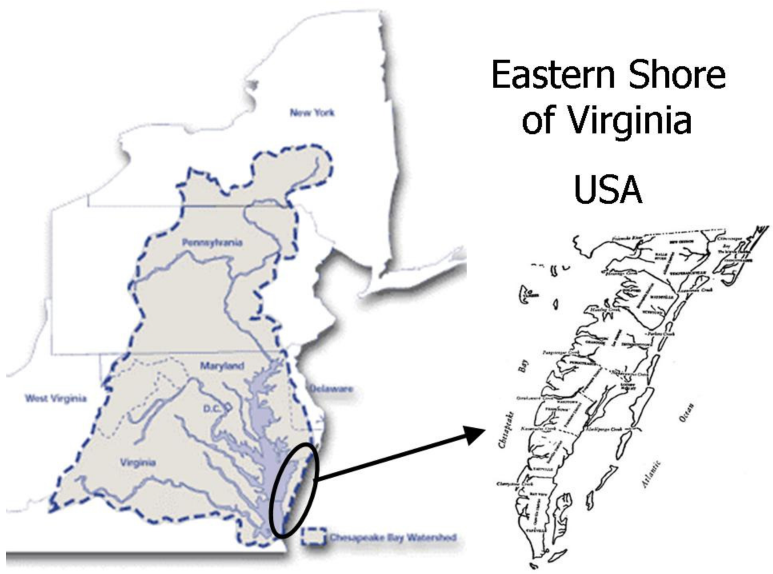

Figure 1.1. The Eastern Shore of Virginia (insert) relative to the northeast United States. The grey, shaded, area of the map of the U.S. northeast represents the Chesapeake Bay watershed. After the Chesapeake Bay Program (2002) and Turman (1964).

This geographical setting, at the interface of terrestrial and aquatic systems, is especially suitable for the study of biocomplexity, which is defined in Michener et al. (2001)

as "properties emerging from the interplay of behavioral, biological, chemical, physical, and social interactions that affect, sustain, or are modified by living organisms, including humans." This complex interplay between biological life and the physical environment transacts at multiple spatial and temporal scales, is characteristically difficult to predict, and must be studied both as a whole and piece by piece (Elser and Steuerwalt 2001). This study endeavors to address some of the key questions facing the study of biocomplexity, including: (1) How do systems with living components such as people respond to stress? and (2) Are these adaptations predictable? (Elser and Steuerwalt 2001).

Answering these questions demands the integration of social, economic, and cultural aspects of the human system in addition to strictly, and more traditionally studied, biogeophysical components (Vitousek et al. 1997). Because the scale of natural-human system dynamics is so vast, yet simultaneously minute, relevant ecological measurements are difficult to obtain (Gallagher and Carpenter 1997; Raven 2002). Moreover, by definition, biogeophysical systems are generally too complex to be fully understood through conventional experimentation (Bonn 2005). Thus, this study relies heavily on a rich body of historical data to construct explanatory models of the natural-human system during two distinct periods of Eastern Shore history, represented by the years 1880 and 1920. During both of these periods, socio-economic pressure in the form of farming and fishing practices placed substantial stress on the terrestrial and estuarine systems. These successive periods also represent the use of distinctive (and advancing) human technologies which, in practice, affected the intensity and scale of anthropogenic pressure on the system and, in theory, contributed to system dynamics that potentially transcended conventional scales of social and environmental study.

More specifically, in this study, the natural-human system on the Eastern Shore of Virginia is characterized, quantified, and simulated via a multiple commodity model structure parameterized with historical, ecological, and physical data that enable the simulation of system dynamics in 1880 and 1920. System properties are examined for each time period/technological regime. A suite of deterministic models facilitates comparison between advancing time periods which, in turn, reflect changing technology regimes and socio-economic demands on the natural-human system.

Key Philosophical References

This study was conceptualized within the framework of the National Science Foundation's (NSF) Biocomplexity Research Program (http://www.nsf.gov/geo/ere/ereweb/fund-biocomplex.cfm; research grant BCS – 030846), but the interdisciplinary approach to studying coupled natural-human system dynamics extends to other current channels of research as well. For example Haber et al. (2006) propose the extension of the NSF Long-Term Ecological Research (LTER) network to better reflect human dimensions in environmental study, including a focus on coupled socio-ecological systems, arguing that it is necessary to link biophysical processes to human governance, communication, and "soft knowledge from the humanities" when developing both predictive and explanatory models of environmental system dynamics (Figure 1.2).

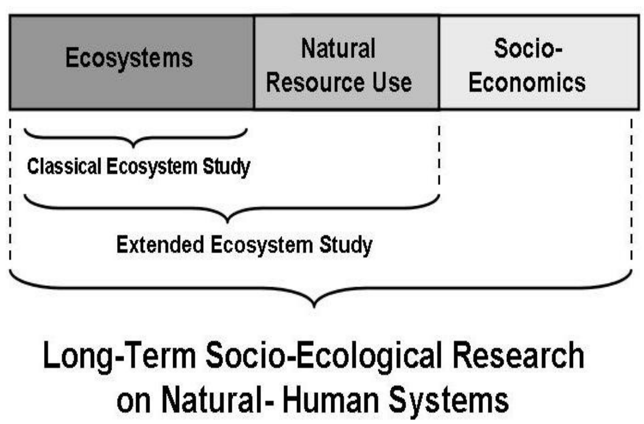

Figure 1.2. The study of environmental systems is extending to incorporate human dimensions beyond natural resource use. After Haber et al. (2006).

There are several key philosophical elements that warrant emphasis in the summary of this research given their prominence in the design, implementation, and intellectual ramifications of this study. These overarching themes contribute substantially to the unique theoretical and practical implications of this study and include:

(1) Interdisciplinary Research Approach: Environmental modeling has traditionally relied nearly exclusively on biogeophysical data to identify system (model) components, processes, and parameters. Although there is great value in this approach to modeling, these physical features—biological, chemical, and otherwise—do not reflect the entire spectrum of system properties in a human-dominated world. This research was conceptualized and developed as an interdisciplinary project from its inception. As such, numerous sources for socio-economic data improve our understanding of the natural-human dynamic being examined. More specifically, this model incorporates detailed demographic, agricultural, fishing, and economic/market data from the U.S. Population Census, the U.S. Agricultural Census, corollary demographic, agriculture, fishing, and economic/market reports, and other sources. These rich data sources inform the science behind the modeling effort and greatly improve our understanding of both the natural and anthropogenic aspects of these systems as well as their interactions. An extended discussion about data sources is presented in Appendix A and Appendix B.

(2) Explanatory Modeling: It is important to note that the models constructed in this study are explanatory rather than predictive in nature. While many models currently represented in peer-reviewed scientific literature are designed to forecast system dynamics over time, models in this study are designed to describe system properties and dynamics in great detail at specific historical points in time (1880 and 1920). This period between 1880 and 1920 can, perhaps, be best characterized as “a time of great change” on the Eastern Shore of Virginia (Thomas, Barnes, and Szuba 2007), and any effort to capture such transformation in technologies, markets, and demands on natural resources in a single model would

inevitably face a tradeoff between breadth (attempting to accommodate so many fundamentally differing system properties) and depth (understanding a specific time period in great detail). Thus, these models are intended not to predict, but to describe, the successive changes in people, processes, technologies and, ultimately, system dynamics over time. For example, prior to 1884, there was not a railroad line connecting the Eastern Shore and its agricultural products and estuarine harvests to external markets in significant volume beyond Baltimore, Maryland to the north and Norfolk, Virginia to the south (and even those markets were at the practical extent of geographic boundaries given the commercial transportation technology available in the region at the time). This limitation is reflected in the 1880 model, which is appropriate and necessary to understand system dynamics at that time, but it also makes the analytical tool antiquated as a descriptor of the natural-human system after 1884 once the railroad had been established on the Eastern Shore. Such a limitation restricts the predictive power of the model, but the depth of understanding that it provides for that single point in time is critical given its purpose of elucidating relationships and assessing the properties and dynamics of that specific time/technology regime. In contrast, the 1920 model reflects the prominent role the railroad played in connecting Eastern Shore agricultural and estuarine products to far-reaching geographic markets—because it is specifically the economic vitality of those pre-depression 1920 markets and 1920 agricultural and fishing technologies that drove Eastern Shore land use decisions, conservation efforts, and, by extension, changes to biogeophysical components and processes in both terrestrial and estuarine settings. Any model that fails to explicitly incorporate those critical factors will not adequately describe the natural-human system on the Eastern Shore during that time period.

(3) Changing Technologies and Technology Use: As referenced above, the period between 1880 and 1920 witnessed tremendous change in the technologies available to people living on the Eastern Shore. Some of these changes were new innovations for the time,

including improvements in commercially available fertilizer and commercial fishing tools. Other technologies were not new in their own right, but only in the sense that they became available to people on the Eastern Shore for the first time. The most obvious example of this is the arrival of the railroad line down the crest of the peninsula in 1884, decades after railroads had marched west across the rest of the nation. This significant transportation technology connected Eastern Shore agricultural products and estuarine harvests to markets throughout the vast majority of the United States and even Europe. Moving potatoes in locally constructed barrels and oysters in refrigerated rail cars, for example, made the people on the Eastern Shore relatively wealthy and drove many of their decisions regarding the use of "their" natural resources. The rail line also changed the human geography of the Eastern Shore. Village life that once was centered on the bay- and sea-side wharves was relocated to towns that arose around the 28 train depots down the peninsula. The emergence and pace of these changing technologies framed the selection of the two time periods modeled in this study, with a goal of reflecting different technology regimes that contributed uniquely to the natural-human systems in 1880 and 1920.

(4) Expanding the Definition of Ecosystem: The modern definition of an "ecosystem" has a long and evolving history. Shugart (1998) traces its origins from the Greek naturalist and philosopher Theophrastus (c. 370 to 285 BC) through Tansley (1935), Lindeman (1942), Odum (1953), and others. A contemporary definition of the ecosystem concept from Watson and Zakri (2003) is "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit." Throughout the evolution of this definition, there has been an enduring controversy related to the appropriate scale of the ecosystem concept. Much of this discussion has focused on geographical size, but this study will argue to extend the idea to include factors beyond traditional biogeophysical components and into more abstract concepts that nonetheless result in tangible influences on study

systems. In this example of the Eastern Shore of Virginia, competitiveness in economic markets played a very real role in human land use decisions and fishing intensity within the system. More concretely, human knowledge about commodity prices in eastern markets (e.g., oats in 1870) changed the crop choices of Eastern Shore farmers in Accomack and Northampton counties. Subsequent land use choices, including the growth of fertilizer use, contributed substantially to system change. Similarly, information about overfishing and declining oyster stocks led to early conservation efforts that affected the system, having an impact on fish harvests, farming intensity (making up for lost fishing revenue and food sources), food webs, and the overall health of the Chesapeake Bay. These and other examples explored in this study had material effects on anthropogenic pressures on the natural system and, correspondingly, the processes, interactions, and dynamics within the ecosystem. As such, an argument is made to include in the ecosystem concept socio-economic knowledge that originates outside of the geographical area of examination when it materially changes system properties.

Research Approach

Objectives

The objectives of this study are:

1) To characterize, quantify, and model the natural-human system on the Eastern Shore of Virginia in 1880 and 1920 via a single multiple commodity model structure.

    a. To parameterize the multiple commodity model with historical, ecological, and physical data that accurately depict the 1880 time period/technology regime.

    b. To parameterize the multiple commodity model with historical, ecological, and physical data that accurately depict the 1920 time period/technology regime.

2) To simulate system dynamics during these two time periods (represented by the years 1880 and 1920).

    a. To assess system properties for the 1880 period/technology regime.

    b. To assess system properties for the 1920 period/technology regime.

    c. To compare and contrast 1880 and 1920 periods/technology regimes.

3) To establish an isotopic signature of the Eastern Shore as recorded in sediment cores from a bayside tidal creek.

    a. To assess whether this isotopic record is consistent with model simulation findings as well as our historical understanding of system dynamics.

Key Questions

Natural-Human System Modeling

1) For each time period/technology regime (represented by the years 1880 and 1920) simulated by the multiple commodity model:

    a. Is the natural-human system in the Eastern Shore of Virginia stable and/or heading toward an equilibrium trajectory?

    b. If the system is stable, does the introduction of advancing technologies change system stability or equilibrium trajectories?

    c. If the system is stable, how, and to what degree, does the system demonstrate resistance to change (i.e., the system's internal inertia relative to external perturbations)?

    d. If the system is stable, how, and to what degree, does the system demonstrate resilience following change (i.e., the time required to return to its original state after being disturbed)?

2) How, and to what degree, do measured system properties vary between advancing time periods/technological regimes, as assessed by comparing output from models parameterized for 1880 and 1920?

Geochemistry

3) What is the geochemical signature of the study catchment as established by sediment cores from a tidal creek in the study area?

a. What is the $\delta^{13}C$ record in the sediments?

b. What is the $\delta^{15}N$ record in the sediments?

c. Are these data consistent with model simulations and our historical understanding of system dynamics?

Hypotheses

Modeling the Effects of Technological Advances on the Natural-Human System

$H1_o$: The 1880 simulation will demonstrate system stability with respect to human populations, estuarine harvests, and farm productivity.

$H2_o$: The 1920 simulation will demonstrate system stability with respect to human populations, estuarine harvests, and farm productivity.

$H3_o$: The introduction of advancing technologies will not change measures of system stability.

$H4_o$: Both time period/technology regime simulations (represented by the years 1880 and 1920) will produce similar measures of stability, regardless of the time period and technological advances.

Geochemistry

$H5_o$: The $\delta^{13}C$ record in the tidal creek core sediments will not change significantly with respect to time (core depth).

$H6_o$: The $\delta^{15}N$ record in the tidal creek core sediments will not change significantly with respect to time (core depth).

Site Selection

The Eastern Shore of Virginia (USA) forms the southern tip of the crescent-shaped Delmarva Peninsula at latitude 37° 30’ N and longitude 75° 45’ W. It is located entirely within the North American Atlantic Coastal Plain between the Chesapeake Bay to the west and the Atlantic Ocean to the east (Figure 1.1). The Virginia peninsula runs from its northern border with Maryland approximately 120 km to its southern terminus at Cape Charles and ranges from 8 to 25 km wide, encompassing a total of 1,290 km^2 of surface land area.

The Eastern Shore of Virginia is comprised of two counties, Accomack to the north (spelled as Accomac until 1943) and Northampton to the south. Though politically distinct entities, these counties share a largely common social, economic, and environmental history. Much of the historical and environmental literature referenced in this study treats the entire Eastern Shore of Virginia as a singular entity and, in fact, includes eastern Maryland and parts of Delaware (making up the Delmarva Peninsula) as a largely cohesive biogeophysical unit, despite notable political differences and subtle socioeconomic differences described throughout the paper (Figure 1.3). As described in the modeling chapters, Appendix A, and Appendix B, U.S. Census data used to parameterize the models in this study were recorded for the Franktown Enumeration District which lies entirely in Northampton County (Figure 1.4).

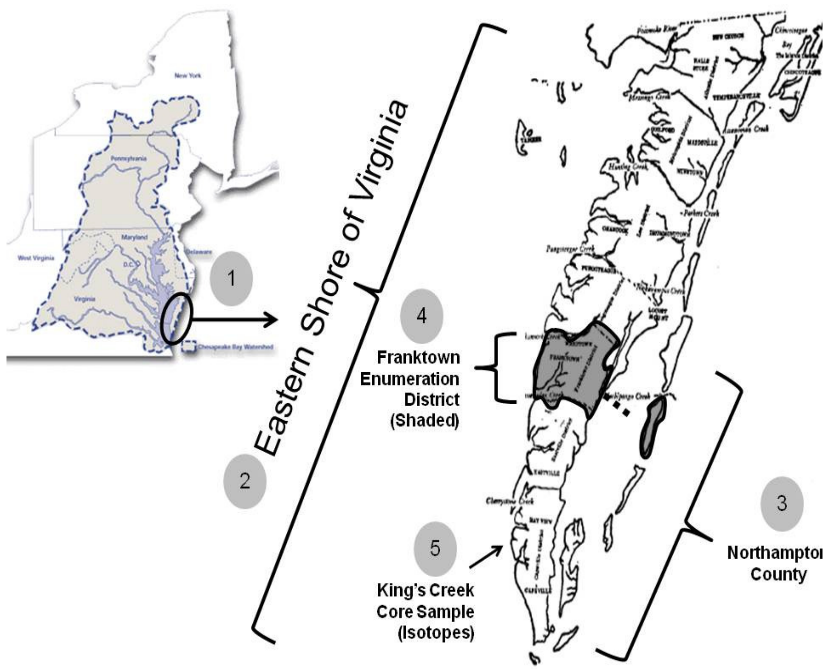

Figure 1.3. A review of the geographic scale of this project from the largest to smallest units: (1) the northeast United States showing the Chesapeake Bay and its watershed (shaded in light grey); (2) the Eastern Shore of Virginia; (3) Northampton County; (4) Franktown Enumeration District (shaded in dark grey); and (5) King's Creek core sample (for isotope analysis). After the Chesapeake Bay Program (2002) and Turman (1964).

Man and Nature

Like all organisms, humans modify their environment. Assessing natural-human dynamics demands not only an understanding of the biogeophysical components of the system, but also relevant human dimensions (both impacts and responses), including population growth, individual resource consumption, and technological advances (Raven 2002). Failure to account for these attributes can lead to exaggerated or otherwise faulty appraisals of system dynamics. For example, Malthus' famous 1798 prediction of imminent and recurring vice and misery facing human societies (war, famine, and disease) was predicated on the belief that "population increases in a geometric ratio… while the means of subsistence increases in an arithmetic ratio" (Landry 2001). This assertion famously fails to account for human capacity to alleviate misery through laws (e.g., land use), social standards (e.g., sanitation), and technological advances (e.g., enhanced productivity through improved farming practices).

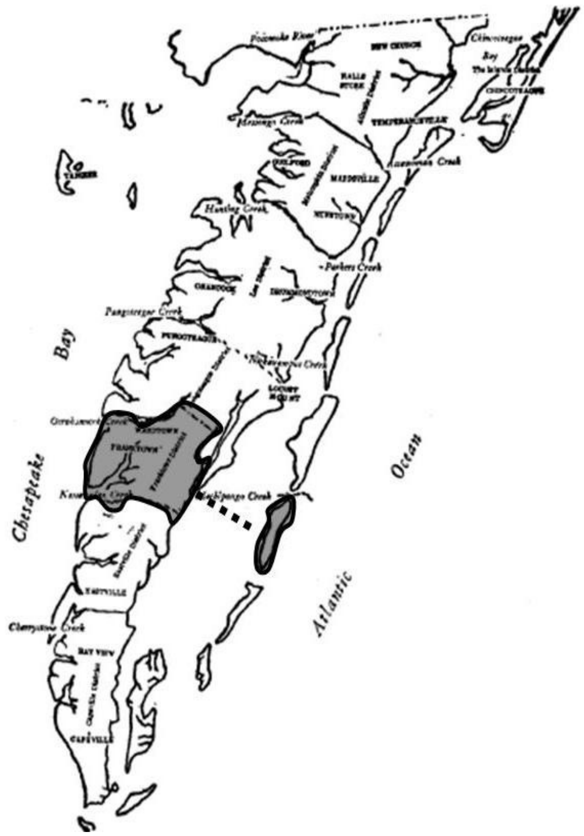

Figure 1.4. The Franktown Enumeration District (shaded) lies entirely within Northampton County, includes Hog Island, and is bounded by Accomack County to the north and the Eastville Township line to the south. After Turman (1964).

Anthropologists, geographers, sociologists, historians, and even scientists have long studied the relationship between man and the environment. Davidson-Hunt and Birkes

(2000) chronicle several prominent efforts to characterize our place in and with nature as human ecology (Park 1936), cultural ecology (Steward 1955), ethnoecology (Conklin 1957), population dynamics (Ehrlich 1968), ecological anthropology (Bateson 1973), environmental history (Cronon 1983), and political ecology (Greenberg and Park 1994). More recently, the term "human ecosystem" has been used to refer to systems in which the human species is a central agent (Vitousek and Mooney 1997; Stepp et al. 2003). Many now argue that that the whole planet is a human ecosystem, in that all Earth ecosystems have been influenced by humans (Vernadsky 1945; Tielhard de Chardin 1959; and others).

Early intellectual roots for these theories arise, in some part, from the concept of environmental determinism, which postulates that the physical environment, rather than social conditions, determines culture. While this belief is viewed by many to be one-dimensional (e.g., Sluyter 2003), a refined and intellectually more tenable version holds that favorable geography and a temperate climate contribute significantly to critical aspects of human advancement and history. For example, Diamond (1997) argues that the geographical advantages and environmental stability of Eurasia permitted the development of a complex agrarian foundation from which intellectual and sociological advances arose—factors that strengthened these societies relative to populations in, for example Africa, where geo-climatic change along a broader latitudinal gradient did not comparably encourage social stability and cultural development. A niche within this theory, "climatic determinism," is exemplified by the provocative, but largely unsubstantiated, "equatorial paradox," which asserts that roughly 70 percent of a country's economic productivity can be predicted by its distance from the equator. Such "anthropogeographics" have sometimes been applied to people who live under advantageous environmental conditions and, according to some theoreticians, are destined to rule and control populations living in less bountiful settings—people who were, by nature, "more lethargic, less courageous, and less intelligent" (Moran 1979, p. 24).

These philosophies of man and nature have often been used to justify prejudices, injustices, and other rationalizations for one society's dominance over another. Early Greeks, Romans, and Arabs, along with many of the dominant European countries of the 18th and 19th centuries, relied heavily on environmentally deterministic theories, in concept if not in name, to justify social behavior not otherwise acceptable in civilized culture (Moran 1979; Berkes et al. 2002).

Despite recent reconsideration of the social implications of environmental determinism and other unjustifiably applied theories of man and nature, there is no dearth of evidence that people and their environment are closely linked. From an abstract, yet logical, perspective, we appreciate that the Earth's geomorphology and climate generally determine where people live. Where there are mountains, there are often inclement and uninhabitable weather conditions associated with high elevation. And where there are fertile fields, there are likely flood plains enriching the soils that support productive farming and, in turn, feed people.

Despite this logic, during the Age of Enlightenment humans were believed to transcend the environment (as described but not advocated in Davidson-Hunt and Birkes 2000), but most contemporary thinkers reject the notion of "man apart from and dominant over the rest of the world" (Lotspeich 1995). Rather than limiting our perspective to man's accommodation to his environmental constraints, however true that may be, we now also recognize the reciprocal perspective—man's unique role in transforming his environment. Jackson et al. (2001), for example, argue that humans have been transforming ecological systems since long before modern scientific inquiry was equipped to assess it. In fact, that man has brought about substantial change to his own environment is of little debate—it is firmly an issue of both science and history. Arguments concerning the links between man and nature have been available in popular scientific literature for a very long time. As far back as 1874, for example, George P. Marsh asserts that the Earth was being modified by human action (Marsh 1874). More recently, Howard Odum describes man overpowering nature through the use of fossil fuels (Odum 1971); Reid Bryson documents human land use choices and desertification in India (Bryson and Murray 1977); and Jared Diamond describes interactions between the powerful forces of the environment and human culture (Diamond 1997). These specific examples represent a growing body of literature that confirms the belief that man is not only influenced by his environment, but also, in turn, affects the environment as well. Veldcamp and Fresco (1996) make an even stronger statement about man's role by arguing persuasively that by far the most important factor in land cover modification is human use rather than natural change.

Human activities modify not only the structure and function of ecosystems, but also their interaction with the atmosphere, aquatic systems, and terrestrial components (Vitousek et al. 1997; Brown et al. 2002; Kirby and Linares 2004). The industrial revolution, for example, expanded human alteration of the global environment to an unprecedented scale and extent (Steffen et al. 2004). Anthropogenic activities, including farming, manufacturing, pollution, and urbanization, have radically transformed "natural" landscapes and exerted profound effects on the structure and function of ecosystems (Brown et al. 2002). Humans now transform the land and sea through farming, fertilizer use, deforestation, and the propagation of asphalt parking lots. We alter carbon, nitrogen, and water biogeochemical cycles, and we change population and community dynamics directly via recreational hunting, commercial fishing, and monoculture farming, and indirectly through habitat modification. The intimate connection between people and their environment is intensifying and our biogeophysical system has become, at least to some extent, a product of our economic, social, and national security interests (Lubchenco 1998; Hughes 2005; and others). The changes are not insignificant. In addition to altering the surface properties of the Earth, land use modification can affect local and global climates and other large scale processes (Shugart 1998).

Although this paper examines natural-human systems through the lens of past history, many researchers believe that the future impact of human activity is both global and increasing (e.g., Western 1998; Kareiva 2007; and numerous others). Vitousek et al. (1997) contribute to such a claim when highlighting the degree of human influence on the environment. For example, between one-third and one-half of the Earth's land surface has been transformed by human action; the carbon dioxide concentration in the atmosphere has increased by nearly 30 percent since the beginning of the Industrial Revolution; more atmospheric nitrogen is fixed by anthropogenic activity than by all natural terrestrial sources combined; more than half of all accessible surface fresh water is used by people; and about one-quarter of the bird species on Earth have been driven to extinction. Lash (2001) adds that one-half of the world's jobs depend on fisheries, forests, or small-scale agriculture, yet two-thirds of the world's fisheries are being harvested beyond sustainability, forest loss is accelerating, and soil degradation is widespread and worsening. Other consequences of human activities include homogenized landscapes, simplified food webs, and elevated nutrient inputs and imbalances. By these and other standards, it is clear that we live on a human-dominated planet. Kareiva et al. (2007) asserts that there is no longer such thing as nature untouched by human influence and, perhaps more disquieting, Western (1998) argues that such human modification of ecosystems will have tremendous effects on natural systems and biological life and may, in fact, largely determine the future course of evolution.

With respect to the study of natural systems, Geertz (1963) was an early proponent of models that incorporated both biological and social entities and processes. Lotspeich (1995) correctly applies such a unified approach when describing economics as a subset of ecology. He argues, in fact, that it is ecology that drives economics given that our biophysical infrastructure serves as the foundation for all economic activity. In other words, ecosystems are the natural capital necessary for mankind to exist, and it is our natural resources that serve as the raw materials for any and all production, fuel for transportation, and food for the workforce.

Complex Systems, System Properties, and Systems Modeling

But they have only analyzed the parts and overlooked the whole,
and, indeed, their blindness is marvelous.

— Dostoevsky, 1880
The Brothers Karamazov

Thinking about "systems" requires thinking about relationships—man and nature, terrestrial and aquatic, biotic and abiotic to name but a few. Unfortunately, it is often difficult to identify the links between sometimes seemingly unrelated pieces of a puzzle. A holistic look at climatology, for example, might begin with an account of the Earth's eccentricity, precision, and obliquity (the Milankovitch Cycle), progress to an examination of the atmospheric chemistry and a general circulation model, and end with a consideration of ozone levels and other aerosols that pollute the atmosphere—and one still couldn't always accurately predict the temperature in Topeka! Thus, it is exceedingly tempting to study complex systems like the Earth's climate from a reductionist point of view. Grasping at the issues one piece at a time at least appears to be manageable. But in doing so, one risks losing appreciation for the fact that it is, quite literally, the interaction of the pieces that paints the big picture. The great challenge for students of Earth systems, therefore, is to realize that we often need to account for more than the sum of the parts.

Since its emergence as a field of study, a primary goal of ecology (particularly in its early stages) has been to understand the fundamentals of the use and development of natural resources, sometimes referred to as "natural capital" or the "economy of nature" (DiCastri 2000). But properly accounting for man's place in nature beyond this traditional focus on resource extraction has been a great challenge (Kangas 2004).

Ecologists who once sought to study pristine ecosystems without confounding human influence now largely agree that there are no longer any ecosystems unaffected by human activities (DeLeo and Levin 1997; Gallagher and Carpenter 1997; Scoones 1999; O'Neill and Kahn 2000; and others). Precisely because of the interconnectedness of man and environment, Lacitignola (2007) argues that the analysis of socio-ecological systems requires "an integrated assessment of ecological, social, and economic factors." Haber (2006) contends that understanding contemporary socio-ecological systems requires the study of historical sources to reconstruct past system states because past ecological conditions, social structures, and historical events undoubtedly influence current structures and functions of socio-ecological systems. Thus, socio-ecological models that integrate multiple dimensions, such as economic and ecological dynamics, over a range of temporal scales (e.g., historical legacies) are especially appropriate for analysis of human-natural systems (Ayres 2001; Ibenholt 2002; Foster et al. 2003).

Setting Boundaries on a System

In an effort to keep ecological study tractable, researchers have traditionally endeavored to set geographical or physical boundaries on study sites. Components and processes that existed within these boundaries would be considered a part of the system and studied (either experimentally or observationally). Alternatively, features outside the system would not be considered. For example, a study of biogeographics might look at a lizard population on an island but, by definition, consider all lizards not living on the island to be outside of the system and, therefore, beyond of the scope of the study. Thus, even though lizards might be living on other islands, the system of study is considered "closed" for practical purposes at the physical border between the island and the surrounding water. Similarly, although heat or hours of daylight might affect the dynamics of the lizard population on the island and, therefore, be explicitly addressed in the study, the source of that heat and light energy (the sun) would not be considered to any great extent other than as manifested by the arrival of sunlight (solar energy) to the island. Setting such biogeophysical and intellectual boundaries often makes sense and, in many cases, is the only realistic way to study a system without becoming overwhelmed by the countless connections between one set of components and process and the rest of the systems in the universe (biocomplexity at its grandest).

One concept used by ecologist to set reasonable boundaries on systems of study is the "ecosystem." Shugart (1998) traces the concept's origins back to the Greek naturalist and philosopher Theophrastus (c. 370 to 285 BC) and, more recently, Möbius' "biocoenosis" (1877), Forbes' "microcosm" (1897), and Dokuchaev's "biogeocoenosis" (1889), prior to the first use of the term "ecosystem" by A.G. Tansley in 1935. Since that time, Lindeman (1942), Odum (1953), and others have extended the definition of an ecosystem, which has more recently been defined as "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit" (Watson and Zakri 2003). Abel and Stepp (2003) contribute to the advancement of the concept with a focus on an enduring controversy associated with ecosystem concept—geographical size: "any size so long as organisms, physical environment, and interactions can exist within it... [it can] therefore be as small as a patch of soil supporting plants and microbes; or as large as the entire biosphere of the Earth."

Shugart (1998) frames the definition from the perspective of a systems modeler by arguing that "an ecosystem is defined relative to the objectives of a given study." This utilitarian definition enables system modelers to establish boundaries based on the scale of interactions (system component dynamics) being studied. Another systems modeling perspective is offered by Dale (1970), who defined a system as "a collection of interactive entities… that need not, and in general are not, in one-to-one correspondence with 'real' things… they can represent classes of processes." He emphasizes that a system can be composed of subsystems, each of which can be treated as a system in its own right. Dale's systems are further classified as "open" or "closed" depending on whether variables that affect the interrelationships between system entities are imported or exported. Within this construct, the simplest and most common ecosystem model is the "black box" ecosystem that can be conceptualized most simply as: input → ecosystem (black box) → output (Dale 1970).

System Modeling

Put simply, a model is a quantitative description of a real-life process or system (Cherwell 2000a). Shugart (1998) refines the concept to focus on ecosystem models when describing them as "mathematical expressions developed to be analogous, in some sense, with an ecosystem of interest." Implicit in this are simplification and abstraction, which are an essential aspect of science (Shugart 1998). Thus, at their most basic, models simplify complexity to a level that is appropriate for describing systems and advancing our understanding of system dynamics.

Depending on the system being studied, the tools used to create the model, and relevant research objectives, models can vary greatly in design, complexity, and scale. They range from single species/material compartment (box) models to community/trophic level models, three dimensional hydrodynamic models, airshed models, watershed models, land use/land change models, and complex ecosystem and resource management models (for a review of these types of modeling activities see, for example, Xu and Hood 2006; Ma et al. 2009; and Andre and Cardenet 2009).

Because the scale of natural-human system dynamics is simultaneously universal and subatomic, meaningful ecological measurements can be difficult to collect (Gallagher and Carpenter 1997; Raven 2002). In fact, ecological data rarely are adequate to measure the impact of long-term human disturbance given that most observational records are "much too short, too poorly replicated, and too uncontrolled" to clarify our understanding of many environmental processes (Jackson et al. 2001; Preston and Shackelford 2002). This realization makes systems modeling a progressively more useful tool in the study of complex natural-human relationships. Models can incorporate necessary abstractions and simplifications that may not be feasible under more traditional experimental design. They can also integrate processes across a wide range of spatial and temporal scales not otherwise tractable in observational studies. Finally, model findings can be used to help direct more systematic, experimental analysis of a study system's critical components (Shugart 1998). For example, compartment models (e.g., stocks and flows for material transport) can be combined with agent-based models to better examine the relationships between human decisionmaking and biophysical dynamics (Janssen 2004).

Many early models were intended merely to abstract and simplify complex systems. Computational power for evaluating these models was limited and so, therefore, was the complexity of early models. This does not mean these seminal modeling efforts were unimportant or insignificant. To the contrary, they advanced the science of modeling and our understanding of many of the fundamental dynamic processes that form natural systems. By the late 1970s, however, computational power was growing and systems modeling was on a trajectory toward accommodating increasingly complex natural-human systems (see, for example, Odum 1977; Weinstein et al. 1983; Odum 1996; Lansing and Miller 2003; and Zuchetto 2004).

As described above, there is an increasing need to identify and quantify the relationships that shape the complex natural-human system (Brown et al. 2002). As Kay (1991) so eloquently states, "As a science, ecology is in a developmental stage similar to physics before Newton; there is little consensus about which ecosystem characteristics are important." Fortunately, systems science has emerged to quantitatively describe the behavior of dynamic systems (Few 1992), and the application of modeling expertise to the study of natural-human systems is advancing at a rapid pace (Adger 2000; Casagrandi and Rinaldi 2002; Abel and Stepp 2003; Jannsen and Ostrom 2006; and many others).

System Properties

While there are many properties and characteristics of systems that can be studied, several concepts are common to most analytical efforts. In addition to system boundaries (discussed above), the concepts of scale, stability, resilience, and resistance are often critical to systems analysis.

Scale. Peterson and Parker (1998) define scale as the "physical dimensions of observed entities and phenomena." Frost et al. (1988) extend the application of scale to at least three dimensions: space, time, and the level of biological organization at which systems are considered (Figure 1.5). From a researchers' perspective, Gibson et al. (2000) defines the concept as "the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon."

Scaling is a way to simplify complexity so that researchers can quantify and describe critical physical and biological mechanisms that regulate systems at different tempos or paces (Brown et al. 2002; Paine 2002). Nelson et al. (2006) and Rammel et al. (2007) note that many of the major factors that drive system change are dynamic, cross-scale, and interactive across sub-systems at a wide range of spatial, temporal, and organizational levels. These large-scale processes are difficult to forecast and nearly impossible to control, from either a practical resource management standpoint or an observational/research perspective (Peterson 2000).

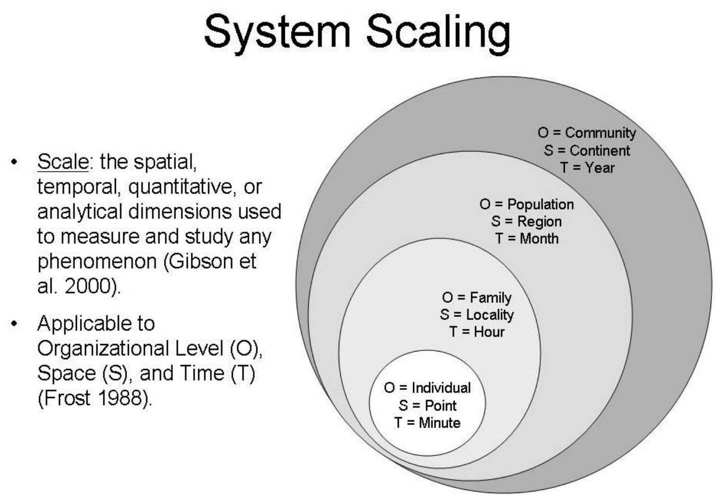

Figure 1.5. Conceptual model of system scaling, as applied to the organizational level, space (geographically), and time.

Stability. Murdoch (1970) narrowly describes the concept of stability as "a population that tends to remain constant." Shugart (1998) presents a definition of stability that can more readily be applied to systems: "the long-term response of a system relative to an external change or perturbation as determined by the return of the system to its original trajectories over time after the disturbance (or as time approaches infinity)." Thus, a system can be stable even in the face of external disturbance so long as it returns to equilibrium (i.e., a "steady state") following perturbation. In a compartment model, for example, a stock is considered to be in equilibrium and therefore stable when the amount of material transferred in and out of the compartments is equal over time (Shugart 2000). Thus, stability is not the absence of change but, rather, the steady and balanced flow of energy and materials over time even in the face of temporary change (Ludwig et al. 1997).

Policymakers, the public, and, indeed, the scientific community long believed that the natural state of the environment was stable absent man's intervention. Marsh (1864, pg 27), for example, held that "nature, left undisturbed, so fashions her territory as to give it almost unchanging permanence of form, outline and proportion, except when shattered by geological convulsions; and in these comparatively rare cases of derangement, she sets herself at once to repair the superficial damage, and to restore, as nearly as practicable, the former aspect of her dominion." But this "balance of nature," as often described by terms such as "stability," and "equilibria," has more often been assumed rather than demonstrated by ecological study (Ehrlich and Birch 1967; Pimm 1992). In fact, more recent study asserts that the once common belief in a balance of nature is now "deeply in question and, with increasing frequency, rejected outright" (Zimmerer 2000). Abel and Stepp (2003) further rebuff traditional assumptions about equilibrium systems and, in its place, recommend ecosystem analysis focused on complexity, adaptation, resilience, hierarchy, scale, nesting, nonlinearity, irreversibility, self-organization, emergent properties, historical precedent, chaotic dynamics, and even surprise.

Resilience. Change is always occurring in nature and small- and large-scale disturbances are a fundamental and continuous forcing process. The response of an ecological system to a disturbance (internal or external pressures and other perturbations) is often described in terms of resilience, which is the proclivity to, and time required for, a system to return to its original state after being disturbed (Steinman et al. 1992; Stone et al. 1998; Cropp and Gabric 2002). Early definitions of resilience focused on return to a "steady state" (Webster et al. 1975; Steinman et al. 1991), which has been revised to the return to an "original state" to reflect the more recent rejection of the "balance of nature" (see discussion above).

Rapport et al. (1998) submit that, in general, the degree of resilience of a system is correlated with the health of that system, but such an assertion may be a value imposed by the researcher. Resilience is, after all, only a positive feature of a system if one assumes that the system was originally stable or, more precisely, that stability in a "pristine" state is a desirable objective. If a system is not in a desirable state, there is no value in it being strongly resilient, as would be the case of a "resilient super-fund site" that returns to its undesirable polluted state in spite of efforts to change its properties (i.e., to clean it).

Because experimental manipulation of large-scale ecological and socio-ecological systems is difficult to conduct, measuring resilience in the real world has tremendous costs, especially if the change that is induced proves to be irreversible (Peterson 2002). Thus, the resilience of ecological systems is generally assessed by means of the mathematical analysis of dynamic system models (Holling 1973; Ludwig et al. 1997; and Carpenter et al. 1999).

Resistance. While some argue that the resilience of a socio-ecological system is measured by the amount of change that a system can experience before it is forced to reorganize (Deutch et al. 2002; Peterson 2000), this concept is more commonly viewed to be a complement of the resilience concept and referred to as resistance. Locke and Sprules (1994) define resistance as "a system's internal inertia relative to external perturbations as measured by the magnitude of displacement from a non-disturbed trajectory or by the level of disturbance required to overcome a stable equilibrium." In other words, resistance reflects the magnitude of perturbation a system can withstand before changing states. Like resilience, resistance is difficult to measure in the real world and is most often assessed via modeling analysis.

System Dynamics

"System dynamics" is simply another way of saying "system change." And as Heraclitus (535-475 B.C.) stated, "nothing endures but change" (sometimes translated as, "the only constant in life is change"). Unstable systems surely change, transitioning from one state to another. But even stable systems change in the movement of materials, energy, or other resources, albeit at levels in which inflow equals outflow.

Changes in ecosystems are usually caused by multiple interacting drivers. These drivers can work over time or across levels of organization and, although they are often ongoing in nature, they are rarely continuous (i.e., they can occur intermittently) (Nelson et al. 2006). A direct driver unequivocally influences ecosystem processes, whereas, an indirect driver operates more obliquely by influencing one or more direct drivers that, in turn, affect the system directly. In addition to many commonly recognized physical and biological drivers, Nelson et al. (2006) identify several categories of anthopogenic driving forces of potentially global significance, including: demographic, economic, sociopolitical, cultural and religious, and scientific and technological.

Holling (1994) presents three paradigms of change that are at the forefront of contemporary systems study and analysis: (1) nature as constant; (2) nature as engineered/resilient; and (3) nature evolving. Levy et al. (2000) describe these paradigms (separating Holling's second paradigm into two, thus leading to four paradigms in Levy) with respect to how they have been adapted intellectually by policymakers and the public to inform our communal perceptions of natural systems and system dynamics (Figure 1.6). While both Holling and Levy agree that none of these conceptual models is correct to the exclusion of the others, the perspectives these paradigms represent explain how many people view ecosystems and management choices.

These paradigms (and corresponding conceptual models) are simplified abstractions of complex systems and subsystems that are connected through a wide range of biogeophysical structures, processes, and organizational hierarchies. Though presented here as examples that are qualitative in nature, they merge separate streams of theory, experiment, observation, and practice that are useful in understanding basic modeling and analytical concepts (Holling 1994).

The first paradigm (Holling 1994 and Levy et al. 2000), *Nature as Constant*, assumes that nature does not change and that there are no practical limits to human exploitation of natural resources. In Figure 1.6a, such a completely stable system is illustrated by a ball that will return to its original state no matter how much it is disturbed.

The second view, *Nature as Ephemeral*, is sometimes referred to as nature preserved. In this paradigm, natural systems exist in such a precarious state that any anthropogenic perturbation will immediately, completely, and irreversibly destroy the delicate balance of nature. In Figure 1.6b, such a system is illustrated by a ball that will leave its original state no matter how little it is disturbed.

The third view, *Nature as Balanced*, emphasizes the sustainability of natural systems as a function of their ability to accommodate most disturbance pressures, although large perturbations can still lead to state changes. In Figure 1.6c, such a system is illustrated by a ball that fluctuates within a range of relatively comparable states in response to disturbances that do not exceed a critical threshold.

The fourth view, *Nature as Resilient*, describes systems that are "adaptive, evolutionary, and self-organizing." These systems maintain their integrity even under highly variable conditions and extreme purturbation. In Figure 1.6d, such a system is illustrated by a ball that meanders across a wide range of basically similar states in response to a great variety of external disturbances.

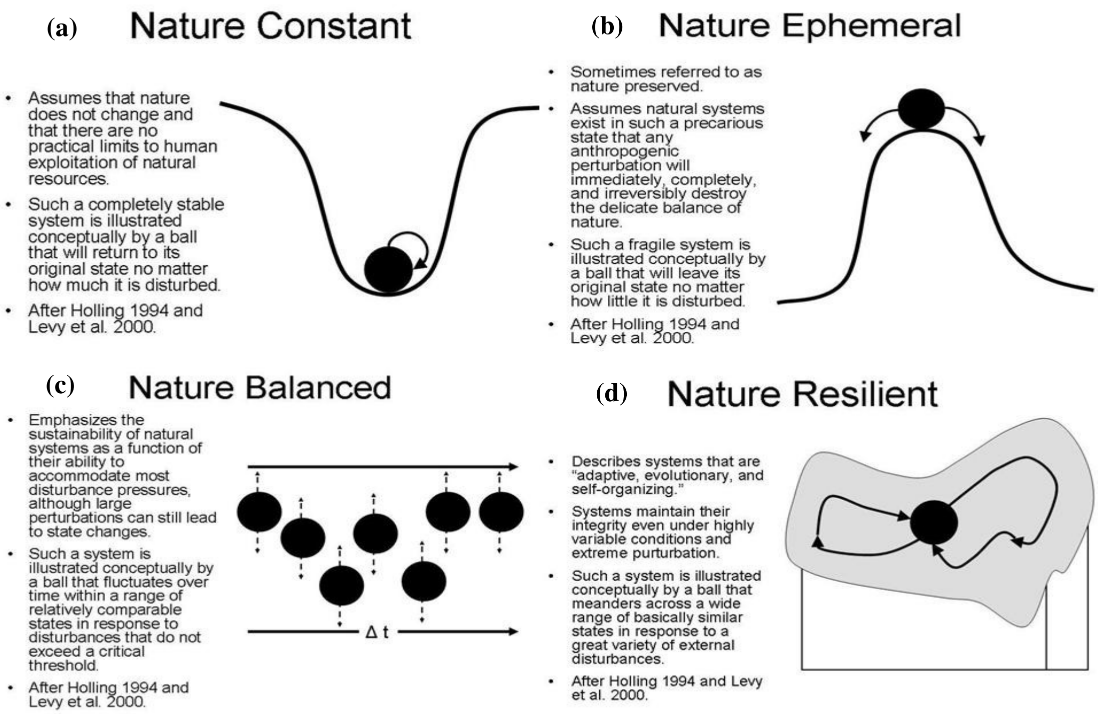

Figure 1.6. Conceptual models of natural system dynamics that commonly influence scientific and social decisionmaking, as identified in Holling (1994) and further explored in Levy (2000).

Modeling Complexity

In order to understand more complex systems, it is often convenient to first consider simpler systems that exhibit similar types of behavior and then explore complexity in greater depth after a basic understanding has been established (Ludwig et al. 1997). For example, Lindeman (1942) was an originator of the study of material transport and ecosystem energetics with his groundbreaking paper on lake systems. Carpenter et al. (1996) extended these core understandings when applying more complex concepts to the analysis of lake ecosystems, which they characterized as either "normal" or "pathological" depending on the numbers of game fish, the effectiveness of grazing on phytoplankton, and the relative occurrence of algal blooms. Other researchers further advanced the study of lake systems and dimensions of complexity when, for example, they identified that systems sometimes *gradually* shift from fast growth to relative stability; yet in other cases, the shift is marked by *abrupt* crashes and destruction (Odum 1973; Daly 1997; Ludwig et al. 1997; Zucchetto 2004). Ludwig et al. (1997) further advances complexity study when reporting that these ecological systems can sometimes exist in multiple stable states, some of which are at least partly determined by history (e.g., they may also show a hysteresis effect).

Modeling this type of complexity can, itself, become a complex endeavor; yet, there are limits to how complicated a model can become and yet still be tractable. Thus, abstraction and simplification must be introduced appropriately. The industrial statistician, George Box, emphasizes this theoretical limit to modeling when asserting, "All models are wrong. Some models are useful" (Box 1979). When constructed and applied appropriately, modeling can be a useful analytical tool that can inform and advance our understanding of complex dynamic natural systems and the role people play in them.

Stable Isotopes

Stable isotope geochemistry is a powerful tool in the study of natural systems (Peterson and Fry 1987; Lajtha and Michener 1994; and others). Because direct instrumental measurements of past systems were not conducted over the greatest part of Earth history, current research on antecedent systems focuses instead on identifying other biotic and abiotic records that reflect system states and processes—commonly referred as proxy records (Bradley 1985). In fact, a wide range of interdisciplinary research has relied on both organic and inorganic geochemistry to generate suitable proxies for source materials, sedimentation patterns, substrate characteristics, food sources, vegetation, and geomorphology over recent, historical, and prehistorical periods (e.g., paleoecological and paleoclimatological) (Engstrom 1985; Marcus et al. 1991; Pasternack et al. 2000; Jackson et al. 2001; Christiansen et al. 2002).

Because of their ability to link sources and processes, stable isotopes have been useful in the study of food webs. Harrigan et al. (1989), for example, traced carbon and nitrogen isotopes to examine the gray snapper food web in both mangrove and seagrass habitats, while MacAvoy et al. (2001) used isotope analysis to derive the relative proportions of nutritional sources for aquatic predators. Similarly, Haramis et al. (2001) relied on isotopes to assess the impact of changes in submerged aquatic vegetation on the diet of canvasback ducks in the Chesapeake Bay. Wayland and Hobson (2001) used stable isotopes of nitrogen ($\delta^{15}N$), carbon ($\delta^{13}C$), and sulfur ($\delta^{34}S$) to trace the movement of nutrients derived from sewage and pulp-mill effluent in freshwater ecosystems and riparian food webs.

More specifically with respect to this work, Horrigan et al. (1990) relied on stable isotopes to confirm the seasonal cycling of nitrogen in the Chesapeake Bay and Russell et al. (1998) used stable isotopes to identify organic and inorganic sources of nitrogen in wet deposition that contributes to eutrophication in the Bay. Zimmerman and Canuel (2002) extended this analysis to reconstruct the progression of eutrophication and hypoxia in the Bay during the past five centuries. The stratigraphic record of sediment cores, as examined through stable isotopes, has extended the understanding of climatic and anthropogenic impact on the Chesapeake Bay well beyond the availability of historic records (Cooper and Brush 1991). Bratton et al. (2003), for example, examined the influence of humans on Chesapeake eutrophication cycles over the past 2,700 years based on carbon and nitrogen isotope analysis of piston (sediment) coring in the Bay.

Jackson et al. (2001) studied sedimentation, pollen, seeds, diatoms, and geochemistry in sediment cores to reconstruct the ecological history of the Chesapeake Bay watershed over the past 2,000 years to determine that environmental and biological fluctuations since European settlement were greater than pre-settlement rates of change. Other evidence suggests that this environmental disturbance due to nutrient influx did not arise until late 18th century, and that the recurring, yet periodic, eutrophication and anoxia deep in the Bay were apparent by the early 19th century (Zimmerman and Canuel 2000). Similarly, Marcus et al. (1991) argues that coastal erosion may be the dominant process driving sediment input along many tributaries of the Bay throughout the past several centuries. More recently, Fulford (2007) presents compelling evidence that the Chesapeake Bay has suffered from a long history of eutrophication that has led to increased phytoplankton biomass (Kemp et al. 2005), decreased water clarity (Gallegos 2001), increases in the severity and geographic extent of seasonal hypoxia (Breitburg 1990; Boicourt 1992; Hagy et al. 2004), and decreases in submerged aquatic vegetation (Kemp et al. 1983; Orth and Moore 1983; and Orth et al. 2002). Thus, stable isotope geochemistry has helped researchers to identify links between terrestrial land use and anoxic conditions (and the subsequent transformation of the estuarine food web from primarily metazoan driven to bacterially driven) as well as the potentially concurrent effects of both man and climate (Malone et al. 1986; Malone 1992; Curtin et al. 2001; Jackson et al. 2001 and others).

Hoefs (1997) defines an isotope as an atom of an element whose nuclei contain the same number of protons but a different number of neutrons—that is, isotopes are atoms of the same element with different atomic mass. The key to using isotopes to study biogeochemical processes is fractionation, or the discrimination (but not exclusion) of an isotope so that there is either enrichment or depletion of one isotope relative to another as a function of either isotope exchange (the redistribution of isotopes without a net reaction) or kinetic effects (unidirectional change governed by physical processes or enzymes) (Faure 1986). Isotope fractionation occurs because of differences in atomic weight (i.e., mass differences) and the corresponding variation in an atom's vibrational energy. Put simply, heavier isotopes of an element have less vibrational energy and greater bond strength than lighter isotopes, causing them to react (exchange) at differing measurable rates (Hoefs 1997).

Stable isotope values are normally reported in terms of delta (δ), which is presented as a per mil (‰) value. Delta values represent the difference between a sample reading and an international standard. Delta values are determined using the following equation:

$$[(R_{SAMPLE} - R_{STANDARD})/R_{STANDARD}]*[1000] = \delta‰$$

in which the R value represents the ratio of the heavier isotope to the lighter isotope. For example, for carbon, the R value is equal to $^{13}C/^{12}C$.

Isotopes commonly used in biogeophysical study include carbon, nitrogen, sulfur, and oxygen.

- Carbon occurs in three isotopic forms: ^{12}C (98.89 %), ^{13}C (1.11 %), and ^{14}C (cosmogenic and not stable). The international isotopic standard ($R_{STANDARD}$) for carbon is PDB (PeeDee Belemnite Cretaceous formation in South Carolina) (now PDB-V).
- Nitrogen occurs as two isotopes: ^{14}N (99.64 %) and ^{15}N (00.36 %) with an international isotopic standard ($R_{STANDARD}$) of atmospheric nitrogen (N_2).
- Sulfur has four isotopes: ^{32}S (95.02 %), ^{33}S (00.75 %), ^{34}S (04.21 %), and ^{36}S (00.02 %) and an international isotopic standard ($R_{STANDARD}$) from the Canyon Diablo Troilite (CDT) meteorite.
- Oxygen appears in three isotopic forms: ^{16}O (99.63%), ^{17}O (00.0375%), and ^{18}O (00.1995%). The international standard ($R_{STANDARD}$) for oxygen is Vienna Standard Mean Ocean Water (VSMOW), a recalibrated version of Standard Mean Ocean Water (SMOW) used to assess oxygen isotopes since the 1960s.

Summary and Anticipated Products

In addition to this introduction (Chapter 1), Chapter 2 describes the human history of the Eastern Shore of Virginia as it reciprocally influences and is influenced by the biogeophysical parameters of the region's terrestrial and aquatic system. Chapters 3 and 4 present the rationale, methods, results, comparisons, and conclusions of model analyses of the Eastern Shore's natural-human systems in 1880 and 1920. Chapter 5 relies on these systems analyses to present a theoretical argument for extending the concept of an ecosystem to include socio-economic information that originates outside of the geographical area of examination when it materially changes system properties. Chapters 2-5 are presented in the form of research papers, each of which will be submitted for publication in peer-reviewed journals. The titles of these chapters (papers) are as follows:

Chapter 2. Biogeophysical Features of the Eastern Shore of Virginia: The Impact of Natural Commodities and Resource Management Choices on the Peninsula's Socio-Economic History

Chapter 3. A Model of the Natural-Human System on the Eastern Shore of Virginia Circa 1880: The Implications of Selected Technology and Socio-Economic Factors on System Dynamics

Chapter 4. The Natural-Human System on the Eastern Shore of Virginia: A Comparison of Life in 1880 and 1920 Using Historical Records, Isotope Analysis, and Systems Modeling

Chapter 5. Extending Ecosystem Theory to Include Economic Information and Market Forces in Natural-Human Systems: A Case Study of the Eastern Shore of Virginia in 1880 and 1920

The thesis summary in Chapter 6 assesses the broader implications and intellectual significance of this work, including detailed discussion of the research value of explanatory modeling, the use of interdisciplinary data to inform systems modeling, and the proposed extension of the definition of an "ecosystem' to include knowledge that originates outside of the geographical area of study. The summary will also discuss logical next steps to this approach to research, both on the Eastern Shore and in the field of natural-human systems modeling in general.

Appendix A provides details about data used to parameterize the 1880 model while Appendix B provides the same information for the 1920 model. Appendix C and Appendix D include the code produced in ModelMaker 4.0 for the 1880 and 1920 system models. Appendix E is a reprint of Thomas, Barnes, and Szuba (2007) and Appendix F presents isotope data for a core sample from Nandua Creek in Accomack County. A complete list of references used throughout the paper is included following the appendices.

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Chapter 2. Biogeophysical Features of the Eastern Shore of Virginia: The Impact of Natural Commodities and Resource Management Choices on the Peninsula's Socio-Economic History

Abstract

The Eastern Shore of Virginia, which forms the southern tip of the Delmarva Peninsula, is perhaps best defined by is its proximity to, and dynamic relationship with, both the Chesapeake Bay to the west and the Atlantic Ocean to its east. With its complex settlement history, rich documentary resources (both historical and scientific), and location at the mouth of one of the world's most productive estuaries, the Eastern Shore offers an ideal site for the study of the complex dynamics of natural-human systems. Like many areas, but perhaps more than most, the economic health, social structure, and core culture of the Eastern Shore of Virginia was, and is, intimately linked to its environment. This paper explores the natural-human system that evolved at this interface between terrestrial and estuarine settings, as well as the critical role natural commodities (i.e., farming and fishing harvests) played in the development of the social and environmental history of the peninsula. It also describes links between land use practices and the health of the Chesapeake Bay that have degraded the Bay's benthic habitats and, consequently, caused conflict between agricultural and fishing interests in the region. This interdisciplinary examination of the history, geography, and ecology of the Eastern Shore of Virginia and Chesapeake Bay serves as a powerful example of man's role as a critical component of the unified natural-human system.

Introduction

> *It is confidently believed that in no other region of the world can so many of the good things of life be obtained so readily and at such moderate cost. The abundance of oysters, fish, wild fowl, and many other things that are ordinarily in reach only of the wealthy, and the varied products of farm and garden here combine to nourish a people unsurpassed in energy, vigor, and all the higher elements of human civilization.*
>
> – F.P. Brent (1891)

Reflecting on the debate about the relationship between man and nature, H.H. Barrows asserted in the Annals of the Association of American Geographers (1923, pg 3), "Geographers will, I think, be wise to view this problem in general from the standpoint of man's adjustment to the environment, rather than from that environmental influence. The former approach is more likely to result in the recognition and proper valuation of all the factors involved, and especially to minimize *the danger of assigning to the environmental factors a determinative influence which they do not exert*." [italics added]

Since that time, geographers, anthropologists, sociologists, historians, and environmental scientists from many fields of inquiry have continued to study the relationship between man and the environment. Davidson-Hunt and Birkes (2000) chronicle several prominent efforts to characterize our place in and with nature as human ecology (Park 1936), cultural ecology (Steward 1955), ethnoecology (Conklin 1957), population dynamics (Ehrlich 1968), ecological anthropology (Bateson 1973), environmental history (Cronon 1983), and political ecology (Greenberg and Park 1994). More recently, the term "human ecosystem" has been used to refer to systems in which the human species is a central agent (Vitousek and et al. 1997; Stepp et al. 2003). Many now argue that that the whole planet is a human ecosystem, in that all Earth ecosystems have been influenced by humans and, in spite of Mr. Barrows argument from 1923, Zucchetto (2004, pg 197) quotes an opinion originally expressed by Odum (1971) that is now supported by most contemporary researchers of the subject: "… the cultures that say only what is good for man is good for nature may pass and be forgotten like the rest."

Like all organisms, humans modify their environment. Thus, assessing natural-human dynamics demands not only an understanding of the biogeophysical components of the system, but also relevant human dimensions, both in terms of human impact on, and societal response to, the changing environment. This includes human population growth, resource consumption, and technological advances (Raven 2002). Failure to account for these capacities can lead to exaggerated or otherwise faulty appraisals of system dynamics. For example, Malthus' notable 1798 prediction of imminent and recurring vice and misery facing human societies (war, famine, and disease) was predicated on the belief that "population increases in a geometric ratio… while the means of subsistence increases in an arithmetic ratio" (Landry 2001). This assertion famously fails to account for human capacity to alleviate misery through laws (e.g., land use), social standards (e.g., sanitation), and technological advances (e.g., enhanced productivity through improved farming practices). Yet, laws, standards, and technologies targeted at managing the natural resources and commodities can create as many problems as they solve (Costanza 2000)—as was evidenced on the Eastern Shore of Virginia in the 19th and early 20th centuries.

<u>A History of "Natural Commodity" Use on the Eastern Shore</u>

> *An Eastern Shoreman with nothing but a piece of raw meat for a bait and a clam-shell for a sinker can catch enough crabs to buy a fishing hook and line; with this he can soon catch enough fish to buy a boat; with his boat he can soon catch enough oysters to buy and furnish a farm; and a man owning a farm on the Eastern Shore of Virginia is the most contented and independent being in the world.*
>
> — The Honorable John S. Wise, 1891

Like many areas, but perhaps more than most, the economic health, social structure, and core culture of the Eastern Shore of Virginia was, and is, intimately linked to the environment. As the Native American populations before them, early European inhabitants of the Eastern Shore lived off both terrestrial and aquatic resources throughout their tenure on the peninsula (Kirkley 1997). Burell et al. (1972) assert that the fishing business of the Eastern Shore is probably the oldest industry in Virginia. And as far back as the 17^{th} and 18th centuries, life on the Eastern Shore was focused on agricultural development and commerce via the predominant transportation technology of the time—ships to Europe (Turman 1964). Technology and market influences continued to drive transformations in Eastern Shore life throughout the 19th and 20th centuries, as evidenced by shifts in the predominant cash crops from oats to white and sweet potatoes. Competition to grow these products, as well as changing market demand, contributed to these shifts in agriculture. Technology and market forces also influenced the intensity of estuarine harvests, leading to depleted oyster stocks, as well as dramatic shifts in finfish catches from overharvesting—all compounded by then unknown links between land use practices and estuarine health.

Transportation technologies were integral drivers behind these dynamics. Regular steamship service was followed by the arrival of the railroad and, later, the improvement of the road system, all of which broadened demand for the natural commodities of the Eastern Shore (farming and fishing) in distant markets. Moreover, improvements to fishing technologies increased commercial opportunities for fishermen, whereas the delivery of guano and, later, nitrogen fertilizers directly transformed agricultural production and had indirect, yet substantial, consequences on the estuarine environment. The lens of history and a thorough review of the biogeophysical setting of the Eastern Shore helps us to study these technological "pacts with the devil" (Spreng et al. 2007) that were championed as sound economic policy, efficient resource management, and technological innovation throughout the 19th and early 20th centuries.

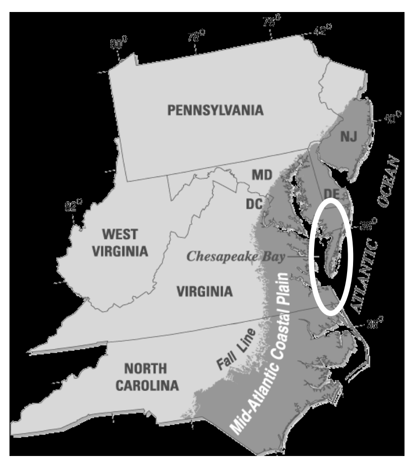


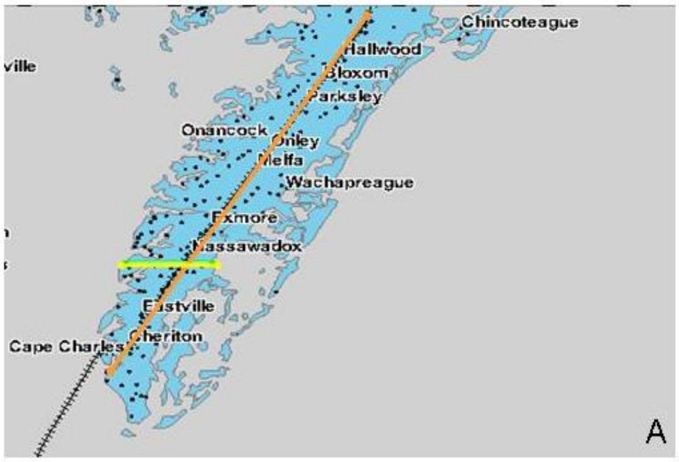
Figure 2.1. The Eastern Shore refers to the Virginia peninsula with the Chesapeake Bay to the west and Atlantic Ocean to the east. Source: U.S. Geological Survey.

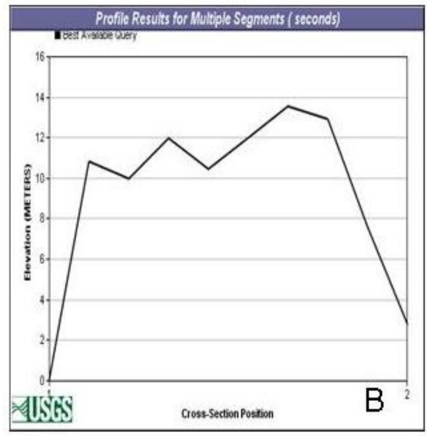
<u>A Geophysical Introduction to the Eastern Shore</u>

The Geology of the Eastern Shore of Virginia

The Eastern Shore of Virginia forms the southern tip of the Delmarva Peninsula at latitude 37° 30' N and longitude 75° 45' W. It sits between the Chesapeake Bay to the west and the Atlantic Ocean to the east

(Figure 2.1) and runs from its northern border with Maryland approximately 120 km to its southern terminus at Cape Charles, ranging from 8 to 25 km wide and covering 1,290 km^2 of surface land area (Figure 2.2).





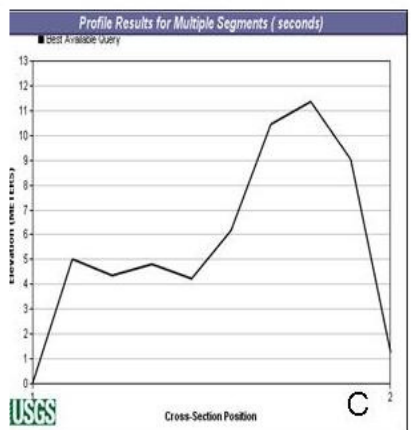


Figure 2.2. (A) Map of the Eastern Shore of Virginia; (B) Cross-sectional elevation (in meters) of the east-west transect (yellow line) that crosses the study region and runs 14.2 km along latitude 37° 27’ 01.03” N between longitude 075° 58’ 43.73” W and 075° 49’ 22.17” W; (C) Cross-sectional elevation (in meters) of the northeast-southwest transect (orange line) that crosses the study region and runs 85.9 km along the spine of the peninsula between Cape Charles (latitude 37° 14’ 13.10” N and longitude 075° 59’ 49.72” W) and upper Accomack County near Chincoteague Island (latitude 37° 56’ 56.08” N and longitude 075° 32’ 57.06” W). Source: USGS Digital Elevation Model data from *The National Map Seamless Server* available at http://seamless.usgs.gov/website/seamless/viewer.htm.

Chambliss (1974) correctly recognizes three physiographic formations that characterize the Eastern Shore of Virginia peninsula:

- Mainland – Generally flat and ranging in elevation from sea level to about 20 meters; includes nearly all the agriculturally productive soils of the region.
- Coastal Islands – A loose chain with sandy soils and low elevation; buffers the main peninsula from the Atlantic Ocean.

- Marshes – Low-lying, wet, grass lands that serve as the transition zone between land and water; particularly productive biological systems.

More generally, the Eastern Shore has been described as a peninsular mainland penetrated by numerous bayside tidal creeks to the west and buffered from the ocean by a string of low barrier islands and associated marshlands to the east (Burrell et al. 1972). The numerous bays, inlets, tidal creeks, and barrier islands combine to form over 1,200 km of shoreline, which constitutes nearly 25 percent of the state of Virginia's total shoreline. The Eastern Shore also contains 47 percent of Virginia's salt marshes (Eastern Shore Soil and Water Conservation District 1972).

Soils. Eastern Shore soils are primarily sands, sandy loams, and loamy sands (Eastern Shore Soil and Water Conservation District 1972). It is of post-tertiary formation and a function of the alluvial marine plain beginning in Massachusetts and extending along the Atlantic coast to the Gulf of Mexico. Surface drainage is sluggish due to the region's low elevation relative to sea level.

The soil is the basis for all agricultural and forest activities and is approximately 90 to 115 cm deep over a fine or coarse sand substratum. An unconfined aquifer, the Columbia, occurs at a depth ranging from 8 to 20 meters below ground elevation (Reay and Lunsford 1996). Unconsolidated sediments extend to between 900 to 1,350 meters at which point they transition to various igneous and metamorphic complexes at deeper levels (Eastern Shore Soil and Water Conservation District 1972).

Although the Eastern Shore has no major perennially flowing streams, surface runoff into tidal creeks connects terrestrial and aquatic systems. In addition to surface water runoff, wind and shoreline erosion deposit sediments into adjoining aquatic systems. Anthropogenic activity contributes significantly to this terrestrial erosion and estuarine sedimentation (e.g., Brush 1984; Donoghue 1990; Cooper and Brush 1991; Pasternack et al. 2001; Christiansen et al. 2002; and numerous others).

Climate. With respect to climate, the Chesapeake Bay region is generally characterized as temperate, yet humid, and under substantial influence of the warm tropical currents of the Gulf Stream (Kutzbach and Webb 2001). Figure 2.3 shows that between 1955 and 2007, the average maximum temperature for the Eastern Shore was 19.7°C, with a monthly range between 8.2°C (January) and 30.3°C (July). The average minimum temperature was 9.3°C with a monthly range between -1.4°C (January) and 20.4°C (July). An average of 110.8 cm in total annual precipitation fell during this time, with a maximum average monthly rainfall of 11.9 cm (July) and a minimum of 7.4 cm (November). Cronin et al. (2000) report that since 500 BP the Chesapeake Bay region has undergone no fewer than 14 wet/dry cycles, four of which have occurred since 1800. Stahle et al. (1998) argue that extreme drought conditions may have played an important role in human survival during initial European settlement of the region. Abler and Shortle (2000) corroborate this notion by persuasively demonstrating that climate is a key factor in determining the productivity of farming activities in the region surrounding the Chesapeake Bay.

Average Monthly Temperature (°C) and Precipitation (cm) for Painter, Virginia (1955-2007)													
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Avg Max. Temp (°C)	8.2	9.4	13.6	19.2	23.8	28.1	30.3	29.6	26.4	20.9	15.8	10.4	19.7
Avg Min. Temp (°C)	-1.4	-0.7	2.9	7.6	12.7	17.6	20.4	19.6	16.2	10.2	5.4	0.7	9.3
Avg Total Precip (cm)	8.9	8.3	10.5	8.1	8.6	9.2	11.9	10.5	9.1	9.4	7.4	8.9	110.8
Source: Southeast Reg	Period of Record : 12/1/1955 to 12/31/2007												
http://www.sercc.com/products/historical/historical_va.html													

Figure 2.3. Average Monthly Temperature (°C) and Precipitation (cm) for Painter, VA (1955-2007).

The Chesapeake Bay

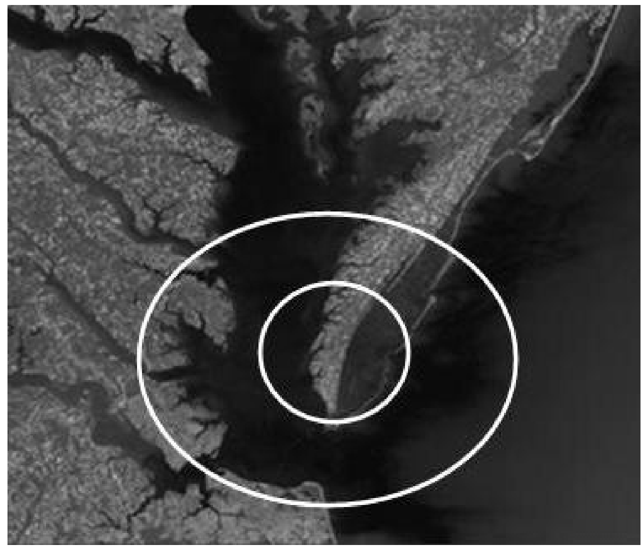


Figure 2.4. The 90 km wide Chesapeake Bay Impact Crater at the mouth of the Chesapeake Bay originated as a meteorite impact 35 million year ago (represented by inner circle). An outer secondary fracture zone 155 km wide was also formed (represented by outer circle). Landsat image from NASA Goddard Space flight Center (after Powars 2000).

Perhaps the most significant factor in the biogeophysical setting of the Eastern Shore of Virginia is its proximity to, and dynamic relationship with, both the Chesapeake Bay and the Atlantic Ocean. The Bay has as its origins an impact crater formed about 35 million years ago when a large meteorite crashed into the shallow shelf on the western margin of the Atlantic Ocean (Powars 2000). The 90 km wide crater (centered near the town of Cape Charles, Virginia at the southern tip of the Eastern Shore) caused terrestrial stream flow to converge toward the depression and form the mouth of the Chesapeake Bay (Figure 2.4).

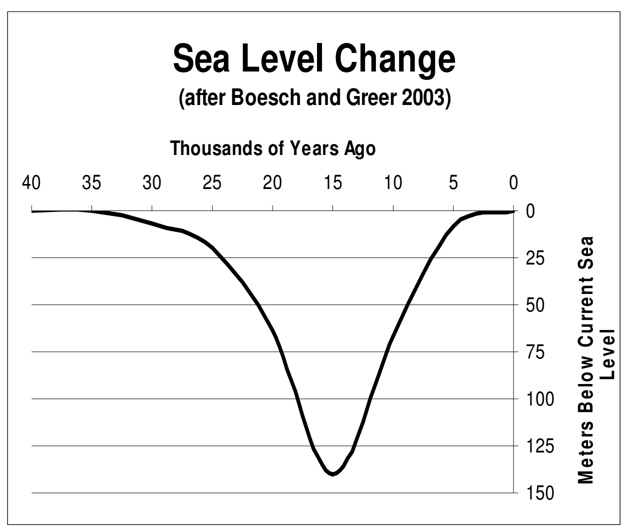


Figure 2.5. Sea level variation over the past 40,000 years, largely as a function of glacial advance and retreat. After Boesch and Greer (2003).

Although the Chesapeake Bay has a history of filling and draining throughout four successive glacial and interglacial periods (Fisher and Schubel 2001), the current mainland-marsh-barrier island complex that constitutes the Eastern Shore of Virginia is a product of a late Holocene sea level rise that most recently inundated the Susquehanna River valley and formed the current boundaries of the Chesapeake Bay between 6,000 and 2,000 BP (Donoghue 1990; Grumet 2000; and Boesch and Greer 2003). Figure 2.5 demonstrates sea level change that accompanied glacial formation and melting throughout the past 40,000 years (Boesch and Greer 2003).

The Chesapeake Bay watershed covers 17 million hectares throughout portions of six mid-Atlantic states, including New York, Pennsylvania, West Virginia, Maryland, Delaware, and Virginia (Figure 2.6). It has a water surface area (excluding tributaries) of 650,000 hectares and an average depth of 8.4 meters. It is nearly 300 km long and, at its widest point, almost 47 km across. It has been classified as a "drowned river" type of estuary (Cronin 1971; Donoghue 1990)—an extension of the traditional definition of "estuary" described by Pritchard (1967) as "semi-enclosed coastal water bodies which have a free connection to the open sea and within which sea water is measurably diluted with freshwater derived from the land." The Chesapeake is the largest estuary in the United States and has, throughout human history in the region, supported some of the world's most productive fishery harvests (Dauer and Alden 1995; Jackson et al. 2001).

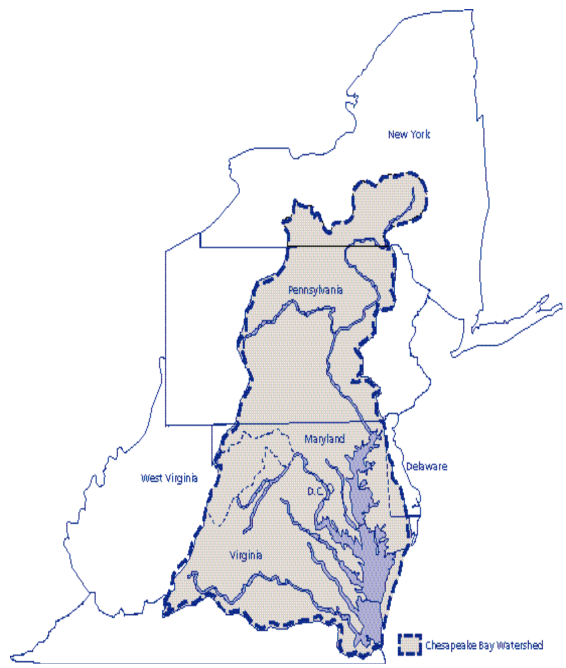


Figure 2.6. The Chesapeake Bay watershed includes portions of New York, Pennsylvania, West Virginia, Maryland, Delaware, and Virginia. Graphic from The Chesapeake Bay Program (2002).

Human History on the Eastern Shore of Virginia

> *The farmers of the Eastern Shore are the most prosperous and contented agriculturists in the United States… for safe and profitable investments, these lands offer unsurpassed inducements to capitalists.*
>
> – F.P. Brent (1891)

Settlement and Early History

Native Americans had lived on the Eastern Shore for more than 10,000 years when Giovanni Da Verrazano initiated European contact with the region in 1524 (Whitelaw 1968; Custer 1989; Grumet 2000). By that time, indigenous peoples had established an elaborate social complex that was intimately linked to the natural resources of the Eastern Shore environment, both terrestrial and estuarine in nature (Rountree and Davidson 1997; Grumet 2000). By 1600, an estimated 30,000 - 60,000 Native Americans lived along the borders of the Chesapeake Bay (Miller 2001; Ubelaker and Curtin 2001). These native peoples lived in villages, had a relatively complex social organization, engaged in several languages and subcultures, and demonstrated considerable expertise for surviving in their environment.

Barnes (1997) reports that members of the Accomac and Occohannock tribes hunted shellfish, bird eggs, and seashells on the barrier islands on the Eastern Shore. And when Captain John Smith first visited the Chesapeake, he observed Indians who were well acquainted with oysters and prized them as highly desirable and nutritious food (Wharton 1957). Kennedy and Breisch (2001) describe Native American oyster harvests occurring both on foot and by canoe, while Badger (1992) asserts that early European "settlers" discovered that the American Indians had long shared their taste for oysters, as evidenced by the huge mounds of shells in middens adjacent to Indian villages. The Nanticoke Indians raked large piles of fresh oysters from creek bottoms with "sharpened forked sticks" and engaged in feasts that "sometimes lasted several days" (Wennerstein 1978).

European exploration was followed by permanent settlement with the establishment of the 500-acre Accomack Plantation between Cherrystone Creek and Kings Creek (in current Northampton County), which was first represented in the General Assembly in 1624 (Nordstrom 1981). As has been commonly reported, European exploration of the "new world" was at least partially driven by economic speculation. The first ships to arrive in Virginia and the Eastern Shore came in search of "lignum vitae," the highly valued hardwood timber used in clockworks and ten-pin balls (Turman 1964). After all, by the 16th century, England's forests had largely been cut; moreover, all of Europe had only 25 tree species suitable for construction and timber, whereas North America had close to 525, many of which were visible from the Chesapeake Bay and its tributaries (Silver 2001).

Captain John Smith's summarized his view of the Chesapeake with his oft-quoted assertion: "Heaven and earth have never agreed better to frame a place for man's commodious habitation" (Turman 1964 and others). Yet both historians and scientists have noted that Smith, in addition to having conveyed a sense of bounty about the Bay, also mentioned a fish-kill in his initial foray into the region: "…the abundance of fish, lying so thick with their heads above water as for want of nets we attempted to catch them with a frying pan… neither better fish, nor variety of small fish had any of us ever seen in any place so swimming in the water… and some we have found dead upon the shore" (Schubel and Pritchard 1971).

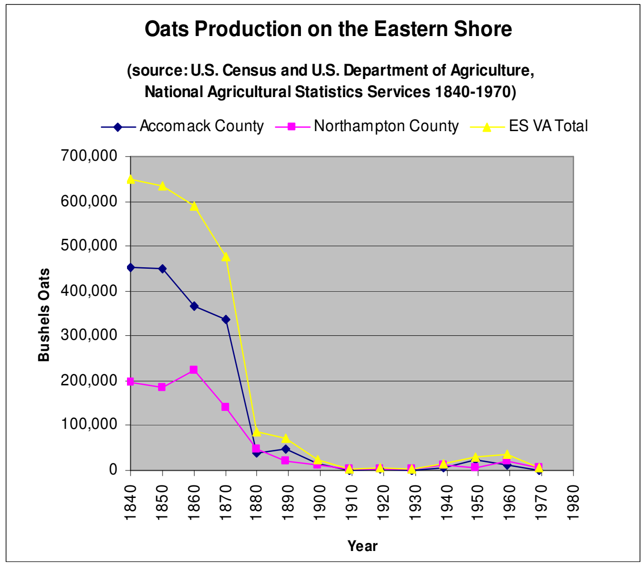
On March 14, 1634, Accomac County (encompassing the entire Eastern Shore) was established as one of the original eight Virginia counties, although the name was changed to Northampton in 1643 (Turman 1964). In addition to routine fishing and salting expeditions (Wharton 1957), a tobacco economy blossomed as well, soon supplemented by the production of grains, beef, and hides. These latter industries seemed well suited to the Eastern Shore, as cattle were permitted to roam freely within the natural confines of the necks of land situated between tidal creek "fences" (Barnes 1997). Coastal trade flourished, as the Eastern Shore was generously endowed with natural ports (tidal creeks) that didn't require navigation beyond the fall line (Rouse 1968).

Terrestrial Activities

> *In the late 19th century, Eastern Shore farms were self-contained units. They grew vegetables for the table and for sale, and the corn crop subsidized the livestock and poultry business, which in turn provided eggs, milk, cheese, butter, hams and bacon, sausage and scrapple, soap and lard, and a frying chicken for Sunday dinner.*
>
> – Curtis Badger (1986)

The 17th and 18th centuries had proven to be a progression of settlement, growth, conflict, and mild prosperity for European immigrants becoming Americans (the native American population having been largely removed). Like much of Virginia, the Eastern Shore found tobacco to be an important commercial crop during these years, but by 1800, tobacco was no longer the dominant cash crop on the Eastern Shore due its inferior quality relative to that grown on mainland Virginia and the loss of its primary export market in England following the War of Independence (Thomas, Barnes, and Szuba 2007). Despite the labor-intensive nature of cotton farming, it soon became a significant cash crop. Technology facilitated this shift upon the invention of the cotton gin in 1793 and its first widespread use on the Eastern Shore in 1812 (Turman 1964).

Between 1840 and 1880, market demand motivated Eastern Shore farmers to plant oats as their primary means for making a profit. Soon, however, the oats that had once nourished the pockets of local farmers were feeding the horses of the Union cavalry during



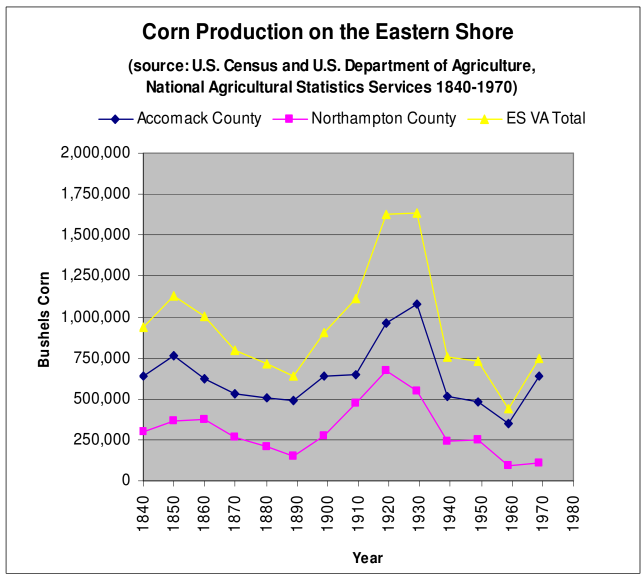


Figure 2.7. Oat production on the Eastern Shore never recovered following the decline after the Civil War. Corn production also declined following the war and was not to increase again substantially until the turn of the century. Source: U.S. Census and the U.S. Department of Agriculture, National Agricultural Statistics Service, 1840-1970.

the Civil War—because of the unfavorable geographic position of the peninsula with respect to defense from Union armies, the Confederacy abandoned the Eastern Shore of Virginia at the onset of hostilities, and the Union Army occupied the entirety of the peninsula for the duration of the conflict (Turman 1964).

Although tobacco, cotton, wheat, Indian corn, and oats had been the staple crops at various times throughout the 18th and early 19th centuries, the period following the Civil War introduced a radical transformation in agriculture on the Eastern Shore. Tobacco had long been abandoned and oats and corn were no longer raised in considerable quantity by the latter years of the century (Figure 2.7). Moreover, although oats and corn had been profitable crops, the digging of northern canals and the extension of the railroads from the East coast into the fertile agricultural lands of the West so cheapened these commodities in major Eastern markets that Eastern Shore farmers could no longer competitively price these products in Baltimore, Philadelphia, and New York (Nock 1900).

Prior to the Civil War, there had been only a few steamboats transporting products and people between Baltimore and the Eastern Shore. After Civil War occupation, the first permanent, large-scale, steamship company began service to the Eastern Shore (Mason 1973), and soon landings along the bayside creeks expanded potential markets for agricultural and estuarine resources (Boesch and Greer 2003). By the 1880's nearly every bayside creek of sufficient depth (about eight feet) was being provided with passenger and freight services by the Eastern Shore Steamboat Company (Mears 1961).

While rail transportation had been introduced in England as early as the 17th century and the first North American "gravity road" had been erected for military use in 1764, the earliest map of the United States to indicate the existence of a commercial "tramroad" did not arise until 1809 (in Pennsylvania) (Modelski 1975) and the dawn of the railroad age in America did not arrive until 1827 with the establishment of the Baltimore and Ohio Railroad Company (Chambers 2000). The Virginia frontier, the development of its agriculture, and exploitation of its natural resources was generating a demand for new ways to move people and goods from one place to another, and by the 1830's railroads and steam powered trains had been introduced to help meet these transportation needs (Modelski 1975). But this society-changing technology had eluded the Eastern Shore until late in the 19th century. In fact, the region an almost entirely unknown to the rest of the world because of its comparative isolation, due primarily to the lack of rail linkages to the great centers of population and commerce.

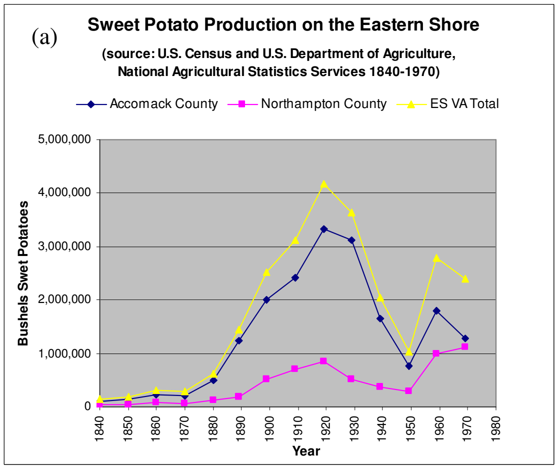
In an 1879 article in *Harper's New Monthly Magazine*, Howard Pyle described an Eastern Shore of Virginia that slumbered in "a Rip Van Winkle sleep… floating in the indolent sea of the past, incapable of crossing the gulf which separates it from outside modern life" (Pyle 1879; Thomas, Barnes, and Szuba 2007). This condition applied to many aspects of Eastern Shore life including, in large part, farming. Paarlberg and Paarlberg (2000) assert that well into the 19th century, a farmer from Old Testament times visiting America would have recognized many of the agricultural worker's tools, practices, draft power, crop species, and common irrigation techniques; and crop yields would have seemed unremarkable to such a visitor. These perspectives aptly characterize life on the Eastern Shore, both in terms of the general culture and agricultural efforts, throughout the 19th century.

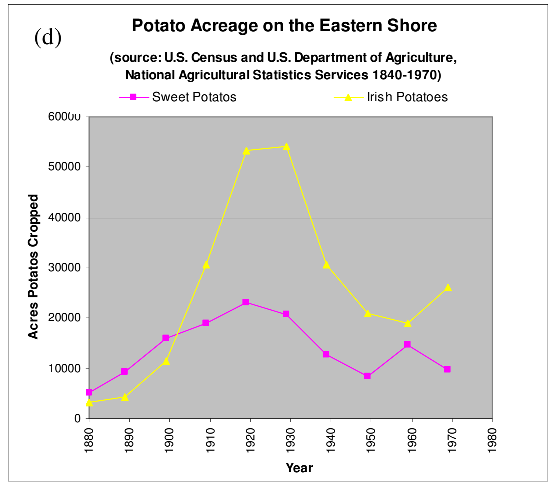
But Alexander J. Cassat had a different vision for the Eastern Shore. As president of the Pennsylvania Railroad, he recognized the untapped potential in the two isolated Virginia counties (Clark 1950). In 1883, Cassat constructed the New York, Philadelphia, and Norfolk Railroad connecting the southern land terminus of the Virginia peninsula (later Cape Charles City) with Delmar, Delaware and, by extension, the rest of the nation (*Peninsula Enterprise*, January 16, 1968, Vol. 5, p 16). It was no coincidence that the rail line ran directly down the middle of the Eastern Shore—in addition to being flat land with maximum elevation, it also minimized delivery time for the perishable goods that would become freight (Schotter 1927). Rail transportation soon enabled the rapid delivery of Eastern Shore produce to markets as far as Boston and, in some cases, Canada. "Fresh and tempting fruits and vegetables" could be delivered to New York in 12 hours, Boston in 20 hours, and Montreal in 30 hours (Thomas, Barnes, and Szuba 2007). "The railroad opened the fertile fields of the Shore to the waiting larders of the nation. Agricultural products in a tonnage undreamed of by the previous generation of Shoremen [would roll] Northward year after year in an increasing volume" (*Peninsula Enterprise*, August 8, 1936 Volume 5. p. 1).

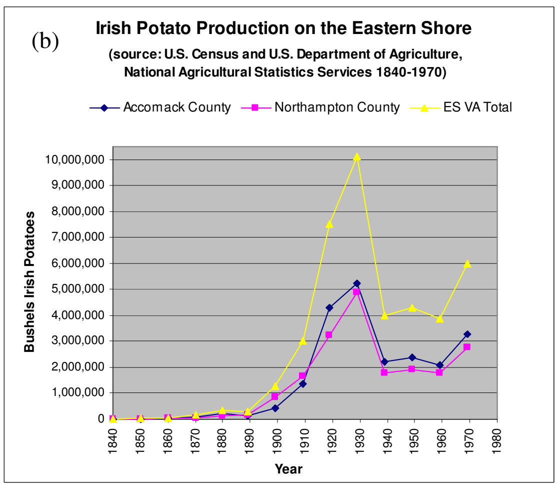
Other technologies also contributed to the rapidly increasing productivity of the Eastern Shore. Although land had always been productive (and maintained its productivity despite being cultivated every year in corn, oats, and "trucks" since early settlement), farm land was being revitalized by burned oyster shells as well as the Magothy Bay bean (*Cassia Chamaecrista*), which was commonly recognized to be a good soil builder (Bailey 1911). Commercial fertilizers, largely guano and nitrate deposits from the Caribbean and South America (brought in by steamship), were also used considerably. Moreover, the Eastern Shore enjoyed the agricultural advantages of a mild climate, abundant rainfall, and a long growing season (Thomas, Barnes, and Szuba 2007). As the Virginia Commissioner of Agriculture said of the Eastern Shore in 1879 (pg, 122): "Its cultivation is exceedingly cheap, as a one-horse plough is sufficient generally, and horses require no shoeing, and vehicles and farm utensils will last double as long as in the mountain regions."

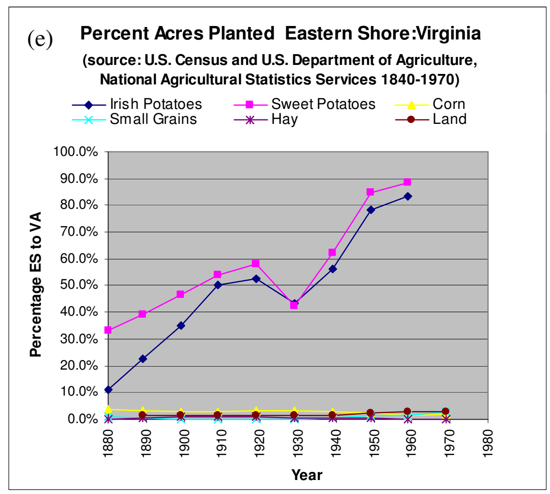
> *It has been said that but for rice the Chinese as a people and nation could scarcely exist; and it can be said with equal truth that but for the sweet potato the Eastern Shore of Virginia and its people would not be by far what they are today. It has not only brought comforts, luxuries, wealth, and population, but to it more than to all the other resources combined perhaps is due the present enviable social, moral, and intellectual position of the people of this section. It has brought the money, and the money has made all of these other facts and conditions possible.*
>
> — N.W. Nock, 1900

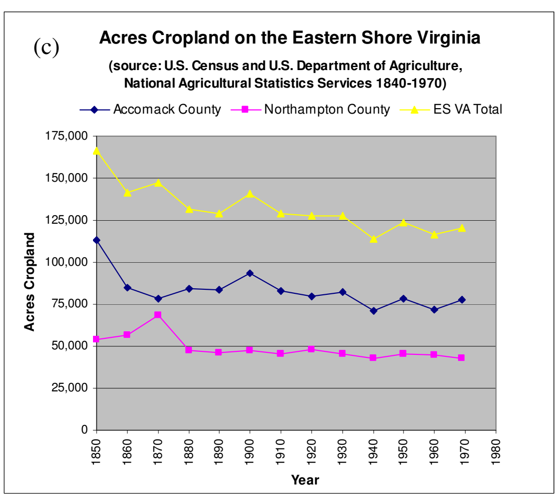
Farmers on the Eastern Shore had raised sweet potatoes as food for themselves, their families, and their neighbors for many years, but it was not until 1835 that the crop assumed substantial commercial importance (Nock 1900). In 1870, less than 300,000 bushels of sweet potatoes were produced in Accomac and Northampton counties, whereas by 1900 over 2.5 million bushels were harvested on route to a peak of nearly 4.2 million by 1920 (Figure 2.8a). During the same period, Irish potato production increased from 159,346 bushels (1870) to more than 1.2 million in 1900 and over 7.5 million in 1920 (U.S. Census 1870-1920) (Figure 2.8b). Although the total area of land cropped on the Eastern Shore was, if anything, slightly











Figures 2.8a-e. show the growth of the sweet and Irish potato industry on the Eastern Shore of Virginia in spite of the slight decrease in the total amount of land under cultivation. Source: U.S. Census and the U.S. Department of Agriculture, National Agricultural Statistics Service, 1840-1970.

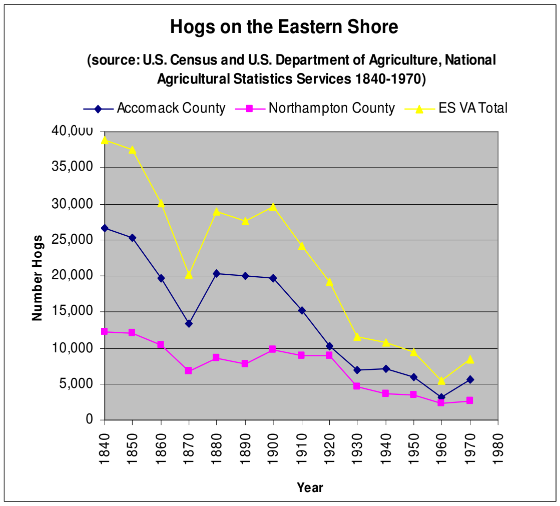
decreasing over these decades (Figure 2.8c), sweet and Irish potato acreage increased substantially between 1880 and 1930, both in terms of total acres planted (Figure 2.8d) and the proportion of acres planted on the Eastern Shore relative to the entire state of Virginia (Figure 2.8e).

By the 1920s, the amount of freight handled along the peninsula was so great that 28 railroad depots were established along the 70 mile line (Clark 1951). As suggested by their yield, sweet potatoes and Irish potatoes were particularly valuable crops, with the Eastern Shore becoming widely recognized as the "most famous sweet potato region in the United States" (Brent 1891). Nock (1900) credits the profits from sweet potatoes, in particular, for building the peninsula's highways, railroads, boats, stores, schoolhouses, churches, and homes… paying the teachers in the schools, the ministers in the pulpits, and the lawyers at the bar… creating banks and bankers, doctors and lawyers, preachers and teachers, and all trades and conditions… healing the sick, feeding the hungry, clothing the naked, and blessing all the land.

In addition to crops, Eastern Shore farmers had always raised livestock as a matter of standard practice. Beef, pork, lamb, poultry, and milk, butter, and even cheese were all "produced" to varying degrees and quantities throughout the peninsula (Census of Agriculture, 1840-1900). In fact, the natural boundaries of the Eastern Shore peninsula and its tidal creeks were well suited to raising livestock until a "no fence law" was established in 1896 (Barnes 1997). Previously, animals roamed the countryside freely, "fenced" only by the natural confines of the necks of land between tidal creeks, and farmers were expected to fence in their crops to protect them from the damaging effects of grazing. After the law was passed, livestock were required to be confined by fences of regulated size and construction or else their owners would be responsible for damage done to cropland (Turman 1964).

Although there was already limited commercial interest in livestock farming (likely due to limitations in transporting meat products), this change in practice placed a tangible burden on livestock owners and most surely contributed to diminishing interest in raising animals. Alternatively, the law's effect of protecting crops from roaming foragers certainly was welcome to planters. As such, and in contrast to crop production, data show both the number of hogs and sheep at their apex in 1840 (when records were first collected) and decreasing consistently thereafter (Figure 2.9). Cows also generally decreased in number after a peak in 1890 (Figure 2.10a). The ongoing need for dairy production in the period prior to refrigeration may have contributed to this delayed decrease in the milk cow population (compared to hogs and sheep) until the middle of the 20th century, at which point even most farm families probably purchased dairy products from grocery stores. Although the number of hogs, sheep, and eventually cows decreased substantially between 1840 and 1970, active, albeit small, populations remained through the 1950s, perhaps because of the realized benefits of raising animals for farm use (work and food) and local commercial gain (i.e., sale to neighbors on the Eastern Shore).

In contrast to hog, sheep, and cow populations, the number of horses and mules showed little change until 1870, at which point there was a steady and substantial increase in the number of these working animals that were to contribute so much to the growth and productivity of Eastern Shore agricultural activity (Figure 2.10b). Perhaps not surprisingly, the number of horses and mules peaked in 1920, shortly before the introduction of the tractor and the truck, neither of which were reported on Eastern Shore farms prior to 1930. Upon the availability of these two new pieces of technology, the number of horses and mules decreased severely, presumably because the duties of these working animals had been assumed by their mechanized replacements (tractors and trucks) (Figure 2.10c). In fact, Eastern Shore farm use of tractors and trucks was quite heavy, outpacing comparable use throughout the rest of Virginia quite substantially (Figure 2.10d and Figure 2.10e).



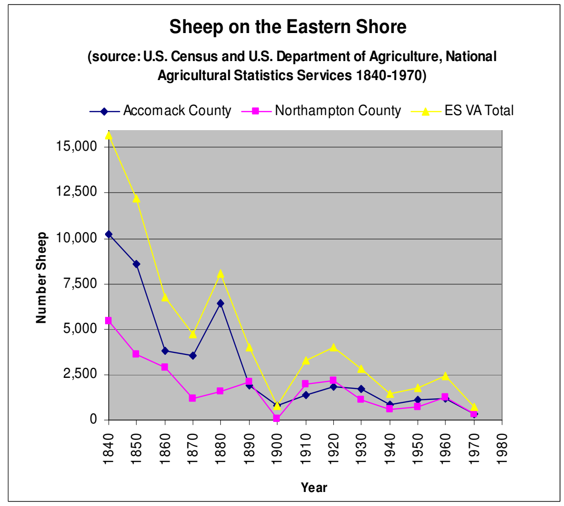
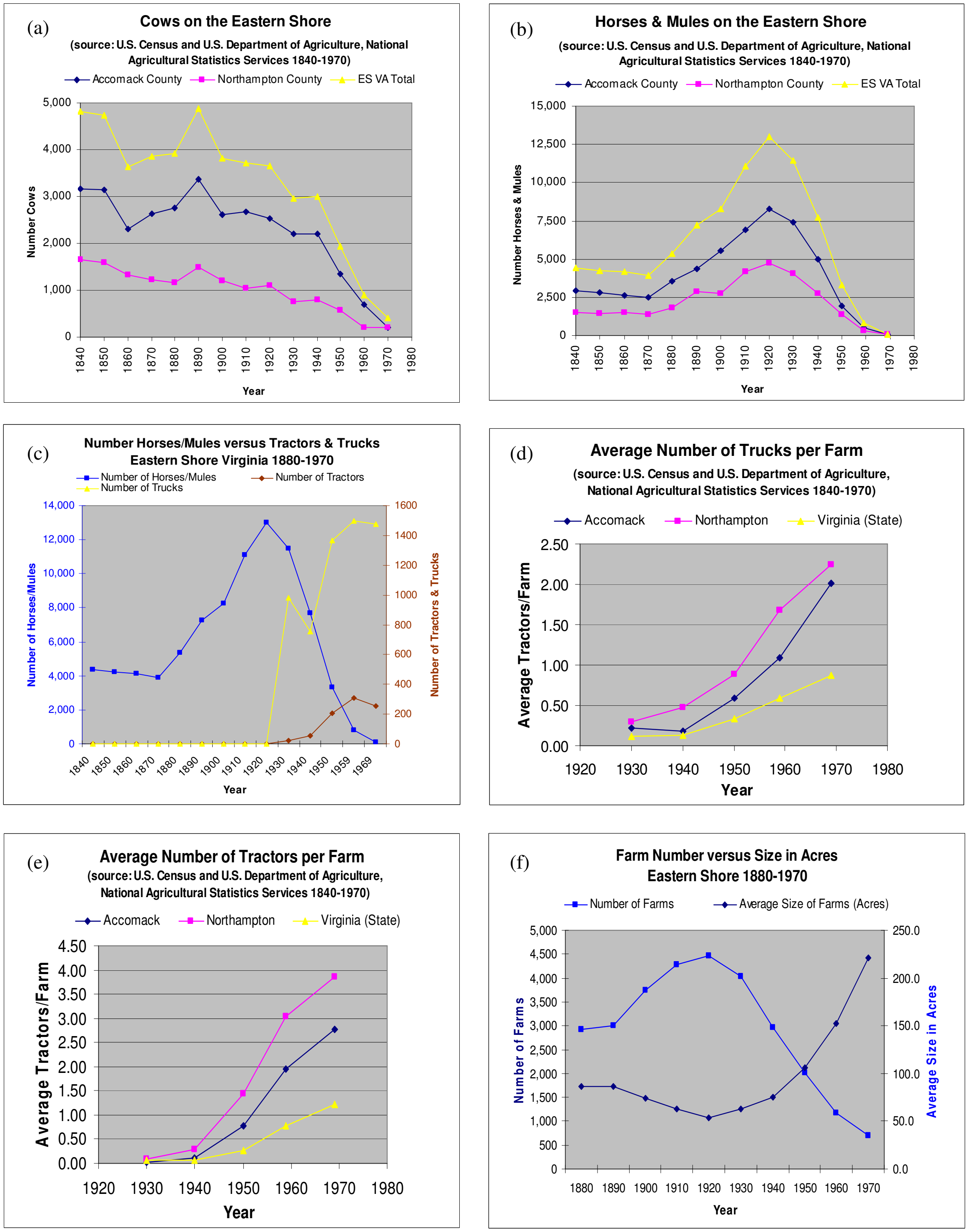


Figure 2.9 shows a substantial decline in the number of hogs and sheep on the Eastern Shore from 1840 through 1970. Source: U.S. Census and the U.S. Department of Agriculture, National Agricultural Statistics Service, 1840-1970.

Between 1870 and 1920 the average value of farmland rose from \$16 to \$137 per acre in Accomac and \$15 to \$197 in Northampton. Moreover, in 1910, Accomac boasted the highest per capita income of any non-urban county in the United States and, in 1919, Northampton and Accomac had the highest crop values per acre in the nation (Thomas, Barnes, and Szuba 2007). Clearly, agriculture was flourishing on the Eastern Shore of Virginia. Curiously, this trend toward increasing farm productivity on Accomac and Northampton counties occurred at a time when the United States was otherwise generally shifting its economic focus away from agriculture, forestry, and fisheries and toward mining, manufacturing, construction, utilities, and services (Nakicenovic et al. 2000).



Figures 2.10a-f demonstrate a decrease in the cow population on the Eastern Shore, as well as an inverse relationship between working animals (horses and mules) and trucks and tractors on Eastern Shore farms. It also shows the inverse relationship between farm number and farm size. Source: U.S. Census and the U.S. Department of Agriculture, National Agricultural Statistics Service, 1840-1970.

In addition to changes in crop selection, harvest amounts, the role of livestock, the introduction of tractors and trucking technology, and profitability, other transitions occurred in Eastern Shore farming as well. Since settlement and through the early 20th century, farm ownership had traditionally passed from father to sons, with a father dividing his farm in shares to his male inheritors. In this way, a realtively small number of larger estates were broken into a larger number of smaller farms, thereby promoting the growth of a healthy middle class (Brent 1891). With access to newly established markets, Eastern Shore family farming was becoming Eastern Shore family business and, as the productivity statistics above demonstrate, business was good. By 1920, there were 4,465 farms on the Eastern Shore with an average size of 53.7 acres, both an increase in the number of farms (and, in fact, a peak) as well as a decrease in size (the lowest point) relative to 1880 (Figure 2.10f). Three issues were to reverse this trend dramatically between 1920 and 1970: (1) there was a practical limit to the size of a farm needed to support a family, and in spite of improvements in farming technologies (e.g., fertilizer use and machinery), a farmer could no longer divide his land with the expectation that the remaining parcels were big enough to support the families of more than one heir; (2) an economic depression in the late 1920s and early 1930s led to defaults on annual seed loans and a substantial number of foreclosures; and (3) coming out of the depression, individual farms were consolidated into large-scale agrobusiness, thereby leading to a new model for farming that focused on corporate management and efficiencies of scale—and a smaller number of larger farms.

Eastern Shore Forests. After the arrival of European settlers, the terrestrial environment of the Eastern Shore and greater Chesapeake Bay region was significantly altered by deforestation. While there is ample evidence that Native Americans burned forests for hunting and cleared land for settlements, the scale of disturbance was relatively low, and in fact inconsequential, relative to the size of the landscape (Miller 2001). After European contact, however, the scale and significance of deforestation increased substantially, with the most extensive land clearance occurring between 1875 and 1930, a timeframe that has been referred to as "the period of commercial agriculture" in the Chesapeake Bay watershed (Brush 1989) (Figure 2.11). Schneider (1996) and others acknowledge that natural processes (e.g., biome shifts resulting from glacial to postglacial periods) surely contributed to the changing composition and pattern of forests in and around the Chesapeake Bay throughout history, but most scholars believe that anthropogenic activity is the predominant factor in the formation of the modern landscape (Brush 1989; Brush 1991; Cooper 1995; Pasternack et al. 2001; and Brush 2001). Prior to European settlement, the Chesapeake Bay watershed was about 90% forested (Brush 1991). Shenk and Linker (2002) report that in 1990 the watershed was 57% forest, 24% agricultural/pastureland, 18% developed, and 1% non-tidal rivers and lakes. Recent Landsat imagery (1991-1993) for the Eastern Shore of Virginia shows 24% forest, 25% agricultural, 1% developed, 11% wetland, and 39% open water (Boesch and Greer 2003).

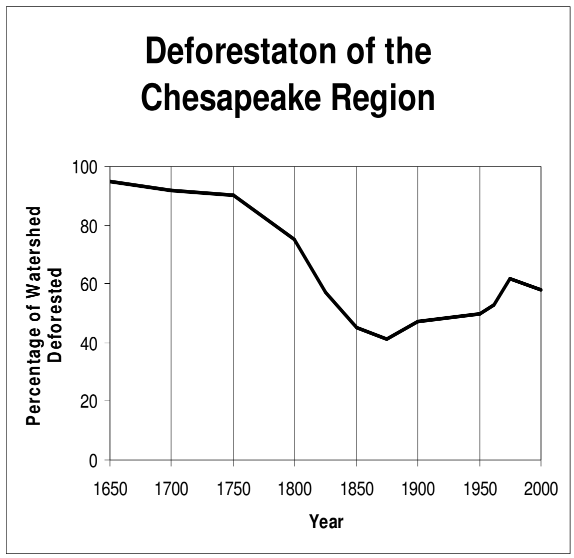


Figure 2.11. A thorough body of research suggests that up to 80% of the Chesapeake Bay region was deforested by the late 19th century (Brush 1989; Brush 1991; Cooper 1995; Pasternack et al. 2001; and Brush 2001). The Chesapeake Bay Program (2002) estimates less, although still substantial, deforestation in the region. Source: The State of the Chesapeake Bay, The Chesapeake Bay Program: Annapolis, MD.

Aquatic (Estuarine) Activities

> *And what does [the Chesapeake Bay] mean? Honestly and intelligently managed, it means untold wealth… The people… have a richer heritage than the coal-fields of Pennsylvania or the silver mountains of Colorado. The two latter may, they must, become exhausted as time goes on; while,*

> *with some little wise and faithful care, the Chesapeake will bring, year after year, millions of dollars… This may seem an extravagant statement; but, if you will consider the facts, you will find that it is but sober truth.*
>
> — B.N. Martin, 1891

Burell et al. (1972) assert that the fishing business of the Eastern Shore is probably the oldest industry in Virginia. In fact, the first Virginia government routinely sent fishing parties around the southern tip of the Eastern Shore peninsula, and fishing played a substantial role in the economy and survival of settlers since early settlement. Wharton (1957) records a report by settler John Rolfe in 1621: "At Dales Gift, being upon the sea near unto Cape Charles, about thirty miles from Kecoughtan [Hampton] are seventeen inhabitants under the command of Lieutenant Cradock. All these are fed and maintained by the Colony. Their duty is to make salt and catch fish."

Kirkley (1997) notes that although fishing was both a means for survival (food) and commerce (profits), the commercial fishing industry through most of the 1800s was relatively undeveloped with respect to Virginia's greater economy. In fact, commercial yield wasn't substantially developed until the mid 1800s and, even then, it was primarily oysters (Quittmeyer 1957). Goode (1887) notes that fisheries greatly increased in both extent and value after 1865, corresponding with advances in both methods for preserving and transporting products. The cessation of hostilities following the Civil War and improved fishing technologies likely contributed as well.

U.S. Commission of Fish and Fisheries. On February 9, 1871, the U.S. Congress established a federal Commission of Fish and Fisheries, mandating that it study "the causes for the decrease of commercial fish and aquatic animals in U.S. coastal and inland waters, to recommend remedies to Congress and the states, and to oversee restoration efforts." The purpose of the U.S. Fish Commission was stated as, “To keep up, if possible, by all means in their power, the supply of fish; to give, not for to-day but for years to come, food and occupation to our people” (*New York Times*, October 3, 1880).

For the next thirty years, the Commission deployed its research vessels on the nation's waterways and oceans, trained fishery agents to document catches, collaborated with scientists on biological and technical innovations, and established numerous fish hatcheries. The first fishing statistics for the Eastern Shore of Virginia were reported by the U.S. Commission of Fish and Fisheries in 1880. Evaluators described conditions on the Eastern Shore as lacking suitable transportation and, therefore, suitable markets. They also noted the plethora of part-time fishermen involved in Eastern Shore fishing activities, contributing to a total of 764 men engaged in shore fisheries in Accomac and Northampton counties. These fishermen employed 668 vessels, 17 pound-nets, 125 gill-nets, and 12 seines (Goode 1887).

Harvests and Characteristics. Catch data statistics provided by the Commission for 1880 showed harvests of 2,300 dozen (27,600 individuals) terrapins (*Malaclemys terrapin*), 8,000,000 or 27,500 bushels of quahogs (*Mercenaria mercenaria*, the Atlantic round clam), 37,910 pounds of shad (*Alosa sapidissima*), 799,663 pounds of Spanish mackerel (*Cybium maculatuan*), 1,003,167 pounds of bluefish (*Pomatomus saltatrix*), 1,143,000 pounds of gray and salmon trout (*Cynoscion regalis* and *Cynoscion maculatus*), 411,000 pounds of sheepshead (*Archosargus probatocephalus*), and 1,512,399 pounds of other fish, referred to as “miscellaneous” in the 1880 Census, for a total of 4,893,729 pounds harvested in 1880. The two counties also caught 15,876,000 menhaden (Census Bulletin No. 281, 1991).

Kirkley (1997) presents a comprehensive description of many of the finfish caught in the waters of the Chesapeake Bay in the 19th and 20th centuries, as shown in the following graphs and supplemented with information from the Chesapeake Bay Ecological Foundation (http://www.chesbay.org), the Maryland Department of Natural Resources (http://www.dnr.state.md.us/), and the Chesapeake Bay Field Office of the U.S. Fish and Wildlife Service (http://www.fws.gov/ChesapeakeBay).

Shad (*Alosa sapidissima*)

- an anadromous species that returns to freshwater to spawn on a seasonal basis
- shad roe is a preferred product by many consumers, whereas the flesh is often used as bait or discarded (Figure 2.12)

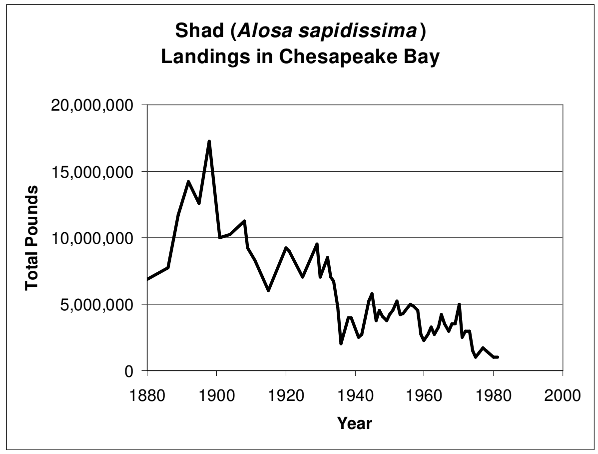


Figure 2.12. Historical landings of shad (*Alosa sapidissima*) in the Chesapeake Bay, 1880-1981. After Cronin (1986).

Gray trout (*Cynoscion regallis*)

- also known as seatrout or weakfish
- closely related to croaker, spot, and black drum
- highly prized by consumers
- the primary commercial gear used to harvest gray trout in Virginia is the gill net
- once plentiful in the Chesapeake Bay with a history of substantial population fluctuations

Striped bass (*Morone striatus*)

- also know as rockfish and striper
- historically important commercial and gamefish species
- anadromous fish of North America that is highly prized by consumers for its flavor and size (Figure 2.13)

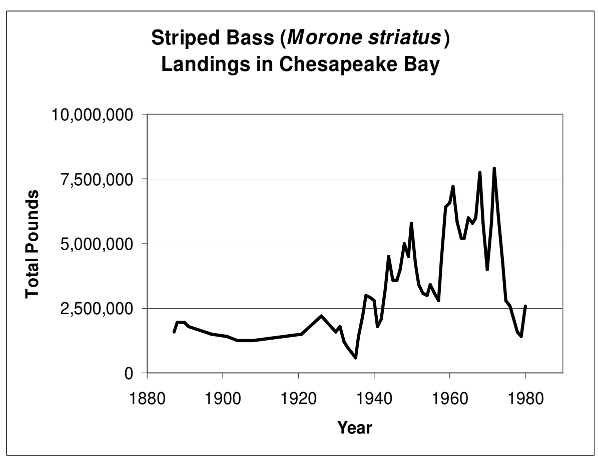


Figure 2.13. Historical landings of striped bass (*Morone striatus*) in the Chesapeake Bay, 1880-1981. After Cronin (1986).

Menhaden (*Brevoortia tyrannus*)

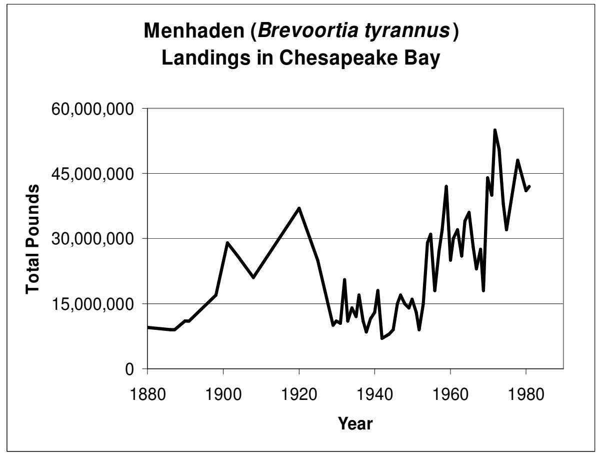


Figure 2.14. Historical landings of Menhaden (*Brevoortia tyrannus*) in the Chesapeake Bay, 1880-1981. After Cronin (1986).

- member of the herring family
- one of the most abundant species of finfish in estuarine and coastal Atlantic waters and the Chesapeake Bay
- spawn in the Atlantic shelf waters in late fall and winter
- juveniles appear in the Chesapeake Bay during early spring and summer
- the Chesapeake Bay is the most important nursery area for juvenile menhaden along the Atlantic coast
- filter feeders that eat planktonic plants
- an adult fish can filter up to a million gallons of water every 180 days
- a healthy Atlantic menhaden population has the potential to consume up to 25% of the Bay's nitrogen in one year
- an extremely important prey species for many predatory fish, including striped bass, bluefish, weakfish, and spanish mackerel
- occur in large schools, sometimes appearing over several square acres
- highly vulnerable to harvesting by purse seine (Figure 2.14)

Bluefish (*Pomatomus saltatrix*)

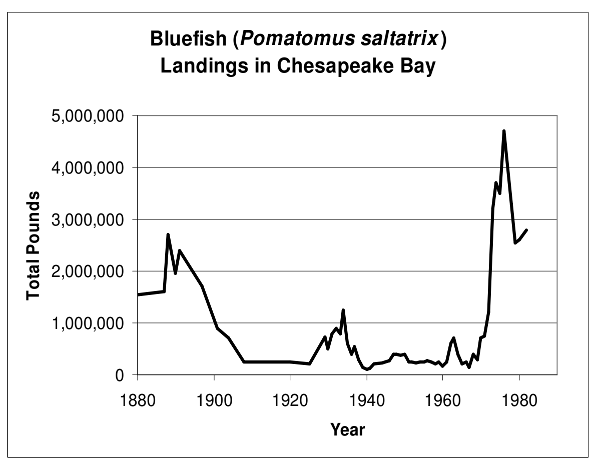


Figure 2.15. Historical landings of bluefish (*Pomatomus saltatrix*) in the Chesapeake Bay, 1880-1981. After Cronin (1986).

- the only members of the family, Pomatomidae; closely related to jacks, pompanos, and roosterfish
- a migratory species found throughout the world, including

the Chesapeake Bay, its tributaries, the Atlantic Ocean, and other coastal bays

- a pelagic schooling species that primarily travel in groups of like-sized fish
- voracious predators and sight feeders
- feed primarily on anchovies, white perch, American shad, alewife and blueback herring, and striped bass in the Chesapeake Bay
- can live to be 12 years old and can reach 40 inches in length (Figure 2.15)

Blue crabs (*Callinectes sapidus*)

- likely the most prized species of Virginia seafood (currently)
- highly desired by consumers around the world
- preferred as whole hard crabs, crab meat, and softshelled crabs
- common in coastal waters, rivers, and estuaries
- major gear used to harvest crabs in Virginia is the crab pot, although crab traps, scrapes, and trotlines are also used (Figure 2.16)

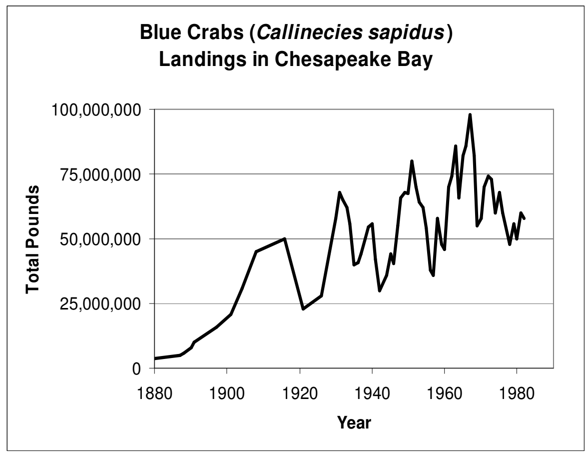


Figure 2.16. Historical landings of blue crabs (*Callinectes sapidus*) in the Chesapeake Bay, 1880-1981. After Cronin (1986).

Hard clam (*Mercenaria mercenaria*)

- also known as quahog, littleneck, top neck, cherrystone, or chowder clams based on differing market qualities
- a highly valued Virginia species
- highly desired by consumers
- commonly found in shallow, high salinity waters over a diverse range of bottom types
- primary harvesting areas in Virginia are the lower James River, the York River, and seaside of the Eastern shore
- primary gear is the patent tong

Oyster (*Crassostrea virginica*)

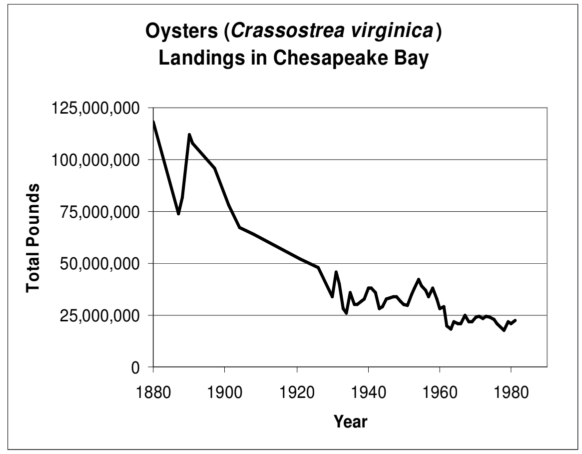


Figure 2.17. Historical landings of oysters (*Crassostrea virginica*) in the Chesapeake Bay, 1880-1981. After Cronin (1986).

- also known as the Eastern oyster, American oyster, and Virginia oyster
- the "prima donna" species of Virginia
- the oyster fishery of Virginia once supported thousands of people
- a staple for soldiers during the Revolutionary and Civil Wars
- found in brackish waters of the Chesapeake Bay
- harvested from public and private grounds in Virginia
- public areas are known as Baylor Grounds and include approximately 250,000 acres (Figure 2.17)

A Focus on the Virginia Oyster

> *The Chesapeake Bay, from which is gathered a large portion of the oysters cultivated in America, is a magnificent basin in which Providence seems to have accumulated every necessary condition for forming an admirable location for the fishery.*
>
> — M. p. de Broca, 1862

Because of the primacy of the Eastern oyster in the cultural and economic history of the Eastern Shore of Virginia, it is appropriate to delve deeper into the organism's rich relationship with humans. How important were oysters to the Eastern Shore? The oyster beds in the waters around Accomac County were so valuable that this one county had nearly as many men and as much capital engaged in the oystering industry as all the other counties in the Virginia combined (Brent 1891). Northampton, of course, engaged in the commercial enterprise substantially as well.

The Chesapeake Bay is one of the world's most fertile food-producing estuaries, and the Eastern oyster (*Crassostrea virginica*) is its most valuable seafood crop (Kennedy and Breisch 2001). In fact, when John Smith first sailed into the Chesapeake in 1608, he wrote that oysters "lay as thick as stones"—so profuse, in fact, that they made navigation difficult (*The Economist* 2008). Wharton (1957) quotes Francis Louis Michel, a French visitor to the Bay in 1701, noting "the abundance of oysters is incredible. There are whole banks of them so that the ships must avoid them. A sloop, which was to land us at Kings Creek, struck an oyster bed, where we had to wait about two hours for the tide. They surpass those in England by far in size, indeed they are four times as large. I often cut them in two, before I could put them into my mouth." Ingersoll (1887) asserts that the most prolific and valuable beds of the 19th century were nearly equally divided between Maryland and Virginia. In addition to value as food, oyster shells were used in a wide array of manners, serving as roads and foot paths, "filling" for wharves, fortifications, and railway embankments, ballast for boats, food for poultry, material for lime, and as a spreading for exhausted fields as a component in fertilizers.

The exploitation of valuable oyster beds increased throughout the second half of the 19th century as the population grew along the east coast. Dredging, which had been unlawful in Virginia waters since 1811, was legalized in 1865 without any corresponding effort to protect stocks or prevent the destruction of oyster structures (Cronin 1986). By 1875, 14 million bushels were harvested from the Chesapeake (Kennedy and Breisch 1983) as oystermen, brokers, and consumers treated the bivalves as if they were an unlimited resource. Oysters were dredged day after day and season after season both winter and summer (Badger 1992). Such disregard of the possibility of limits to supply led to the depletion of the oyster beds, and oyster yields peaked in the late 1800s after overfishing had reduced the vast oyster beds of the Chesapeake Bay to a few percent of original levels (Jackson et al. 2001). Thus, for all practical purposes, the oyster industry was discovered, exploited, and in danger of collapse within a single century (Cronin 1986; Kennedy and Breisch 1983).

Businessmen, consumers, politicians, and scientists wondered whether they could preserve existing oyster beds or make new ones (Martin 1891). Fortunately, there was a long history of artificial encouragement and cultivation of oyster beds on which to rebuild the Chesapeake Bay oyster population. Credit for the first cultivated oyster beds is generally attributed to Sergius Orata, a Greek Praetor in 97 B.C. Historian Valerius Maximus, writing in A.D. 29, describes how Orata enclosed Lucrine Lake to preserve the tranquility of the waters, the oyster grounds and, ultimately, the fresh condition of the delicacy (Gunther 1897).

Pliny, the ancient author and natural philosopher, adds that Orata realized great profit from the oysters he cultured (U.S. Commission of Fish and Fisheries 1873). Ancient Romans prized oysters and used pack horses to carry them, packed in baskets of ice, snow, and hay, inland from northern European coasts. Orata, established artificial oyster beds at Baiae, near Naples, where he also built a palace to host magnificent parties during which thousands of oysters were consumed (Badger 1992). The ancient Romans ground shells for use in skin ointments, road surfaces, and to mend baths (Orata is also recognized as the inventor of the hypocaust, a hanging thermal bath used by Romans) (Scott 2003).

Like the fishermen of the Eastern Shore in the 19th century, the Romans had to overcome issues of preservation and transportation if they were to enjoy their oyster delicacy. To accomplish this, they devised a “deep freeze” in which oysters and other perishables were stored during hot weather. Badger (1992, pg 92) describes a 1949 archaeological find in Carinthia with “a room with a close-fitting door set within a shaded rock wall. The ten-by-ten room had a clay floor and white washed walls. A staircase led to a deeper rock cellar, covered with hard, waterproof whitewash. During the winter Romans brought snow here and packed it until it was the consistency of ice. In the center of this room was the actual 'ice box,' a compartment lined with larchwood and fitted with a strainer and lid. Refrigeration was also aided by an ice cold spring, with waters flowing directly beneath the chamber."

Back in the 19th century, the U.S. Coast and Geodetic Survey decided to commission a study of the extensive oyster grounds in Tangier and Pocomoke Sounds. Results of this two-year survey (1878-79), known commonly as the Baylor Survey after the native Virginian who was selected to chart all of Virginia's natural oyster grounds, included descriptions of the structural and biological differences between older (harvested) grounds and new grounds that had yet to be fished (Kennedy and Breisch 1983 and Badger 1992). Winslow (1881) concluded from the findings that an informed Commission free from political interference should be convened to oversee management of the oyster fishery, asserting that it must: (1) be empowered to prevent exhaustive dredging; (2) protect grounds with young oysters; (3) enforce a closed season that included the spawning period; and (4) attempt to control pests and predators (Kennedy and Breisch 1983).

Estuarine Decline

> *The wealth of our waters can only profit us in the using. It is not expedient to restrict the taking of fish and oysters, except so far as such restrictions are necessary to maintain supply. To restore our fisheries to their former condition [underline added for emphasis], to maintain production at the largest limit compatible with permanence, and to so regulate the conditions as to make these industries profitable to the largest number of people who subsist by them.*
>
> — M. McDonald (1880)

Fishing and fish products had become significant national issues by the late 19th century and the premier newspaper in the nation reported on them frequently, oftentimes citing the importance of the industry both commercially and as a food source, as well as the plight of declining populations and diminishing harvests.

- “As population augments and with it there is additional want of food, unless artificial propagation of fish is carried on, the natural supply is hardly commensurate with the increasing demand.” *New York Times* (February 24, 1880)

- “It should be remembered that the demands for fish food increases enormously every year.” *New York Times* (October 3, 1880)

- “People in this country are hardly familiar with the vast amounts of capital placed in our fisheries, the number of men employed, or the varied interests which all centre [sic] in fish. Then the next census appears, they will be amazed at the extent of the fisheries and the important position they assume in the industries of the country.” *New York Times* (October 3, 1880)

- “Direct fishing, whether by nets, pounds, seines, drift or gill nets, so notably increased during the last 20 years, must have decreased the number of fish.” *New York Times* (December 11, 1880)

Indeed, declines were clear. In addition to substantial decreases in the Chesapeake Bay oyster population, the late 19th century also brought declines in many finfish species. Shad catches were declining by the summer of 1879 (Goode 1887) and, by 1900, the sturgeon, which had helped support the early colonization of Virginia, had all but disappeared (Kirkley 1997). Kennedy and Breisch (2001) identify several recurring and related themes in the history of Chesapeake Bay fishing:

- The decline of the early fishery was predominantly a result of overfishing and ineffective conservation efforts. Nineteenth century yields faded and catch records of the 20th century show a sharp and enduring decline.

- Political considerations, rather than limited biological knowledge, have frequently hampered efforts to improve fishery management.

- Key management steps that have helped sustain the public fishing grounds generally have focused on conservation. Replanting, cull laws, and expanding and protecting natural refuges are needed to help ensure the foundation for future population recovery.

Conflict Between Terrestrial and Estuarine Resource Use

> *The men (laboring class) who ought to cultivate the soil, despise the implements of the soil, because by oystering or fishing two days in the week during "the season" they can make enough to subsist themselves and their families without touching the plough, the mattock, or the hoe during the rest of the year.*
>
> — Fish Commissioner, State of Virginia, 1877

For many years, decreases in the harvest of commercially important fin- and shellfish in the Chesapeake Bay were generally assumed to be a result of this overfishing (Wallace 1951). But Jackson et al. (2001) assert that the extinctions caused by overfishing only foreshadowed other persistent human disturbances to coastal ecosystems, including pollution, degradation of water quality, and anthropogenic climate change.

Although climate has undoubtedly affected water quality throughout the history of the Chesapeake Bay (Brush 1991), the relative influences of climate change and anthropogenic activities were hotly debated throughout the 20th century with regard to impact on the transformation of the estuarine system (Cooper and Brush 1991). Newcombe and Horn (1938) first reported benthic anoxia in the Bay, which has since been corroborated by many (e.g., Karlsen et al. 2000).

Links between terrestrial land use and anoxic conditions (and the subsequent transformation of the estuarine food web from primarily metazoan driven to bacterially driven) have been authoritatively established without diminishing the potentially concurrent effects of climate (Malone et al. 1986; Malone 1992; Curtin et al. 2001 and others) (Figure 2.18).

Moreover, a host of changes to terrestrial/ estuarine coupling processes in the Chesapeake watershed since the introduction of European land use practices have been documented, including: freshwater discharge from the terrestrial surface to the estuary is 30% greater under present conditions than pre-European land use (Bosch and Hewlitt 1982), sedimentation rates have increased (Pasternack et al. 2001), nutrient loads in surface runoff have increased (Cerco et al. 2002), and metal and toxin loads in surface runoff have increased (Brush 1991). The byproducts of

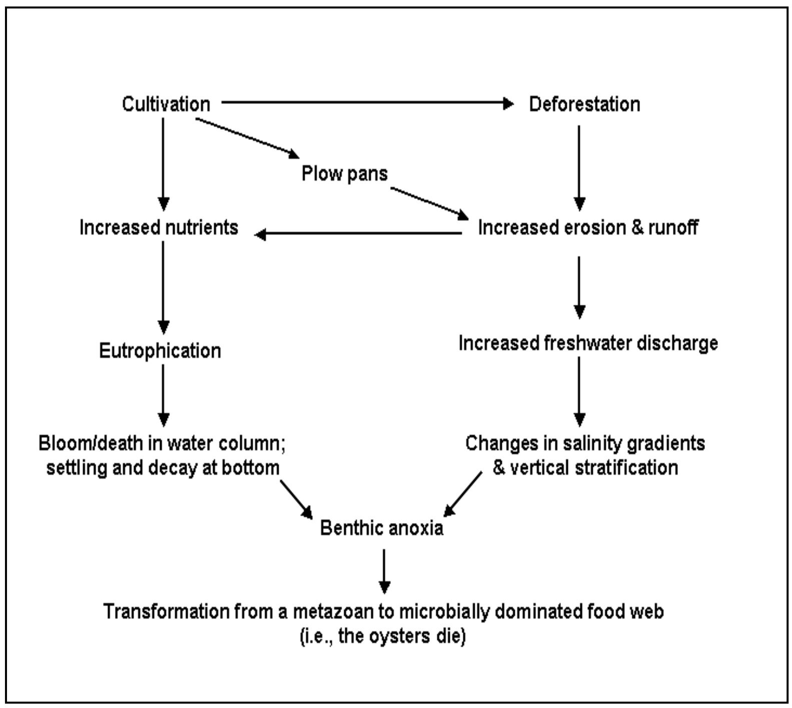


Figure 2.18. Direct and indirect effects of terrestrial agriculture on the Chesapeake Bay system. A positive feedback loop has been initiated by the increase in surface runoff and nutrient load—not only has it contributed to a decline in the oyster population because of benthic anoxia, but it also eliminated one of the only natural remedies to a polluted water column because the dwindling number of oysters grew less and less capable of filtering Bay waters; for a more detailed explanation of these phenomena, see Newcombe and Horn (1938), Boesch et al. (2001), and Horton (2003).

these trends, eutrophication, turbidity, and anoxia, have increased in the Chesapeake Bay as well (Cooper 1995). In addition to this "bottom up" perturbation, overfishing can lead to an anthropogenic "top down" disturbance to the estuarine system as well (Micheli 1999).

Boesch et al. (2001) believe that the roots of eutrophication began with land clearing in the 18th century, well before the mechanized harvest of oysters in the late 19th century. At first, people thought the Bay would recover if pollution from municipal sewers and factories were reduced, but the dynamics have proven to be more complicated (Woodard 2001). There are perceived conflicts between Eastern Shore communities that rely on fishing and those that farm the land. Fishermen now believe agricultural runoff—not overharvesting—has been largely responsible for degraded fisheries. This transformation of the estuary benthos and food web surely has had profound implications on Bay production (e.g., finfish and shellfish) and resource management—many of which are potentially devastating to the economic viability of those watermen and communities that depend on Bay production for their livelihoods.

The Chesapeake Bay Foundation annually calculates a score for the Bay's overall health relative to its potential for supporting life, with 100 representing the "pristine" system John Smith would have encountered in 1607 (Ernst 2003). The environmental index is a composite of three broad categories, each of which is comprised

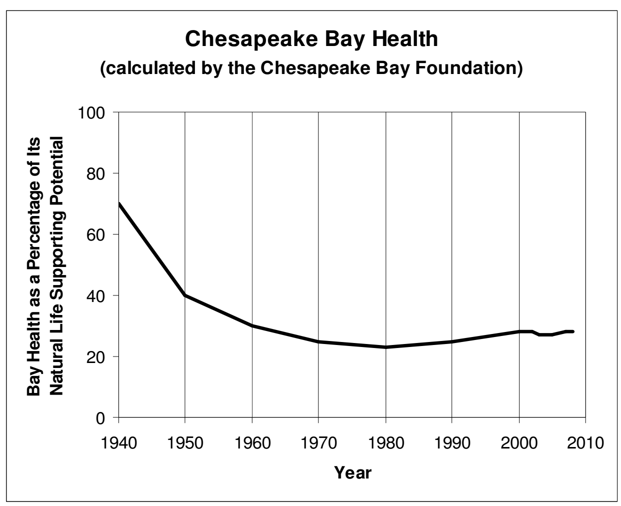


Figure 2.19. The health of the Chesapeake Bay, calculated as a percentage of its overall life supporting potential. Factors include habitat (wetlands, forested buffers, underwater grasses, and resource lands), pollution (toxics, water clarity, phosphorous, nitrogen, and dissolved oxygen), and fisheries (crabs, rockfish, oysters, and shad).

of four subcategories: Habitat (Wetlands, Forested Buffers, Underwater Grasses, and Resource Lands/Runoff Filters), Pollution (Toxics, Dissolved Oxygen, Water Clarity, and Nitrogen/Phosphorous), and Fisheries (Crabs, Rockfish, Oysters, and Shad). As seen in Figure 2.19, the middle of the 20th century demonstrated a severe and largely unrecovered decline in Bay health as measured by the index. More recent efforts to manage the watershed environment (e.g., "Chesapeake Bay Agreements" of 1983, 1987, 1992, and 2000) may have contributed to the relative stabilization seen in the past thirty years, although Bay health is still characterized as "dangerously out of balance" by the index (Baker 2008).

Conclusions

The interplay of human and environmental history, unified as natural history, abounds with examples of man assuming the inexhaustibility of natural resources—there only to meet the needs of us, the stewards of the planet. In many ways, this is the story of the people and bountiful resources of the Eastern Shore of Virginia.

The biogeophysical setting of the Eastern Shore of Virginia at the interface of terrestrial and aquatic systems provided a myriad of natural resources, first, to Native Americans and, later, to European settlers. The period between 1880 and 1920, in particular, witnessed tremendous change in the technologies available to people living on the Eastern Shore. Some of these changes were new innovations for the time, while other technologies were not new in their own right, but only in the sense that they became available to people on the Eastern Shore for the first time.

Lotspeich (1995) correctly applies a unified approach when describing economics as a subset of ecology. He argues, in fact, that it is ecology that drives economics given that our biophysical infrastructure serves as the foundation for all economic activity. In other words, ecosystems provide the natural capital necessary for mankind to exist, and it is our natural resources that are the raw materials for any and all production, fuel for transportation, and food for the workforce.

Precisely because of the interconnectedness of man and environment, Lacitignola (2007) argues that the analysis of socio-ecological systems requires “an integrated assessment of ecological, social, and economic factors.” The intimate connection between people and their environment is intensifying and our biogeophysical system has become, at least to some extent, a product of our economic, social, and national security interests (Lubchenco 1998; Hughes 2005; and others).

Although this paper examines natural-human systems through the lens of past history, many researchers believe that the future impact of human activity on the natural environment is both global and increasing (e.g., Western 1998; Kareiva 2007; and numerous others). Rather than limiting our perspective to man’s accommodation of his environmental constraints, however true that may be, we now also recognize the reciprocal perspective—man’s unique role in transforming his environment. But more than even this, the overarching message of the history of the Eastern Shore of Virginia is the interconnectedness of man and nature to form a single, unified natural-human system.

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Chapter 3. A Model of the Natural-Human System on the Eastern Shore of Virginia Circa 1880: The Implications of Selected Technology and Socio-Economic Factors on System Dynamics

Abstract

The Natural-Human System – Eastern Shore of Virginia: 1880 (NHS-ESVA:1880) model is presented as an interdisciplinary tool for studying complex natural-human system dynamics. More specifically, it examines people as a critical component of the natural system on the Eastern Shore of Virginia, which forms the southern tip of the Delmarva Peninsula, and is perhaps best defined by is its proximity to, and dynamic relationship with, both the Chesapeake Bay to the west and the Atlantic Ocean to its east. Unlike many environmental models that rely nearly exclusively on biogeophysical data to identify system (model) components, processes, and parameters, the interdisciplinary NHS-ESVA:1880 model also incorporates a rich set of socio-economic data that were self-reported to U.S. Census enumerators by the people who lived, farmed, and fished in the system during the 1880 U.S. Census. NHS-ESVA:1880 was developed using ModelMaker® 4.0 and is comprised of a human demographic model and four linked submodels (agricultural productivity, farming costs, estuarine productivity, and fishing costs) that simulate energy balances, human population dynamics, terrestrial land use and agricultural harvests, estuarine productivity and fishing harvests, critical technological and economic components influencing farming and fishing activities, and the links between terrestrial and estuarine systems. Simulations of the natural-human system on the Eastern Shore in 1880 show a farming enterprise that generated enough calories to feed a growing human population stratified in the model by gender, race, and age class. However, farms were shown to operate at an annual financial loss that was unsustainable without financial support from fishing interests. The simulation of advances in farm technologies (e.g., more intense fertilizer use) increased farm productivity and income, but had a negative effect on fishing harvests and income due to then-unknown linkages between terrestrial and estuarine systems (i.e., farming practices caused increased erosion, runoff, and nutrient loads, intensified salinity gradients, eutrophication, and benthic anoxia). The broader implications of NHS-ESVA:1880 include improving our understanding of coupled natural-human dynamics and, perhaps more importantly, serving as an example of the potential significance of interdisciplinary approaches to the analysis of natural-human systems.

Introduction

Like many areas, but perhaps more so, the economic health, social organization, and core culture of the Eastern Shore of Virginia was, and is, intimately linked to the environment. In fact, perhaps the most significant factor in both the socio-economic and biogeophysical settings of the Eastern Shore of Virginia is its proximity to, and dynamic relationship with, both the Chesapeake Bay and the Atlantic Ocean (Figure 3.1).

Figure 3.1. The Eastern Shore of Virginia (insert) relative to the northeast United States. The grey, shaded, area of the map of the U.S. northeast represents the Chesapeake Bay watershed. After the Chesapeake Bay Program (2002) and Turman (1964).

Situated at the southern tip of the crescent-shaped Delmarva Peninsula at latitude 37° 30’ N and longitude 75° 45’ W, the isolated neck of land known as the Eastern Shore of Virginia runs approximately 120 km from its northern border with Maryland to its southern terminus at Cape Charles at the mouth of the Chesapeake Bay. The peninsular mainland is generally flat, with a peak elevation of about 20 meters and a width ranging from 8 to 25 km, encompassing a total of 1,290 km^2 of surface land area. Its numerous bays, inlets, tidal creeks, and barrier islands combine to form over 1,200 km of shoreline, which accounts for nearly 25 percent of Virginia’s total shoreline and approximately 47 percent of the state’s salt marshes (Eastern Shore Soil and Water Conservation District 1972).

This proximity to a myriad of natural resources was apparent to John Smith upon arrival in the region in 1608, as evidenced by his oft-quoted assertion: “Heaven and earth have never agreed better to frame a place for man’s commodious habitation” (Turman 1964 and others). In the Chesapeake Bay, Smith and other European explorers “discovered” 30,000 to 60,000 Native Americans engaged in an elaborate social complex grounded in the abundance of the terrestrial and estuarine system (Rountree and Davidson 1997; Grumet 2000; Miller 2001; Ubelaker and Curtin 2001).

Like the Native American populations before them, early European inhabitants lived off both aquatic and terrestrial resources throughout their tenure on the peninsula (Kirkley 1997). In addition to routine fishing and salting expeditions, life on the Eastern Shore in the 17th and 18th centuries focused on agricultural development and commerce (Turman 1964). Although dependence on natural resources never changed, technology and market-driven influences transformed the natural-human system throughout the 19th and 20th centuries, as evidenced by shifts in the predominant cash crops from oats and corn to white potatoes and sweet potatoes. These changes in crop selection were not a function of local taste or changes in growing conditions; rather, they were motivated by improvements in transportation technology and its effects on competition with Midwestern farmers to deliver products to eastern urban centers like Baltimore, Philadelphia, and New York (Nock 1900).

Seafood harvests, themselves driven in large part by changing market forces and advancing transportation technologies, showed dramatic shifts in finfish yields and oyster stocks as the 19th century ended (and since), but links between terrestrial land use and the degradation of the estuarine habitat were hotly debated throughout the 20th century (Cooper and Brush 1991).

Boesch et al. (2001) believe that several unrecognized linkages between the terrestrial and estuarine systems began with land clearing in the late 18th century and were amplified by the introduction of more intensive farming practices during the 19th century and increased fertilizer use in the 20th century, although many terrestrial/estuarine coupling processes in the Chesapeake watershed have only recently been established authoritatively (see, for example, Malone et al. 1986; Malone 1992; Curtin et al. 2001; and others). Since the introduction of European land use practices (i.e., deforestation, plough pans, fertilizer use, erosion, and runoff), the system now demonstrates greater freshwater discharge (Bosch and Hewlitt 1982), increased sedimentation rates (Pasternack et al. 2001), and higher nutrient loads from fertilizers in surface runoff (Cerco et al. 2002). The consequences to the estuary include increases in eutrophication, turbidity, vertical stratification, and benthic anoxia, thereby transforming the benthos from a metazoan to microbially dominated food web (Cooper 1995). Clearly, terrestrial land use choices influenced the health of the Chesapeake Bay (Figure 3.2).

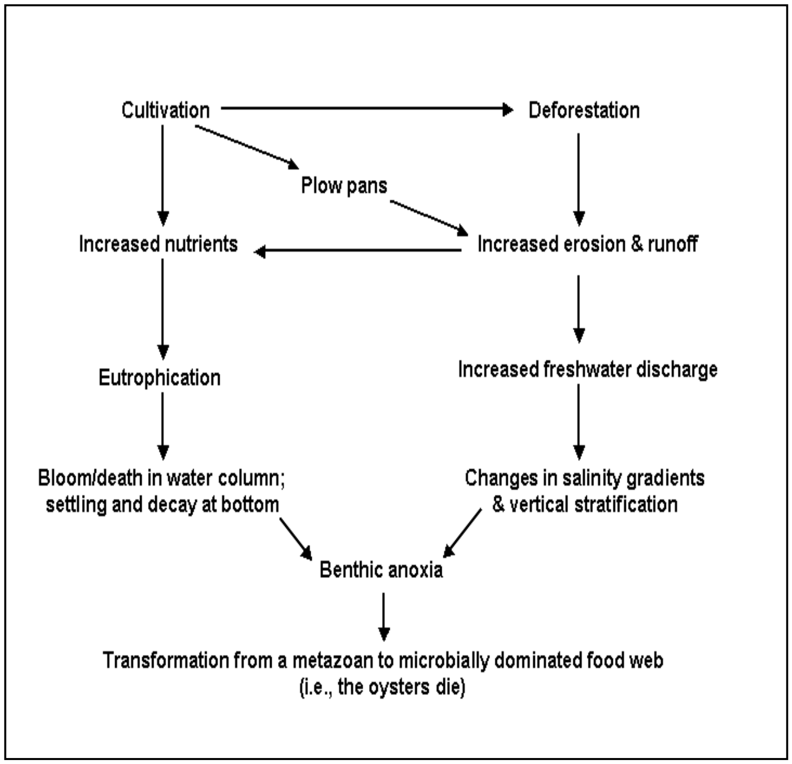

Figure 3.2 Direct and indirect effects of terrestrial land use on the Chesapeake Bay system. The increase in surface runoff and nutrient load has not only contributed to a decline in the oyster population because of benthic anoxia, but has also eliminated one of the only natural remedies to a polluted water column because the dwindling number of oysters are less capable of filtering Bay waters. For a more detailed explanation of these phenomena and their ramifications, see Newcombe and Horn (1938), Boesch et al. (2001), and Horton (2003).

Although both farming and fishing contributed significantly to the region's once flourishing socio-economic system, there is a history of tension between Eastern Shore farming practices and fishing interests. While the "improvements" in agricultural technologies and operations were vital to the production of commercial crops on the Eastern Shore, the resulting transformation of the estuary benthos and food web had profound implications on finfish and shellfish harvests, which has had a devastating effect on the economic viability of those watermen and communities that depend on Bay production for their livelihoods (in addition to being environmentally distressing to the Chesapeake Bay ecosystem).

A thorough assessment of this biogeophysical system through this lens of human history permits us to examine the rich and complicated natural-human system on the Eastern Shore of Virginia, including the complex processes that connect terrestrial and estuarine systems. Set at the interface of terrestrial and aquatic systems, the region and its inhabitants are especially suitable for the study of biocomplexity, which has been defined by Michener et al. (2001) as "properties emerging from the interplay of behavioral, biological, chemical, physical, and social interactions that affect, sustain, or are modified by living organisms, including humans." Investigation of this historical system allow us to examine the unintended consequences of human action as well as some of the key concerns facing the study of biocomplexity including, for example, how systems with living components such as people respond to stress (Elser and Steuerwalt 2001).

Review of Related Modeling Efforts

Models, at their most basic, simplify complexity to a level that is appropriate for describing systems and advancing our understanding of system dynamics. Depending on the system being studied, the tools used to create the model, and relevant research objectives, models can vary greatly in design, complexity, and scale. They range from single species/material compartment (box) models to community/trophic level models, three dimensional hydrodynamic models, airshed models, watershed models, land use/land change models, and complex ecosystem and resource management models (for a review of these types of modeling activities see Xu and Hood 2006; Ma et al. 2009; and Andre and Cardenet 2009).

Environmental modeling has traditionally relied nearly exclusively on biogeophysical data to identify system (model) components, processes, and parameters. Although there is great value in this approach to modeling, these physical features—biological, chemical, geological, and otherwise—do not reflect the entire spectrum of system properties in a human-dominated world. Human activities modify not only the structure and function of ecosystems, but also their interaction with the atmosphere, aquatic systems, and terrestrial components (Vitousek et al. 1997; Brown et al. 2002; Kirby and Linares 2004). These changes are not insignificant. In addition to altering the surface properties of the Earth, human actions can affect local and global climate and other large and small scale processes (Shugart 1998).

Precisely because of the interconnectedness of man and environment, the analysis of socio-ecological systems requires "an integrated assessment of ecological, social, and economic factors" (Lacitignola 2007). Social scientists now recognize the impact of ecology on human behavior (Keller 1997; Evans and Moran 2002) just as ecologists have begun to recognize the importance of the history of human activity as a critical component of ecological study (e.g., Harding et al. 1998). Haber (2006), for example, contends that understanding contemporary socio-ecological systems requires the study of historical human and natural antecedents to reconstruct current system states because past ecological conditions, social structure, and historical events undeniably influence structures and functions in contemporary socio-ecological systems (Figure 3.3). Thus, socio-ecological models that integrate multiple dimensions, such as economic and ecological dynamics over a range of temporal scales, are especially appropriate for analysis of human-natural systems (Ayres 2001; Ibenholt 2002; Foster et al. 2003).

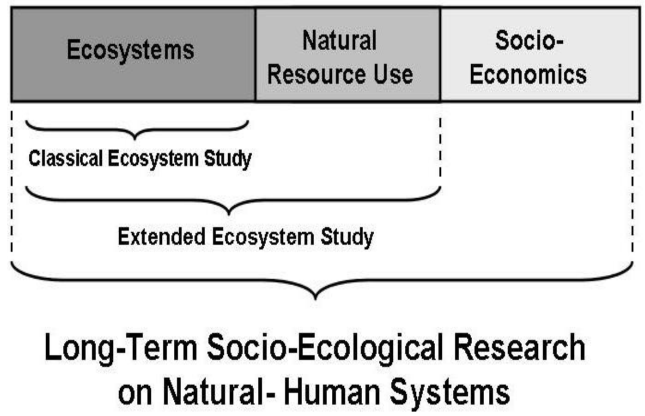

Figure 3.3. The study of environmental systems is extending to incorporate human dimensions beyond natural resource use. After Haber et al. (2006).

Kunstadter et al. (1963) were recognized as developing the first computer simulation in the field of anthropology—a model of the probability of human survival based on demographic variability and mating rules (Dyke 1981). Others followed suit and extended purely demographic models to incorporate environmental characteristics such as settlement sites (Thomas 1972) and subsistence patterns (Zubrow 1975). By the late 1970s, computational power was growing and systems modeling was on a trajectory toward accommodating increasingly complex natural-human systems (see, for example, Odum 1977; Weinstein et al. 1983; Odum 1996, Lansing and Miller 2003; Zuchetto 2004; etc.).

One early human ecosystem model was NUNOA, which simulated a hypothetical population of individuals, families, and extended families in an agricultural and herding community in the high Andes. This model focused on crop and livestock productivity, environmental events (e.g., frost and droughts), family energy balances, and their effects on births, deaths, marriages, and resource sharing. NUNOA integrated a family submodel, crop submodel, and herd submodel to assess how regional environmental factors and social choices interacted to affect population dynamics (Weinstein et al. 1983).

More recently, Lansing and Miller (2003) present a mathematical game theory model to explore the effects of cooperative agricultural practices and other social conventions (water temples) employed by modern Balinese rice farmers in the face of varying environmental conditions (droughts and outbreaks of crop pests) and public policy (government mandates to introduce new crops). The model helps researchers identify and assess critical components of this natural-human system that is effectively managed by farmers without centralized control in spite of highly fragile social and environmental conditions.

With respect to the Chesapeake Bay region, Xu and Hood (2006) illustrate the power of relatively simple biogeochemical models for studying the processes and interactions of biological communities in the Chesapeake Bay. Stow and Scavia (2009) model bottom-water hypoxia in the Bay, while Ma et al. (2009) use a fisheries ecosystem model to explore trophic interactions, habitat degradation, fish stocks, and blue crab population dynamics. Of particular interest to educators, Crouch et al. (2008) describe an interactive model designed to permit non-expert users to parameterize physical properties such as wind speed and direction to evaluate circulation patterns in the Bay. Linker et al. (2000) describe efforts by the Chesapeake Bay Program to develop cross-media models that establish and predict nitrogen and phosphorous allocations for each of the nine major tributaries to the Bay. This project culminated in an integrated watershed model (with a non-point source submodel, river submodel, and hydrology submodel), estuary models focused on water quality, and airshed models for tracking atmospheric nitrogen emissions. It is hoped that these geophysical models will inform policymaking and land use choices to help reduce nutrient and sediment load delivery into the Bay.

The introduction of human activities to geophysical models often produces particularly complex dynamics that can, perhaps, be best analyzed through coupled natural–human systems models. These models often endeavor to account for interactions between human stakeholders and the natural landscape, interactions among human stakeholders, and the responses of those human stakeholders to perceived changes in the natural environments

(Acevedo et al. 2008). With advances in computing power, the development of better modeling tools, and improvements in our understanding of natural-human dynamical processes, systems science has only recently emerged to quantitatively describe the behavior of complex dynamic systems (Few 1992). And with this, the application of modeling expertise to the study of natural-human systems is advancing at a rapid pace (see Adger 2000; Casagrandi and Rinaldi 2002; Abel and Stepp 2003; Jannsen and Ostrom 2006; and many others).

Although there is an increasing need to identify and quantify the relationships that shape the complex natural-human system, establishing links between sometimes seemingly unrelated pieces of the puzzle can prove to be challenging (Brown et al. 2002). Because the scale of natural-human system change is so vast, yet simultaneously minute, relevant ecological measurements are often difficult to obtain (Gallagher and Carpenter 1997; Raven 2002). More so, by definition, the natural-human system, with its socioecological and biogeophysical subsystems, is generally too complex to be fully represented within the confines of conventional experimentation (Bonn 2005). Thus, explanatory models that describe dynamics in human populations, social structures, economic activities, and biogeophysical processes have proven to be an attractive tool for the study of complex natural-human system dynamics.

A Natural-Human Model of the Eastern Shore of Virginia in 1880

Overview

This Natural-Human System Model of the Eastern Shore of Virginia: 1880 (NHS-ESVA:1880) simulates energy balances, human population dynamics, terrestrial land use and harvest, estuarine productivity, critical technological and economic components influencing farming and fishing activities, and the links between terrestrial and estuarine systems on the Eastern Shore of Virginia circa 1880. It reflects and incorporates detailed demographic, agricultural, fishing, and economic/market data from the 1880 U.S. Population Census, and corollary reports such as the 1880 Census Agricultural Report, the 1880 Census Fishery Industries Report, the 1880 Census Report on Mortality and Vital Statistics, the 1880 Census Report on Statistics of Wages, and other primary sources of data from the period.

NHS-ESVA:1880 was parameterized with 1880 data for the Franktown Enumeration District (Figure 3.4), a politically defined geophysical unit in northern Northampton County, Virginia, that included 225 farms (84 owner-operated, 91 rented, and 50 share-cropped) and 2,610 people at the time of the 1880 U.S. Census. While many models currently represented in peer-reviewed scientific literature are designed to forecast system dynamics over time, this model is parameterized to describe system properties and dynamics in great detail at a specific historical point in time (1880), an approach referred to here as "explanatory" rather than "predictive" modeling. NHS-ESVA:1880 helps to improve understanding of both the natural and anthropogenic aspects of this natural-human system (as well as their interactions), but it cannot predict how the system actually evolved over time because the period between 1880 and 1920 was "a time of great change" on the Eastern Shore of Virginia (Thomas, Barnes, and Szuba 2007), and any effort to capture such transformation in technologies,

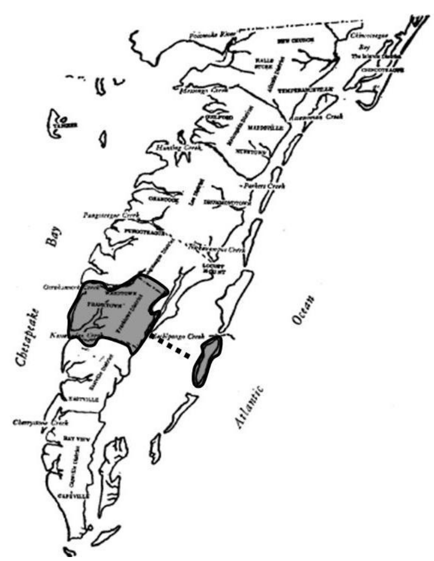

Figure 3.4. The Franktown Enumeration District (shaded) is located entirely within Northampton County, includes Hog Island, and is bounded by Accomac County to the north and the Eastville Township line to the south. After Turman (1964).

markets, and demands on natural resources in a single model would inevitably face a tradeoff between breadth (attempting to accommodate so many fundamentally differing system properties) and depth (understanding a specific time period in great detail). Thus, NHS-ESVA:1880 is not intended to predict, but to describe, the successive changes in people, processes, technologies and, ultimately, system dynamics over time. For example, prior to 1884, there was not a railroad line connecting the Eastern Shore and its agricultural products and estuarine harvests to external markets in significant volume beyond Baltimore, Maryland to the north and Norfolk, Virginia to the south. This limitation is reflected in this 1880 model, which is appropriate and necessary to understand system dynamics at that time, but it also makes the analytical tool antiquated as a descriptor of the natural-human system after 1884 when the New York, Philadelphia, and Norfolk Railroad connected the Eastern Shore to the nation's greater transportation infrastructure (and markets in Philadelphia, Pittsburgh, New York, Boston, and beyond). Such a limitation restricts the predictive power of the model, but the depth of understanding that it provides for that single point in time is critical given its purpose of elucidating relationships and assessing the properties and dynamics of that specific time/technology regime.

Although NHS-ESVA:1880 is designed to describe the Eastern Shore of Virginia in 1880, this limitation is based on the data used to parameterize the model rather than model structure. In other words, the core structure of the NHS-ESVA model could be applied to other natural-human systems at the interface between terrestrial and estuarine or marine settings. It can also be readily reparameterized for different time periods, as has been presented in Chapter 4 to describe and compare system properties and dynamics in 1880 and 1920.

NHS-ESVA:1880 enables modelers to study a wide range of factors that influenced the properties and processes of the natural-human system on the Eastern Shore of Virginia in

1880. This includes assessing the effects of technological advances and socio-economic change introduced to the 1880 system during simulation. For example, increased fertilizer use (a technological advance) had the potential to increase farm productivity on the Eastern Shore (an economic advantage), but it also had a long-term negative impact on seafood production (an economic disadvantage) due to linkages between excess nutrient loads in terrestrial runoff, eutrophication, benthic anoxia and, ultimately, transformation from a metazoan to microbially dominated food web in large parts of the Chesapeake Bay (Figure 3.2). Modelers can also examine the potential impact of other key system components, such as factors that affect crop production or fish harvests (e.g., the effects of extreme weather events and disease), changes in market prices for agricultural and estuarine products, variation in age-gender-race based mortality schedules and birth rates (e.g., as a function of nutritional distress), and/or the introduction of a carrying capacity concept for any of a variety of reasons (e.g., immigration and emigration).

Modeling Environment

NHS-ESVA:1880 was created using ModelMaker Version 4.0, a commercial product developed by Cherwell Scientific Ltd. (http://modelkinetix.com). Modelmaker is a windows-based object-oriented modeling program commonly applied to many areas of modeling science, including environmental science, ecology, chemistry, sociology, and economics. Modelmaker enables users to conceptualize and design systems that include compartments, flows, variables, conditional and unconditional components, dependent and independent event triggers, random number generators, lookup (data) tables, and other useful tools found in many modeling programs. Modelmaker establishes mathematical relationships between these components based on intuitive numerical methods that include conventional mathematical operations as well as Boolean relationships. In addition to choosing the size of time steps, users select from several integration methods (Euler's, mid-point, Runga-Kutta, Burlirsch-Stoer, and Gear's) to numerically solve differential equations depending on the scale of system interactions and rates of change. The program permits sensitivity analysis, optimization, minimization, and Monte Carlo analysis depending on the nature of the study. Output is readily available in both tabular and graphical formats, with users selecting the number of output points as well as a wide range of formatting choices.

Submodels, Structure, and Components

NHS-ESVA:1880 is comprised of a human demographic model and four linked submodels that simulate terrestrial land use and agricultural productivity, farming costs, estuarine productivity, and fishing costs (Figure 3.5).

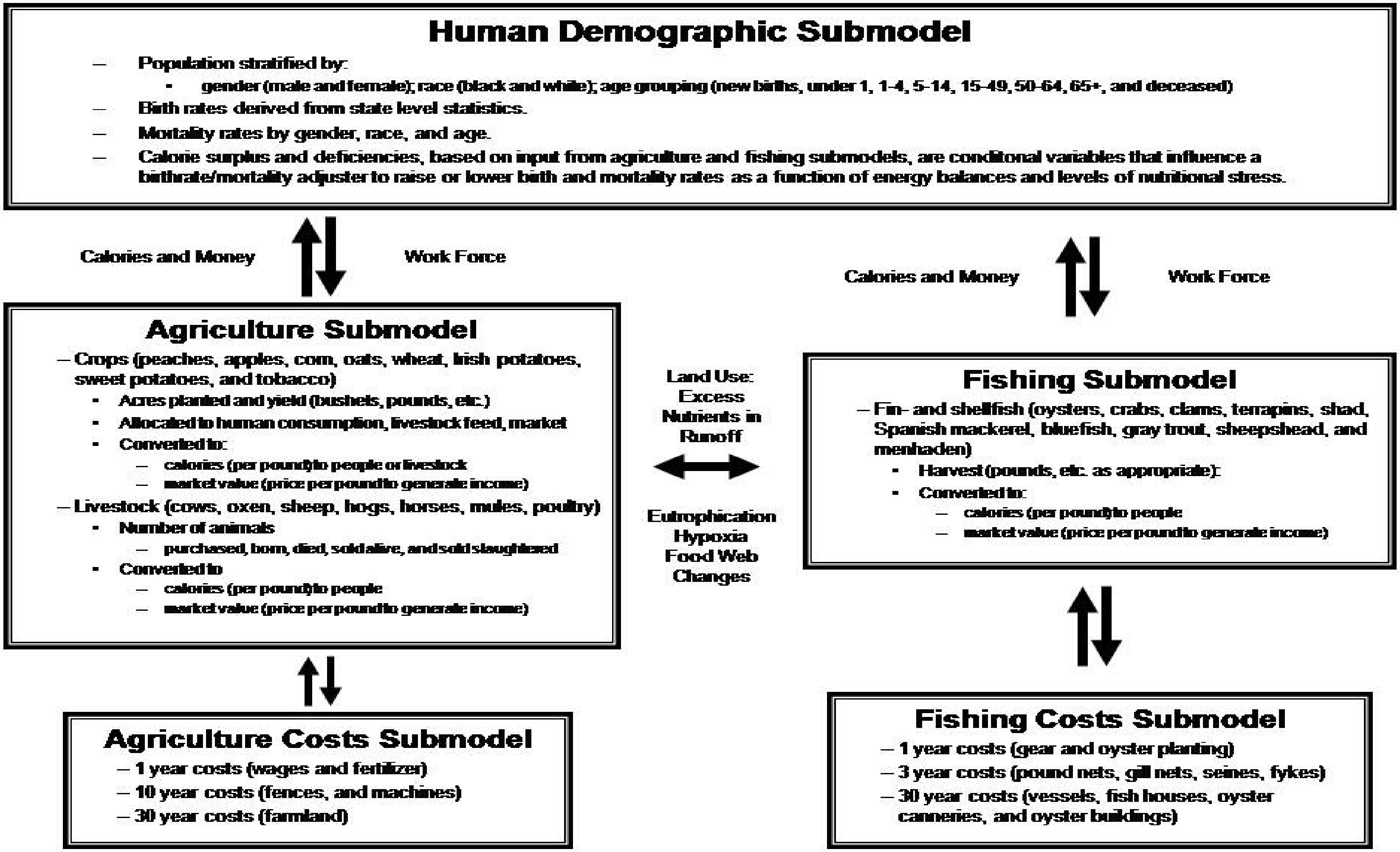

Figure 3.5. Conceptual overview of the NHS-ESVA:1880 model, including a human demographic model and four linked submodels that simulate terrestrial land use and agricultural productivity (farming), farming costs, estuarine productivity (fishing), and fishing costs.

Description of the Human Population Dynamics Submodel

NHS-ESVA:1880 reflects data from the 1880 U.S. Population Census, which shows a total of 2,610 human inhabitants in the Franktown Enumeration District, 1,421 of which were black or mulatto and 1,189 who were white. There were 1,326 males and 1,284 females, 576 of whom were in the 15-49 year old age class and considered to be of child bearing age for the purposes of the demographic model (Figure 3.6). Default birth rates reflect 1880 statistics for Virginia and identify the proportion of male offspring (0.4702 for white women and 0.4991 for black and mulatto women) as well as 147.3 births per thousand females age 15-49. Mortality rates are specific to age class, gender, and race as identified in the 1880 U.S. Census and range from 0.5% (white females age 5-14) to 15.8 % (black males under 1) (U.S. Census Report on Mortality and Vital Statistics 1880).

Description of the Farming Submodel

The farming submodel in NHS-ESVA:1880 reflects activity on 225 farms in the Franktown Enumeration District, totalling 22,904 acres of farm land (48.4% of Northampton County and 17.4% of farmed land on the entire Eastern Shore) (U.S. Census of Agriculture 1880). These farms raised both crops (e.g., oats, corn, peaches, apples, corn, oats, wheat, Irish potatoes, sweet potatoes, and tobacco) and livestock (e.g., milk cows, oxen, other cows, sheep, hogs, horses, mules, and poultry) (Figure 3.7).

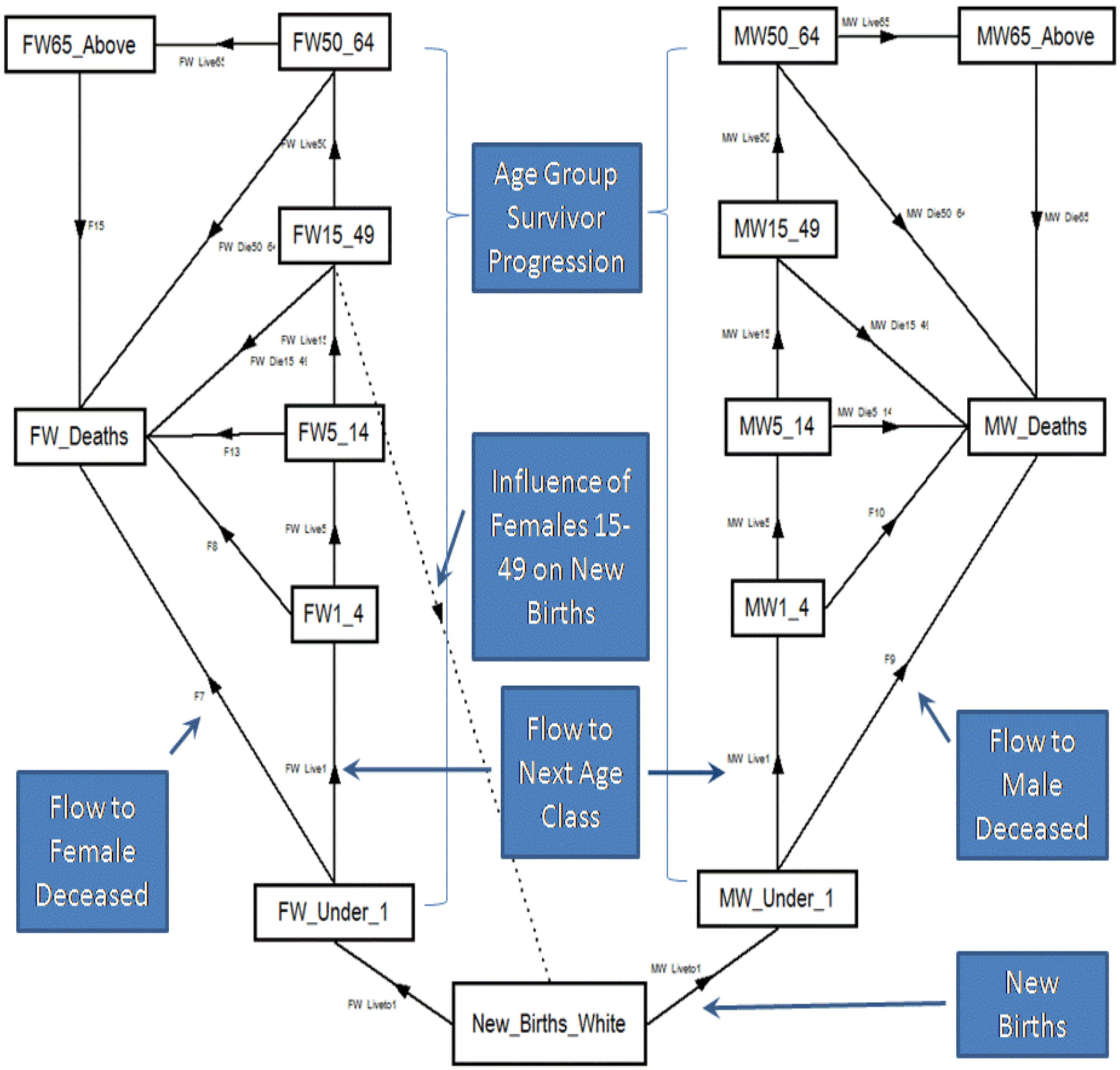

Figure 3.6. Conceptual model of the demographic submodel for the white population age classes (new births, under 1, 1-4, 5-14, 15-49, 50-64, 65+, and dead). A parallel branch is included for the black population, which has different mortality statistics between age class compartments.

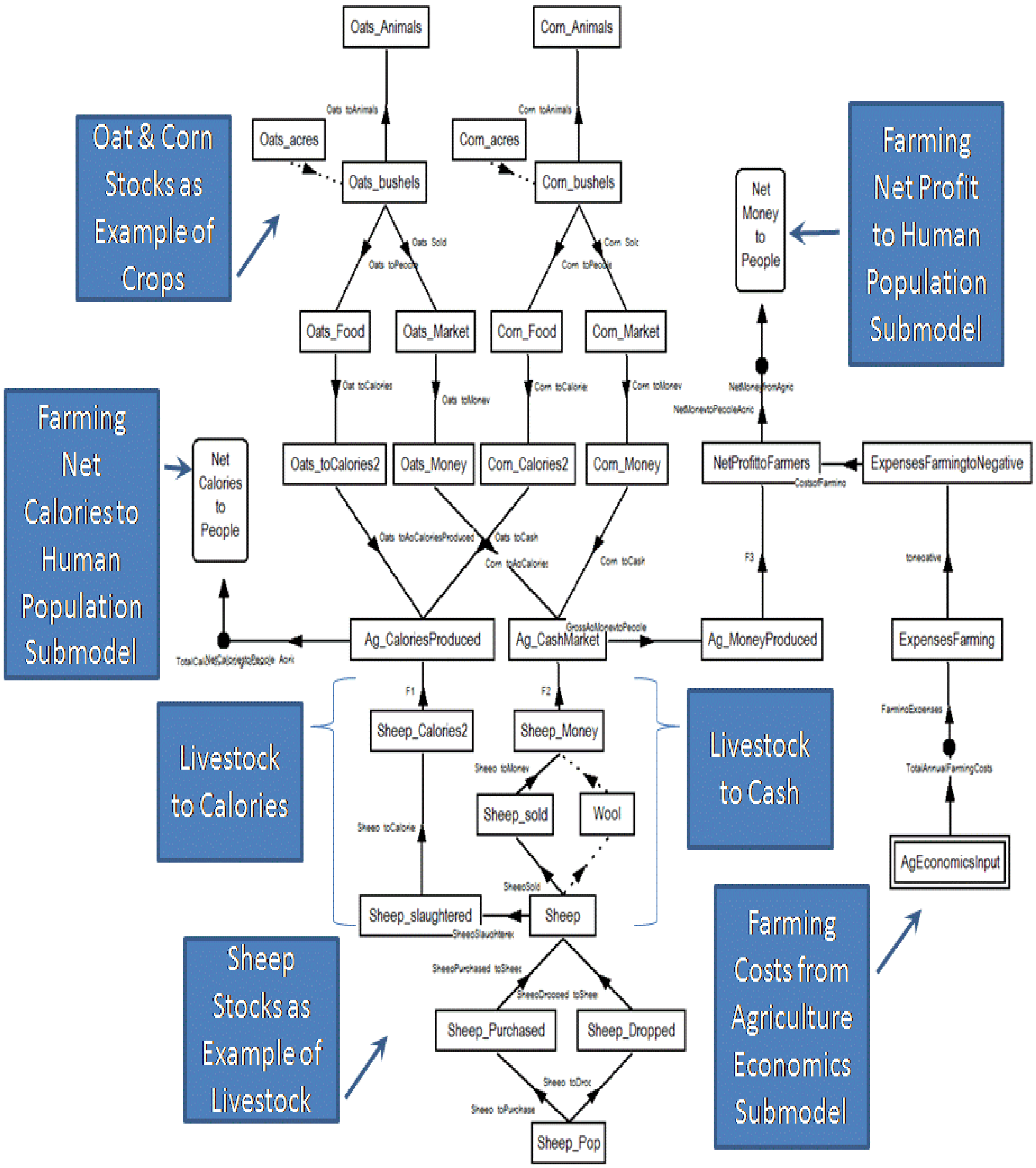

Figure 3.7. Conceptual model of the farming submodel, showing examples of oats and corn (crops) and sheep (livestock). The submodel accounts for acres planted, production (bushels harvested, animals raised, etc.), and allocations to human food, livestock food, and crops to market. Crop production designated for human consumption is converted to calories while crops to market are converted to money, both of which serve as input to the human demographic model. Crops not shown in this figure include peaches, apples, wheat, Irish potatoes, sweet potatoes, and tobacco. Livestock not shown in the figure include milk cows, oxen, other cows, hogs, horses, mules, and poultry. Livestock compartments reflect the number of animals at the time of the Census, the number purchased, born, died, sold alive, and sold slaughtered. Livestock slaughtered are converted to calories (per pound) and money (price per pound or per head) for input into the demographic model.

Calories from crops, livestock slaughter, and other products (e.g., eggs, milk, butter) were allocated to human consumption (16.0%), livestock consumption (73.5%), and market (10.5%) based on data from the period (U.S. Census of Agriculture 1880) although these proportions can be altered in the model. Crop production and livestock slaughter designated for human consumption are converted to calories and serve as input to the human demographic model, as does monetary income from products allocated for sale to market.

Data to parameterize the farming submodel were based on information self-reported by farmers to enumerators during the 1880 U.S. Census of Agriculture. For example, a total of 6,389 acres of corn were planted on 223 of the 225 farms in the model (averaging 28.7 acres per farm and ranging from 2 to 110 acres). These efforts yielded 50,780 bushels (averaging 227.7 bushels per farm and ranging from 15 to 1,200 bushels). Of this harvest, 16.0% was allocated for human consumption (8,125 bushels or 568,736 pounds at 1,655 calories per pound for a total annual yield of 941,258,080 calories to people), 10.50% was sent to market (5,332 bushels at $0.39 per bushel for a total annual value before costs of $2,079), and 73.50% was used to feed farm livestock.

Description of the Farming Economics Submodel

The farming economics submodel captures costs associated with farming activities as reported by the 225 farms in the Franktown Enumeration District. All costs were annualized for model use over a period of thirty years (farm purchase value), ten years (machines and fences), or one year (wage and fertilizer costs) (Figure 3.8). Annualized costs were then input to the Farming Submodel (see above) and subtracted from income generated from the sale of farm products. For example, farmers reported a total of $6,660 in machinery costs and $3,122 in fencing costs, which were aggregated to $9,782 worth of ten-year costs based on the anticipated useful life of these materials and then converted to $978 in annualized costs (one tenth of ten-year costs).

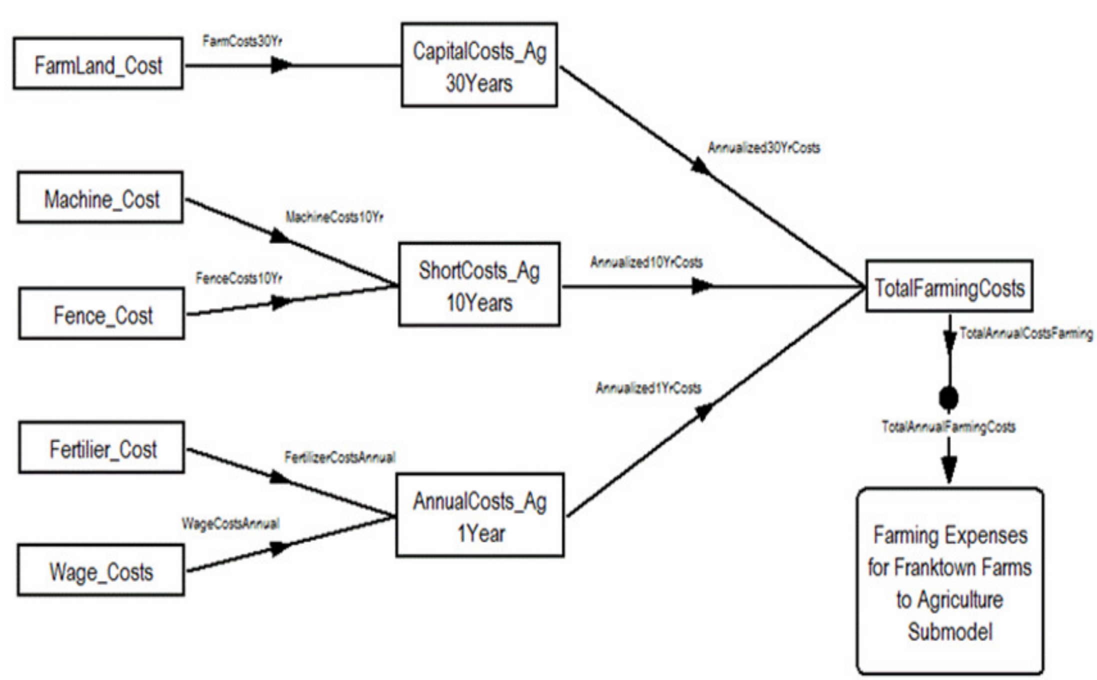

Figure 3.8. Conceptual model of the farming economics submodel, including 1-year costs (wages and fertilizer), 10-year short term costs (fences and machines), and 30-year capital costs (farmland). All costs are annualized (no interest meaning that the annual amount of a 10 year cost is 1/10 of the total cost) and input into the agricultural submodel.

Description of the Fishing Submodel

The first fishing statistics for the Eastern Shore of Virginia were reported by the U.S. Commission of Fish and Fisheries in 1880. The fishing submodel in NHS-ESVA:1880 reflects these data for a wide range of finfish and shellfish (Figure 3.9).

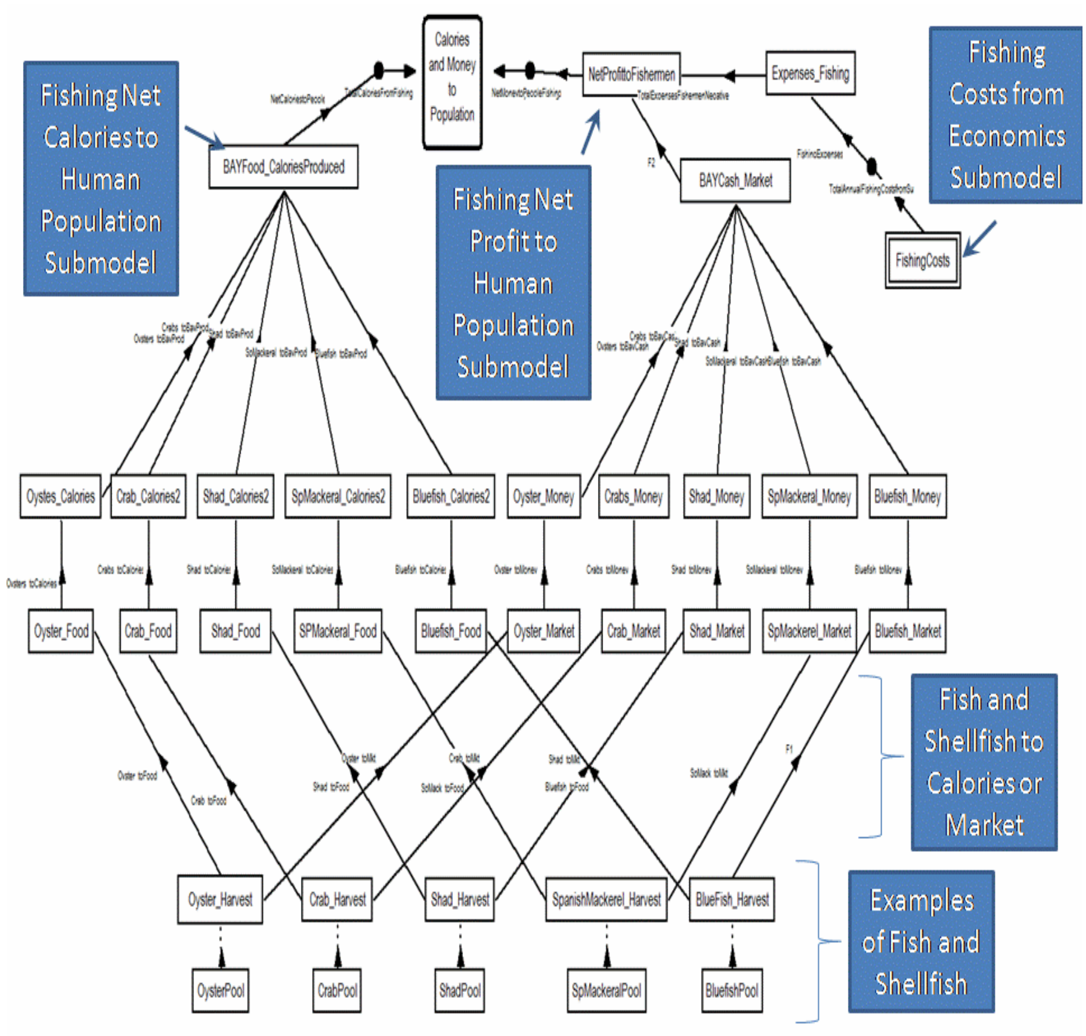

Figure 3.9. Conceptual model of the fishing submodel, showing examples of shellfish (oysters and crabs) and finfish (shad, Spanish mackerel, and bluefish). The submodel accounts for both allocations to human consumption and food to market. Harvests designated for humans are converted to calories and harvests to market are converted to money, both of which serve as input to the human demographic model.

Catch data for the Eastern Shore provided by the U.S. Commission of Fish and Fisheries in 1880 show harvests of 2,300 dozen (27,600 individual) terrapins (*Malaclemys terrapin*), 8,000,000 or 27,500 bushels of quahogs (*Mercenaria mercenaria*, the Atlantic hard shell clam), 37,910 pounds of shad (*Alosa sapidissima*), 799,663 pounds of Spanish mackerel (*Cybium maculatuan*), 1,003,167 pounds of bluefish (*Pomatomus saltatrix*), 1,143,000 pounds of gray and salmon trout (*Cynoscion regalis* and *Cynoscion maculatus*), 411,000 pounds of sheepshead (*Archosargus probatocephalus*), and 1,512,399 pounds of other fish, referred to as "miscellaneous" in the 1880 Census, for a total of 4,907,139 pounds harvested in 1880. The two counties also caught 15,876,000 pounds of menhaden (Census Bulletin No. 281, 1881). These harvest amounts were prorated for model use based on the population of working and part-time fishermen in the Franktown Enumeration District relative to the entire Eastern Shore of Virginia.

Like agricultural products, fish and shellfish harvests were converted to food calories and market-generated income (money) during each time step in the model prior to input in the human demographic model. Local consumption of seafood harvested was calculated to be 19.73% (Census Bulletin No. 281, Statistics of the Fisheries of Virginia, 1881), leaving the balance for sale at market. For example, a total of 189,943 pounds of bluefish were calculated to be the harvest by fishermen in the Franktown Enumeration District, producing 37,470 pounds for human consumption (19.73%) and 152,473 pounds for sale. Bluefish yields 560 calories per pound (U.S. Department of Agriculture 2009) and, therefore, such a harvest produced 20,983,200 calories (food) to the human demographic submodel. Similarly, 152,473 pounds of bluefish at \$0.02/pound generated \$3,049 before fishing costs.

Description of the Fishing Economics Submodel

The fishing economics submodel captures costs associated with fishing activities for the approxiately 91 fishermen in the Franktown Enumeration District. All costs were annualized for model use over a period of thirty years (the value of fishing structures), three years (pound nets, gill nets, seines, and fykes), or one year (oyster planting and gear costs) (Figure 3.10). Annualized costs were then input to the Fishing Submodel (see above) and subtracted from income generated by the sale of seafood. For example, in 1880 fishermen incurred a total of $4,278 in pound net costs, $110 in gill net costs, $900 in seine costs, and $57 in fyke costs, which were aggregated to $5,345 worth of three-year costs based on the anticipated useful life of these materials and then converted to $1,782 in annualized costs (one third of three-year costs).

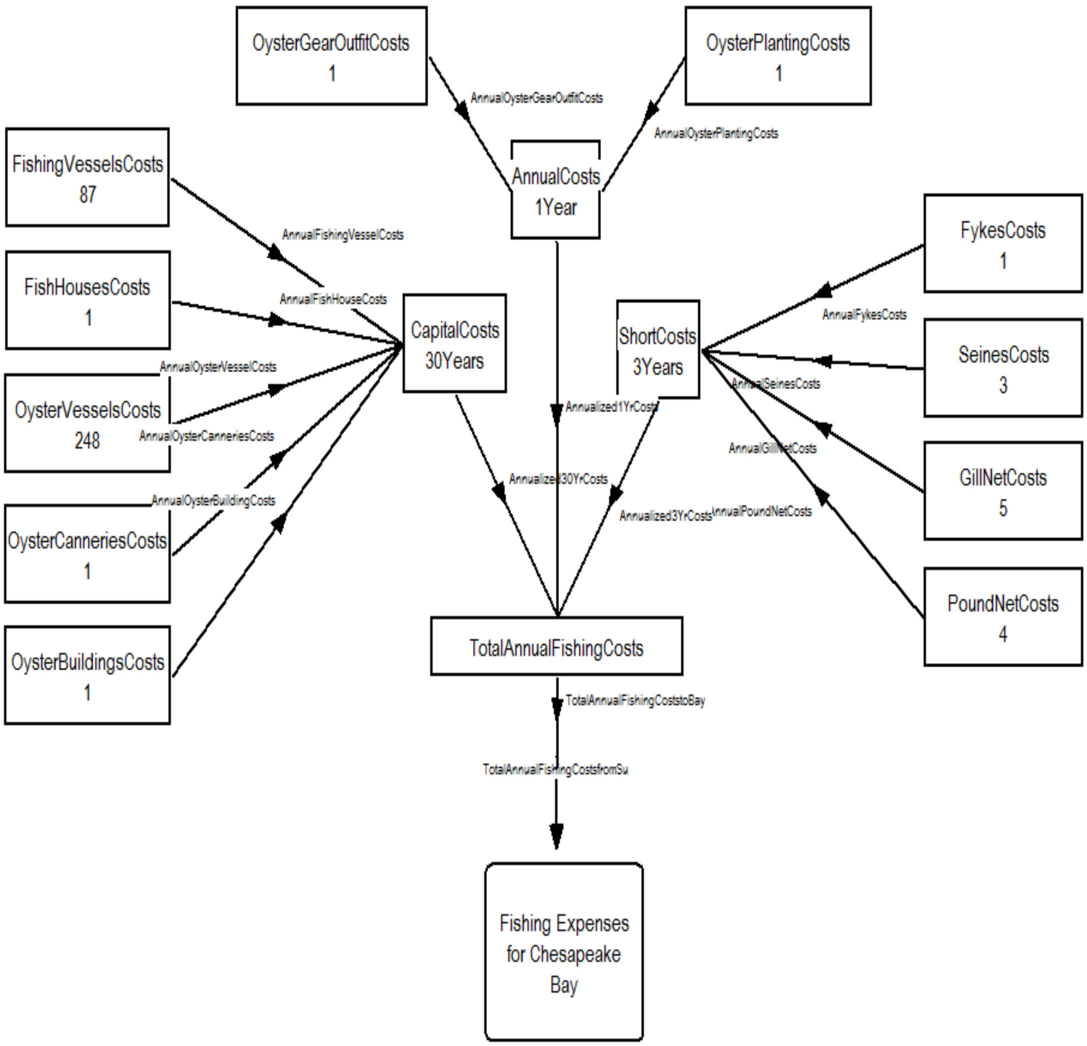

Figure 3.10. Conceptual model of the fishing costs submodel, including 1-year costs (oyster planting and gear), 3-year short term costs (pound nets, gill nets, seines, and fykes), and 30-year capital costs (fishing vessels, fish houses, oyster vessels, oyster canneries, and oyster buildings). All costs are annualized (no interest meaning that the annual amount of a 3 year cost is 1/3 of the total cost) and input into the fishing submodel.

Connections Between Submodels

All farming and fishing activities, including crop and livestock production as well as fish harvests, are converted to either energy or money—the two primary units of currency in this multiple commodity model. These conversions occur in the farming and fishing submodels to yield net calories and net income that are inputs to the human demographic submodel (see Figures 3.5 – 3.10 above).

In order to establish energy balances critical to human demographic change, NHS-ESVA:1880 calculates a ratio of human calorie demand to calorie avialability based on the aggregate number of calories needed to support the existing human population (Figure 3.11). This demand by human inhabitants on the Eastern Shore reflects the number of people in each age class (age <1, 1-4, 5-14, 15-39, 40-65, and 65+) and the number of calories needed by each individual, which, in turn, is dependent on age, gender, and activity level (sedentary, moderately active, and active), and ranges from 1,200 to 2,300 calories per person per day depending on an individual's gender and age-appropriate lifestyle and responsibilities (Pediatrics Calorie Calculator 2009).

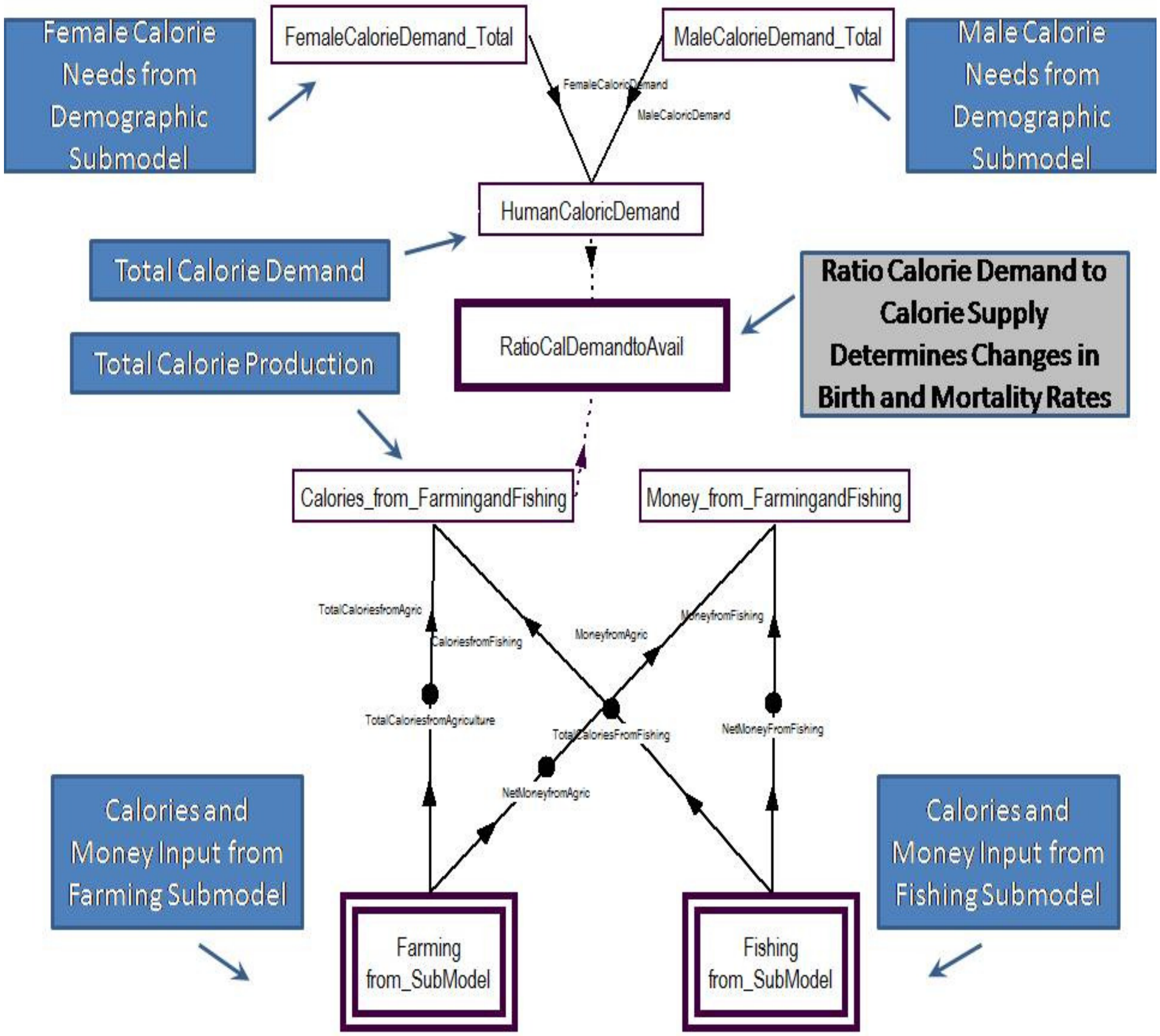

Figure 3.11. Conceptual model of the module for determining the ratio of human calorie demand to calorie availability from farming and fishing production. When there is a net surplus, the population is able to grow unrestricted based on actual birth and mortality rates identified in historical resources. When there is a calorie deficit (i.e., not enough calories to sustain the population at a healthy level), birthrates decrease and mortality rates increase as a function of nutritional stress.

Calorie availability reflects the number of calories produced by farming and fishing activities and allocated for human consumption (see Farming and Fishing Submodels above). When there is a net surplus in the derived calorie demand/supply ratio, the population is able to grow unrestricted based on actual birth and mortality rates for the population as identified in historical resources. In the case of a calorie deficit (i.e., not enough calories to sustain the population at a healthy level), birthrates decrease and mortality rates increase as a function of nutritional stress (Stein and Susser 1975; Hobel and Culhane 2009). Additional capacity limitations can be introduced to the human population as desired (e.g., a ceiling on the number of habitable home sites).

Modelers may also use NHS-ESVA:1880 to investigate complex terrestrial-estuarine linkages including, for example, surface runoff into the Bay that carries excess nutrients from fertilizers and contributes to eutrophication, benthic anoxia, and decreased productivity (Figure 3.12).

Introducing Variability

In addition to a deterministic version of NHS-ESVA:1880, ModelMaker 4.0 enables model users to introduce variability to system dynamics. Stochastic versions reflect the introduction of several potentially random events in the natural-human system that transcend submodels and affect the entire natural-human system. These include, for example, variability in weather, the outbreak of disease, market forces, and changes in fish populations (Figure 3.13). Introducing variability in this manner requires substantial computing power and is not included in this introduction of NHS-ESVA:1880 model.

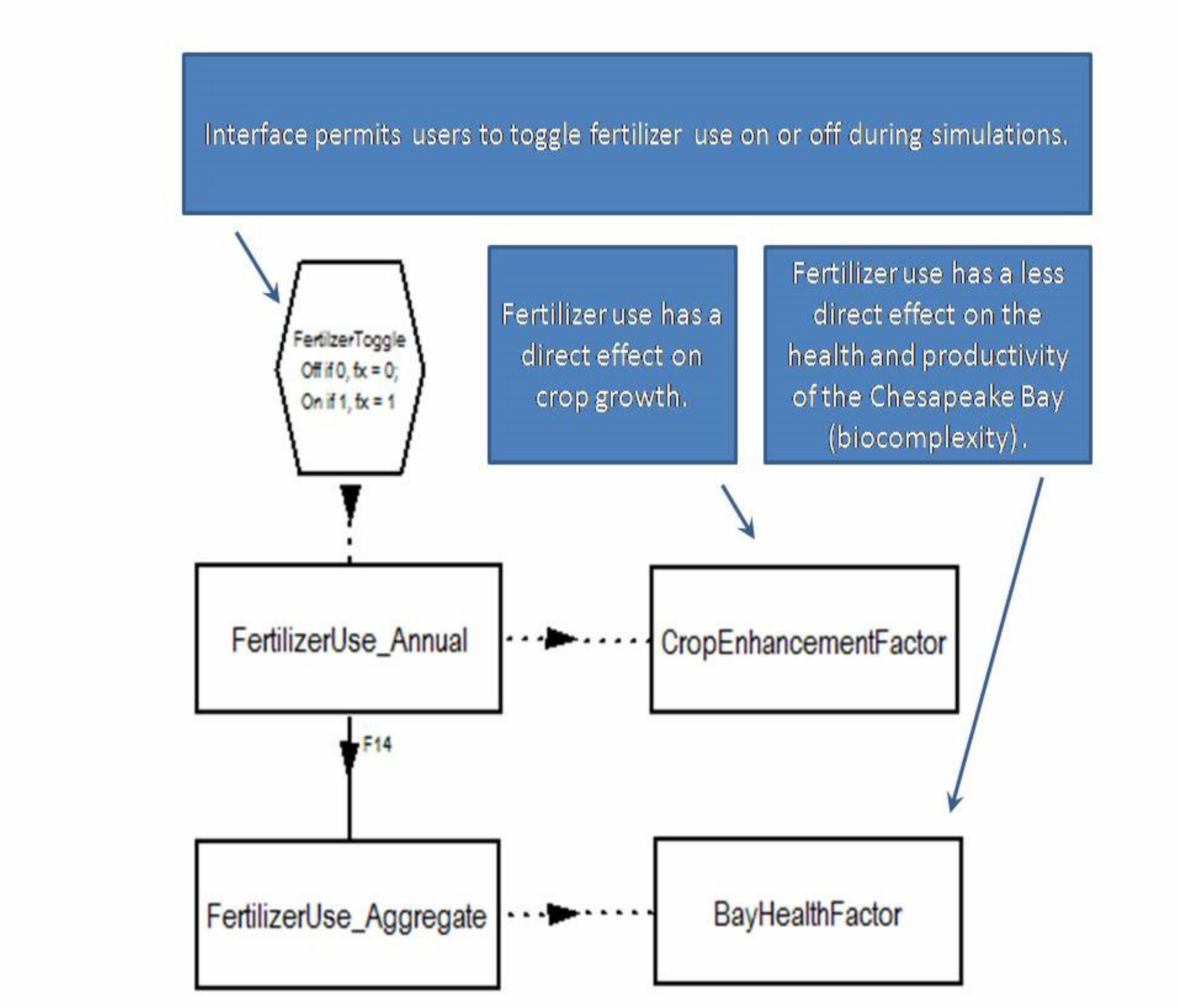

Figure 3.12. Conceptual model of the triggering mechanism for incorporating fertilizer use into the farming submodel (crop enhancement leads to increased productivity) and fishing submodel (increased nutrient loads in surface runoff contribute to eutrophication, hypoxia, and decreased harvests in the Chesapeake Bay).

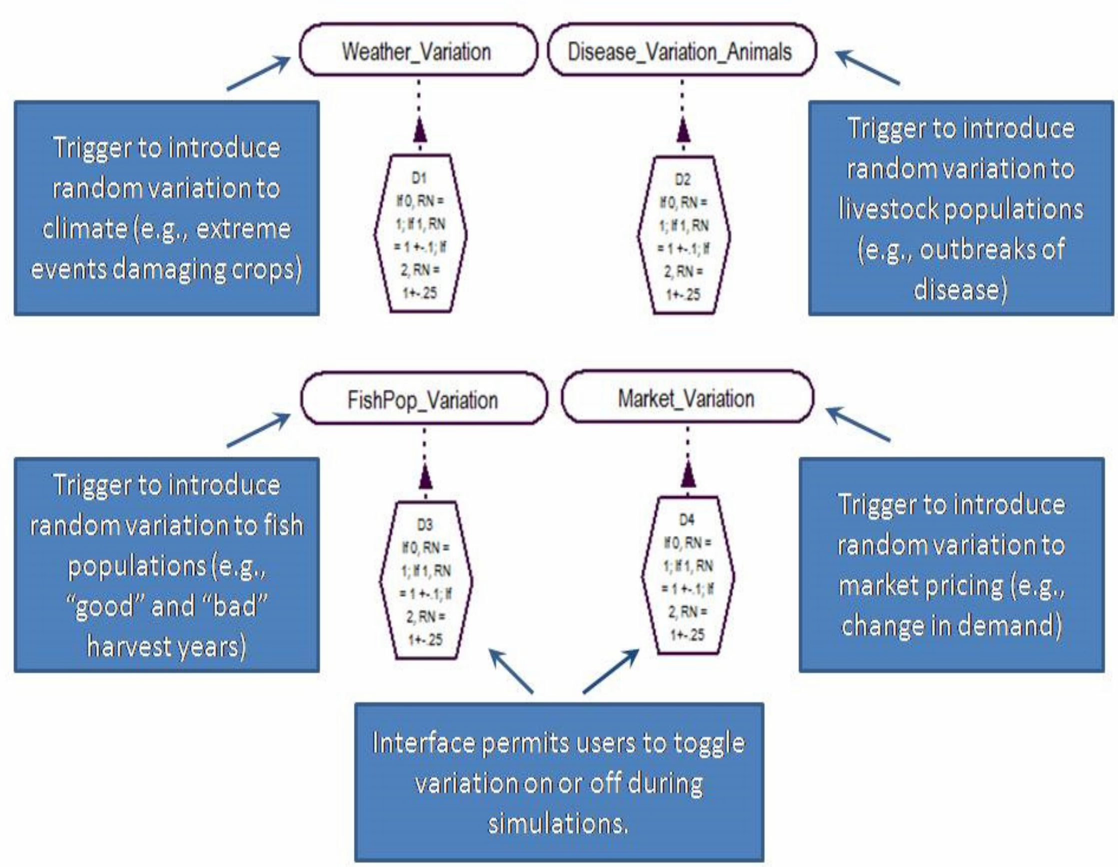

Figure 3.13. Conceptual model of the triggering mechanism for introducing variability in weather, livestock disease, fish populations, and market demand.

Results and Discussion

NHS-ESVA:1880 was used to simulate 200 years (time steps) of natural-human system dynamics on the Eastern Shore of Virginia based on socio-economic, ecological, and physical data circa 1880. Figure 3.14 demonstrates that the incorporation of historical birth and mortality rates for the Franktown Enumeration District without any carrying capacity limitations results in both white and black populations growing exponentially. Interestingly, although the white population was less numerous than the black population in 1880, it surpasses the black population within sixty years under simulated conditions, presumably due to lower mortality rates in all age group classes, especially in males and females <1 and males and females 1-4 (Table 3.1).

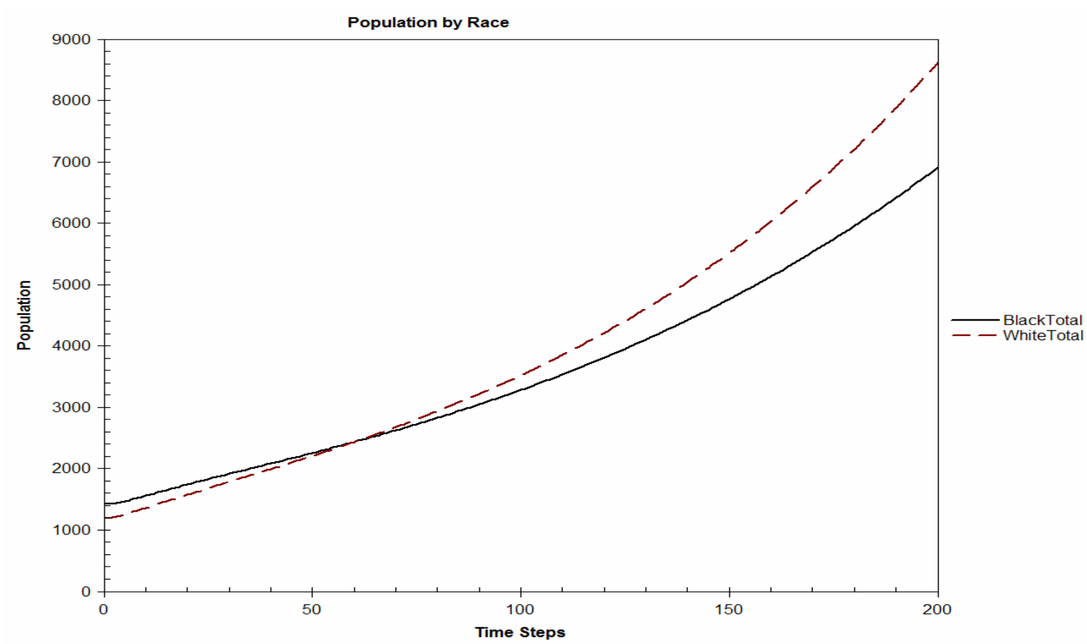

Figure 3.14. Population growth, by race, during the initial simulation of NHS-ESVA:1880.

Table 3.1 Mortality Rates for the Franktown Enumeration District by Age Class, Gender, and Race

	White MALE	White FEMALE	Black MALE	Black FEMALE
Under 1	0.11239	0.11231	0.15860	0.15503
1-4	0.02166	0.02164	0.03056	0.02987
5-10	0.00618	0.00617	0.00872	0.00852
5-14	0.00503	0.00502	0.00710	0.00694
15-49	0.00770	0.00769	0.01087	0.01062
50-65	0.01610	0.01609	0.02272	0.02221
65 +	0.05600	0.05597	0.07903	0.07725

Figure 3.15 shows the combined number of calories generated by the terrestrial system (farming) and estuarine system (fishing) relative to the calorie demands of this exponentially growing human population. As simulated, it is clear that the nutritional needs of the human population are not being met under this scenario, leaving three logical alternatives to explain potential system response and dynamics. The human population will decline unless: (1) calories are imported to feed the human population; (2) large numbers of the growing human population emigrate beyond system boundaries; or (3) birth rates decrease and/or mortality rates increase (i.e., nutritional stress leads to starvation, decreased fertility, or both).

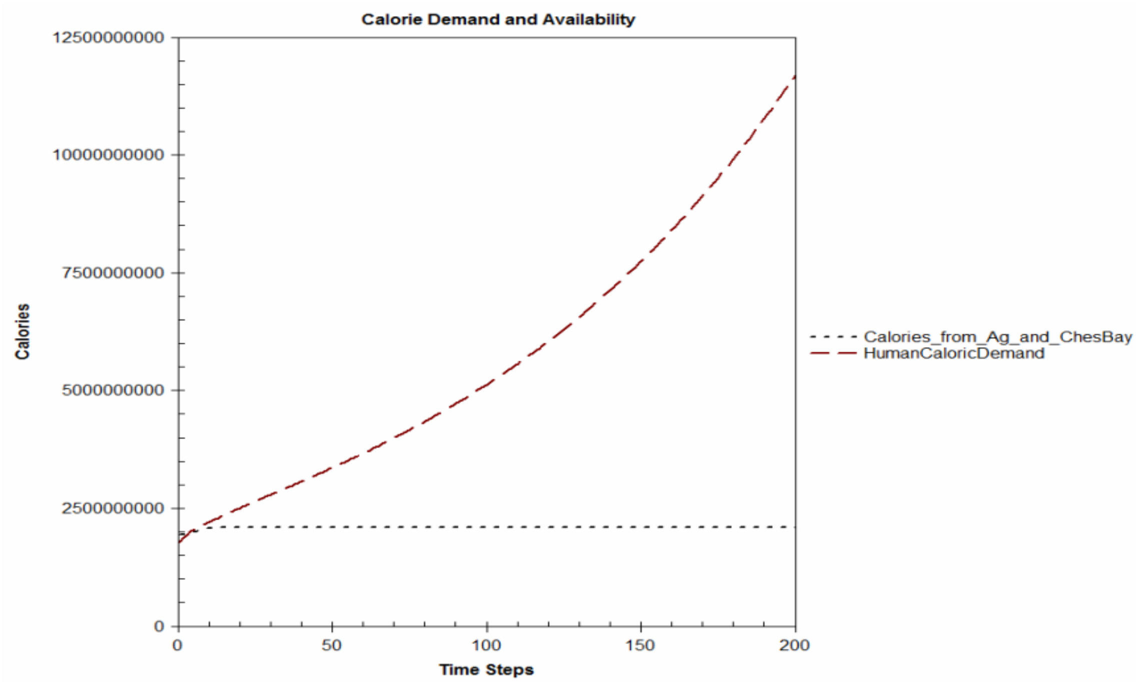

Figure 3.15. Under initial conditions, the nutritional demands of the growing human population quickly exceed calories produced for human consumption from farming and fishing activities.

In an effort to incorporate these logical alternatives, NHS-ESVA:1880 introduces a carrying capacity function through the concept of nutritional stress (Stein and Susser 1975; Hobel and Culhane 2009) and its effects on birth and mortality rates. When there is a net surplus in available calories relative to human caloric demand, the population is able to grow unrestricted (and, perhaps, unrealistically) based on actual birth and mortality rates identified in historical resources (Figure 3.14). When there is a calorie deficit (i.e., not enough calories to sustain the population at a healthy level), however, birthrates decrease and mortality rates increase as a function of nutritional stress. Figure 3.16 shows the relationship between human calorie demand and calorie availability (production for human consumption) when nutritional stress is applied in the model. The same data are redisplayed as a ratio of calories demanded to calories produced in Figure 3.17.

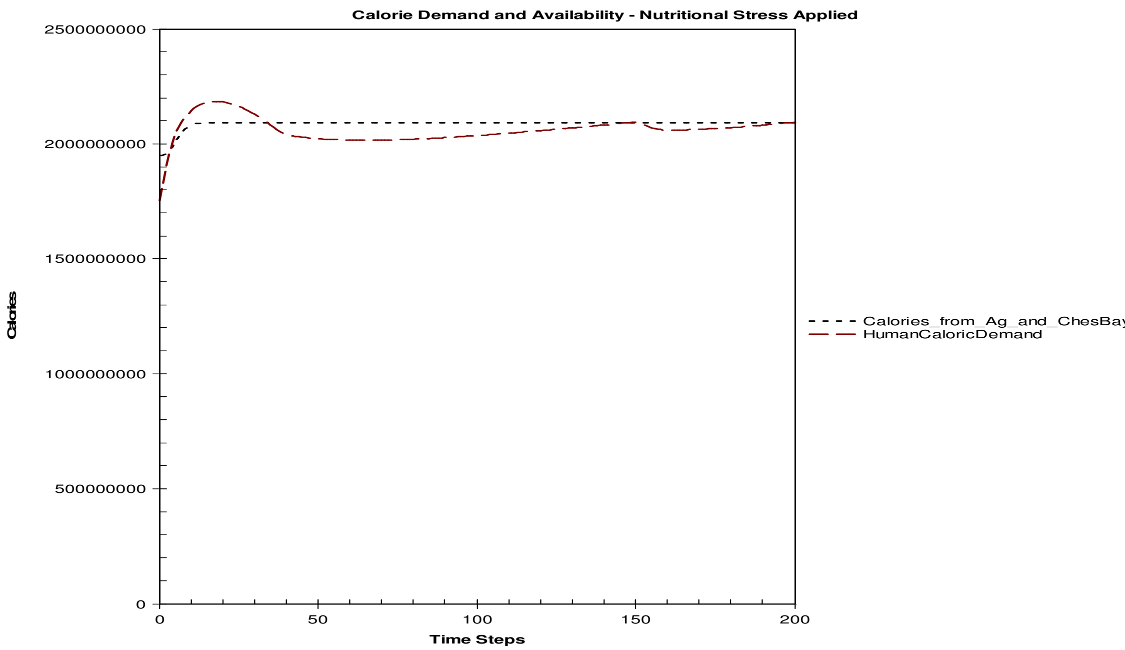

Figure 3.16. The effects of nutritional stress decrease birthrates and increases mortality rates in the human population. Thus, as calorie demand approaches or exceeds availability, members of the population die or reproduce less which, in turn, decreases future calorie demand because of a smaller population.

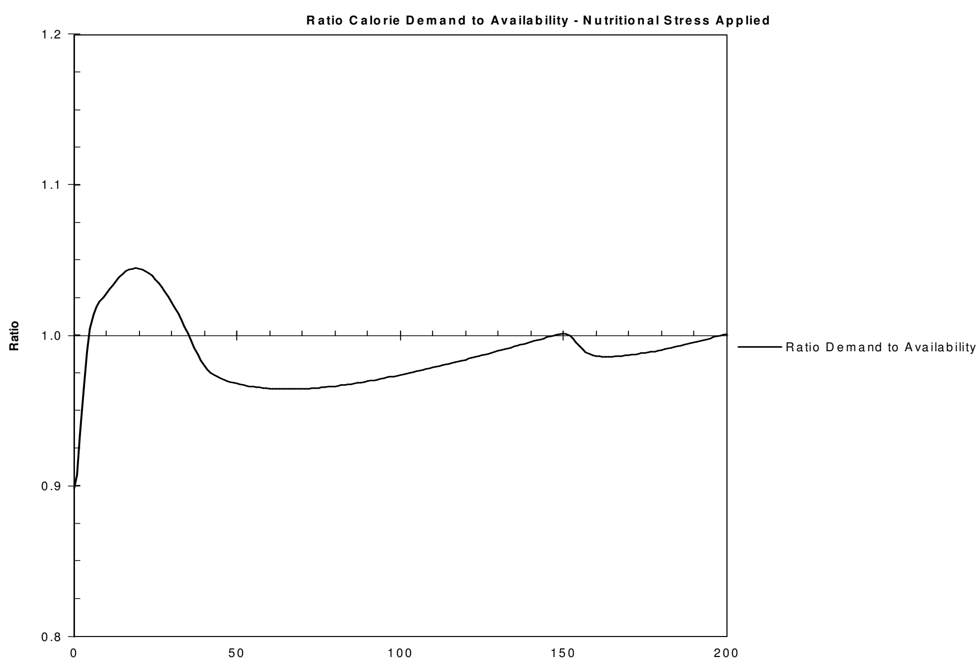

Figure 3.17. The ratio of human calorie demand to calorie production for human consumption when nutritional stress is applied in the model. As the value approaches 1.0, the effects of nutritional stress are introduced because the system is not producing enough calories to feed the human population.

These dynamics result in a relatively stable human population in terms of total number of people supported (approximately 2,700), but differences in black and white mortality rates (Table 3.1 as discussed above) result in dramatic changes in the racial characteristics of that population—the white population grows at the exclusion of the black population (Figure 3.18).

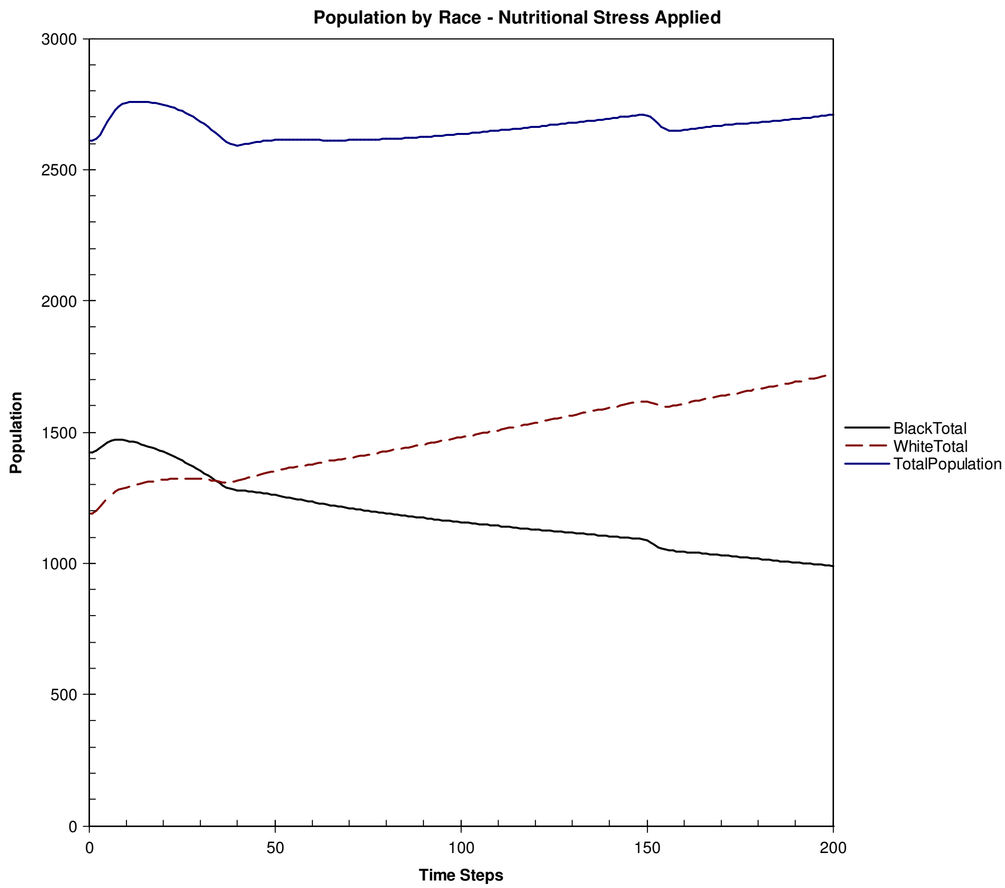

Figure 3.18. Following the application of nutritional stress in the model, the white population grows to the exclusion of the black population.

The denominator in the ratio of human calorie demand to calorie production increases or decreases in NHS-ESVA:1880 as a function of farming or fishing productivity. For example, agricultural production increases with fertilizer use on farms. However, as described in Figure 3.2, a link between terrestrial and estuarine systems exists in the form surface runoff, which transports excess nutrient loads (from fertilizer) and leads to increased eutrophication, benthic anoxia and, finally, transformation from a metazoan to microbially dominated food web in the Chesapeake Bay. Thus, increase in fertilizer not only affects the terrestrial system, but also has substantial repercussions on estuarine health and system dynamics. For example, calorie production allocated to human consumption from Bay harvests decreased even though overall calorie production increases (Figure 3.19).

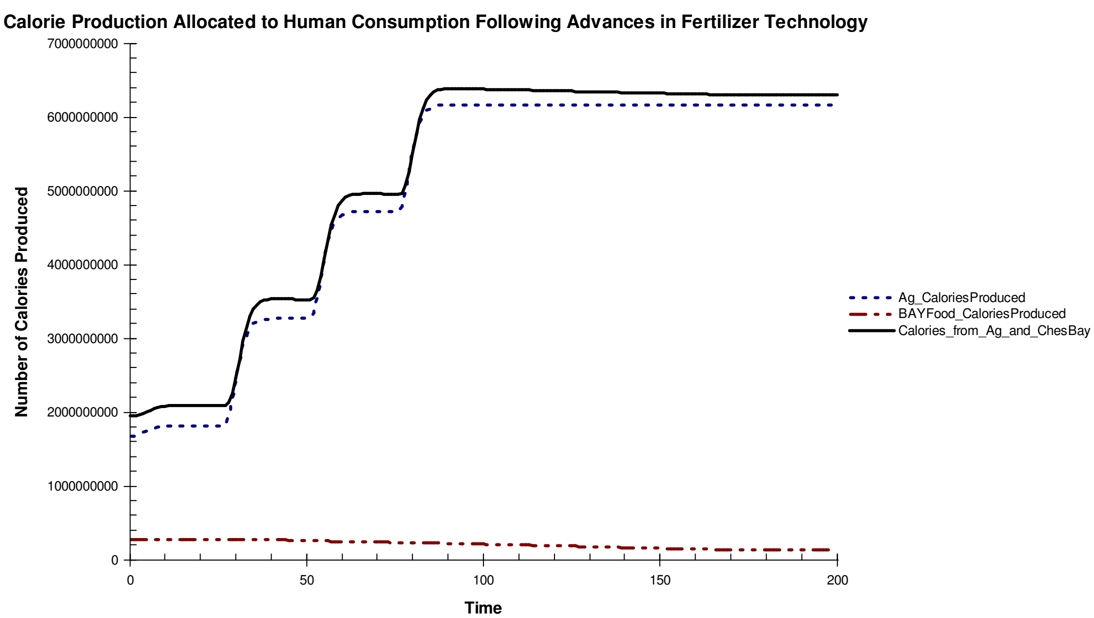

Figure 3.19. Calorie production dynamics following the introduction of increasing fertilizer use as a step function over time (simulating new technological advances). Fertilizer improvements increase farm production, but contribute to a decrease in fishing production due to a long-term damaging effect on the estuarine water quality, habitat, and food web dynamics.

Moreover, in spite of increased agricultural productivity, overall profitability of Eastern Shore agricultural and estuarine harvests decreases substantially following the introduction of fertilizer use in the model. This perhaps surprising dynamic reflects disparities in the amount of agricultural and estuarine products allocated to market (versus human consumption and farm use) as well as market pricing for these products. Put simply, although farming generated substantially more calories for human consumption than fish harvests (Figure 3.19), farming was a net financial loss, made economically worthwhile only by the food it produced (i.e., offsetting the costs of food calories that would otherwise need to be purchased). Profitability was driven by estuarine harvests which, when diminished, had a corresponding effect on income (Figure 3.20).

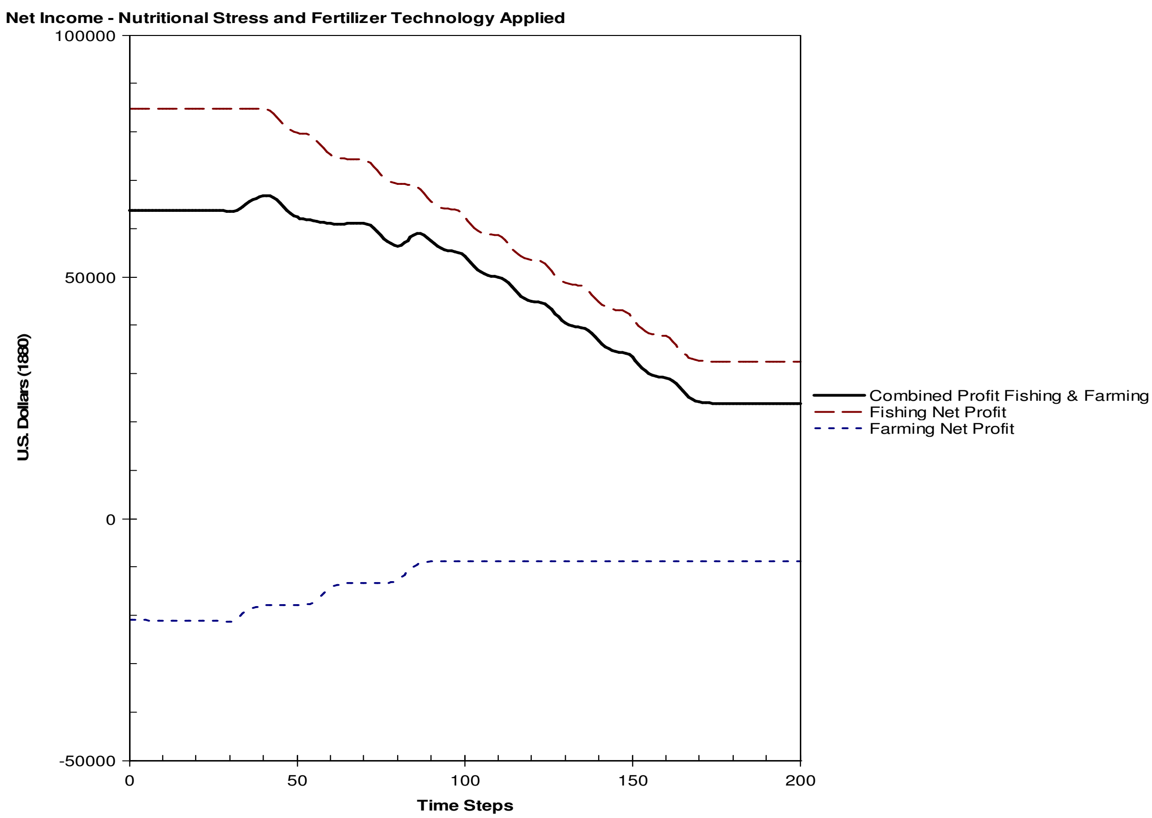

Figure 3.20. Introducing fertilizer effects, both direct (increased farm production) and indirect (decreased Bay health and productivity) in nature, produces a net decrease in overall profitability. Note that farming is a net financial loss in 1880, offset only by the modest profitability of fishing.

The application of nutritional stress and fertilizer use in NHS-ESVA:1880 also combines to produce more a more complex relationship between human calorie demand and calories produced from farming and fishing. Total calorie production increases with fertilizer use at such a fast pace (Figure 3.18) that simulated population growth cannot take full advantage of the bountiful food calories until close to the end of the 200 year simulation—in other words, there is a noticeable surplus of calories throughout much of the simulation following the introduction of advances in fertilizer technology (Figure 3.21). It is likely that much of this surplus would be diverted to market for additional farming income or, alternatively, that birthrates might increase in the absence of other limitations on the capacity of the human population.

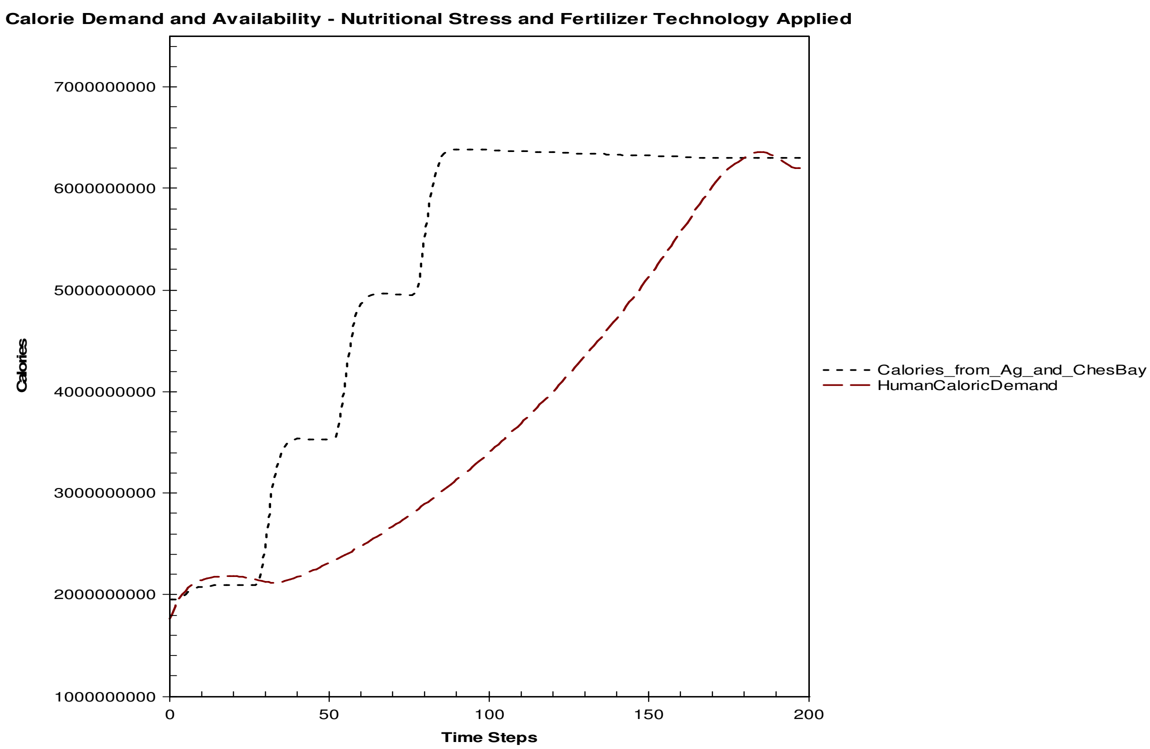

Figure 3.21. Introducing fertilizer produced dramatic increases in calorie production. As originally parameterized, human population growth could not keep pace with the magnitude of these increases until the final years of the simulation. It is possible that such a surplus in calorie availability would result in increased birthrates or the diversion of food calories to market for increased profitability.

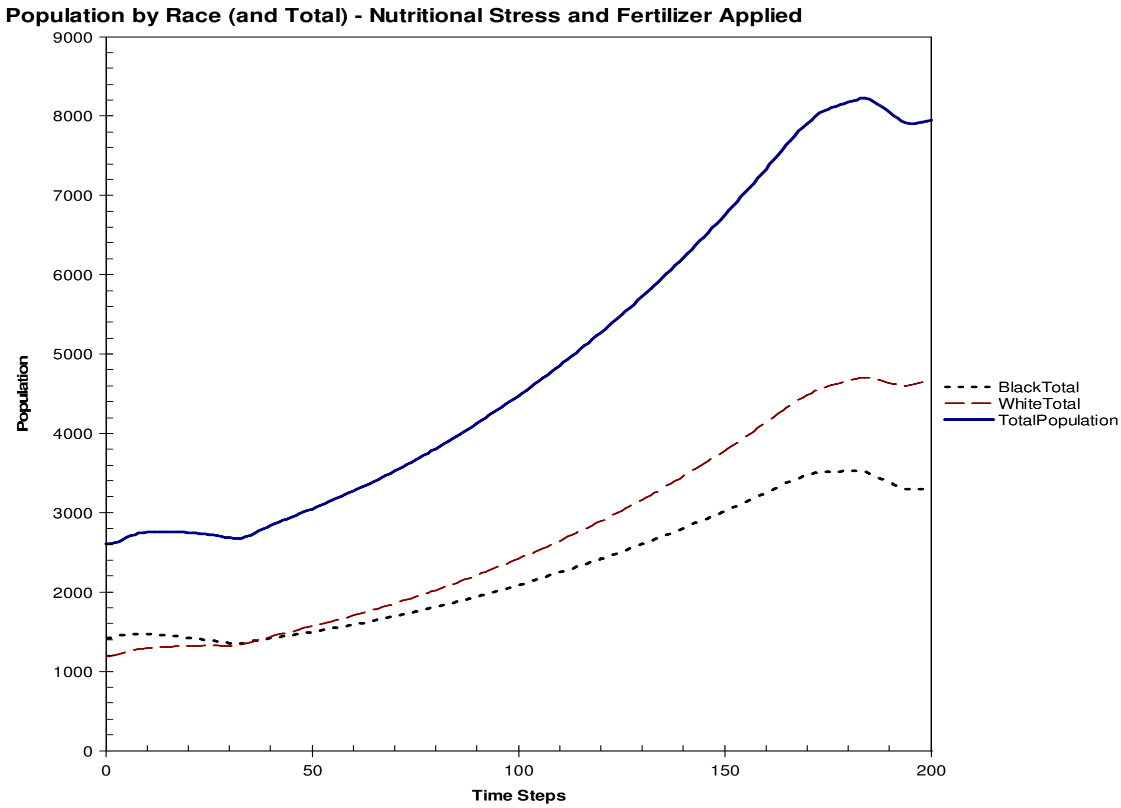

Figure 3.22. The effects of nutritional stress and advancing fertilizer use (technology) on human population, by race (and total population). Although calorie production exceeds human demand (Figure 3.21), the human population grows and eventually plateaus when it reaches system capacity set by nutritional stress (in the absence of additional advances in technology). This fertilizer technology fuels population growth to approximately 8,000 people compared to a capacity of just over 2,700 in Figure 3.18. Moreover, and in contrast to Figure 3.18, the white population grows faster than the black population, but not to its exclusion because of the surplus calories available to people for much of the simulation.

Figure 3.22 demonstrated the effects of nutritional stress and fertilizer use on the simulated human population, which approaches an equilibrium trajectory of 8,000 people—effectively a carrying capacity reflective of increases in calorie production because of fertilizer use. This capacity is much greater than the 2,700 person plateau shown in Figure 3.18 (without advances in fertilizer use). Interestingly, this increase in the total population is driven by gains in both white and black populations, although the white population grows at a faster rate. As indicated in Table 3.1, there are differences in mortality rates between the white and black populations, which lead to these differences in demographic trajectories.

In many ways, the Eastern Shore was an economic meritocracy with respect to race. Any man, regardless of color, who was willing to work long hours on a fishing line could earn enough money to buy better fishing equipment, nets, a boat, crew, and, perhaps someday, enough land to farm as well. But other social restrictions facing blacks throughout the South still applied: they had separate schools, neighborhoods, and living conditions (Thomas, Barnes, and Szuba 2007). During good times, nutritional stress and social pressures were manageable, and the black population grew on the Eastern Shore by 78% between 1870 and 1910 (but by only 24% in the rest of Virginia). But if and when times became lean, the black population was likely to feel it more intensely (as demonstrated in Figure 3.18). It is possible that conditions such as these contributed to the great Northern Migration of black people, albeit less severely on the Eastern Shore until economic times grew tougher during the Great Depression (Hahn 2003).

<u>Conclusions</u>

This Natural-Human System Model of the Eastern Shore of Virginia: 1880 (NHS-ESVA:1880) simulates energy balances, human population dynamics, terrestrial land use and harvest, estuarine productivity, critical technological and economic components influencing farming and fishing activities, and links between terrestrial and estuarine systems on the Eastern Shore of Virginia circa 1880. It reflects and incorporates detailed demographic, agricultural, fishing, and economic/market data, and permits in-depth analysis of these components and their interactions.

NHS-ESVA:1880 is a tool for exploring how people adapt to and shape natural systems—forming a truly natural-human system. Policymakers, the public, and, indeed, the scientific community long believed that the natural state of the environment was stable absent man's intervention. Marsh (1864, pg 27), for example, held that "nature, left undisturbed, so fashions her territory as to give it almost unchanging permanence of form, outline and proportion, except when shattered by geological convulsions; and in these comparatively rare cases of derangement, she sets herself at once to repair the superficial damage, and to restore, as nearly as practicable, the former aspect of her dominion." But this "balance of nature," as often described by terms such as "stability," and "equilibria," has more often been assumed than demonstrated (Ehrlich and Birch 1967; Pimm 1992). Although human populations plateau upon the application of nutritional stress in NHS-ESVA:1880, there is no indication that the system is stable with respect to human population, farm production, estuarine harvests, or profitability. In fact, linkages between terrestrial and estuarine systems highlight the tenuous relationship between farming and fishing, as well as the substantial ramifications of increasing farming or fishing intensity.

Although not presented in this overview of NHS-ESVA:1880, other potential avenues of extended analysis of the natural-human system on the Eastern Shore of Virginia include: (1) long and short-term variation often characteristic of natural populations (e.g., in the form of cyclically "good" and "bad" fish harvests; (2) extreme events that arise periodically (e.g., the outbreak of disease affecting humans, agricultural crops, fish, or shellfish); (3) long and short-term conservation efforts (e.g., replanting sea grasses and other efforts to improve the health and habitats of the Chesapeake Bay); and (4) additional sensitivity analyses to identify the implications of small or large changes to model parameters (e.g., birthrates, mortality rates, market prices, and fertilizer strength).

As Cale, O'Neill, and Shugart (1983) correctly point out, desirable models are sufficiently applicable over a range of "ecological problems." In other words, when suitably constructed and parameterized, good models have the potential to generate and integrate useful information for multiple settings. Although NHS-ESVA:1880 is parameterized specifically to describe the Eastern Shore of Virginia in 1880, this limitation is based on model data rather than model structure. In other words, the core structure of the NHS-ESVA model could be applied to other natural-human systems at the interface between terrestrial and estuarine or marine settings. It can also be readily reparameterized for different time periods, as seen in Chapter 4.

It should be noted, however, that while NHS-ESVA:1880 incorporates the degradation of the Chesapeake Bay benthos due to increased nutrient loads in the water column (e.g., originating from terrestrial fertilizer use), it does not account for all source of nitrogen that contribute to the process, including sewage and atmospheric deposition. Similarly, NHS-ESVA makes no formal distinction between Bay dynamics at its upper and lower reaches, although seasonal benthic anoxia occurs at much higher rates and over larger areas in the upper reaches that are closer to inflow from the Susquehanna River. Future versions of the model may more explicitly address and account for these and other components of water quality.

Because of the interdisciplinary nature of this work – a true synthesis of historical, sociological, and economic data to describe a complex historical natural-human system – NHS-ESVA:1880 is designed for use by researchers and students from across the disciplines who seek to explore and explain the complex and changing natural-human system. Most numerical models of complex system dynamics retain highly quantitative interfaces and output that limit utility to only the most sophisticated users (Crouch et al. 2008). Moreover, many models are "discipline-driven," meaning that an advanced understanding of highly specialized topics, language, protocols, statistical techniques, and conceptual models is required. This object-oriented model enables non-expert users (including students) not only to comprehend the meaning of the simulation, but also to use the descriptive tool to study the natural-human system on the Eastern Shore of Virginia or elsewhere upon modification with high-quality data).

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Chapter 4. The Natural-Human System on the Eastern Shore of Virginia: A Comparison of Life in 1880 and 1920 Using Historical Records, Isotope Analysis, and Systems Modeling

Abstract

This investigation of complexity examines people as a critical component of the natural system on the Eastern Shore of Virginia during a period of intense technological, social, and environmental change. Like many areas, but perhaps more than most, the economic health, social structure, and core culture of the Eastern Shore was, and is, intimately linked to its environment. The interdisciplinary Natural-Human System – Eastern Shore of Virginia (NHS-ESVA) model relies on both historical and biogeophysical data to compare and contrast natural-human system properties in 1880 and 1920. The introduction of a railroad connection to large northeastern markets for agricultural and fishing products in 1884 appears to have had a substantial impact on system dynamics. The ensuing intensification of farming practices led to large increases in system profitability, but also contributed to the degradation of the Chesapeake Bay benthos and conflict with Eastern Shore fishing interests.

Introduction

The period between 1880 and 1920 was a time of great change on the Eastern Shore of Virginia—the southernmost tip of the Delmarva Peninsula, running 120 kilometers from its northern border with Maryland to a southern terminus at the mouth of the Chesapeake Bay (Figure 4.1).

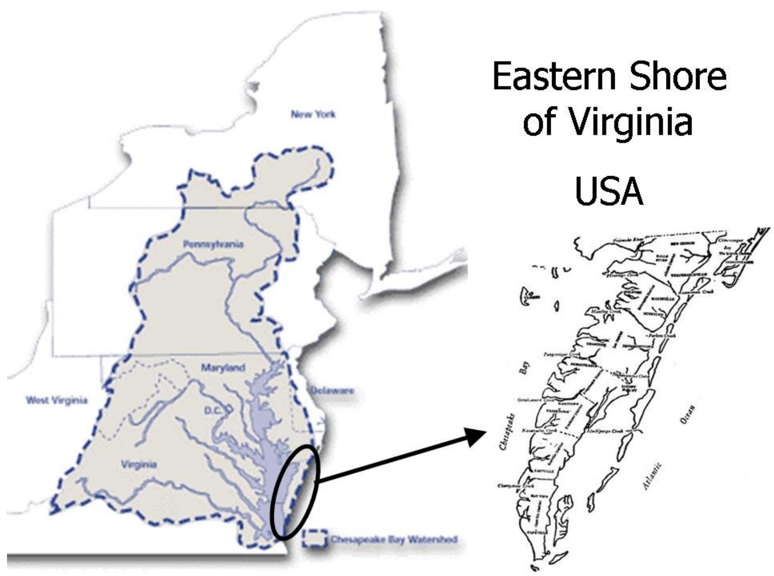


Figure 4.1. The Eastern Shore of Virginia (insert) relative to the northeast United States. The grey, shaded, area of the map of the U.S. northeast represents the Chesapeake Bay watershed. After the Chesapeake Bay Program (2002) and Turman (1964).

In 1870s, this isolated neck of land slumbered in "a Rip Van Winkle sleep… incapable of crossing the gulf which separates it from outside modern life" (Pyle 1879). But by 1920 it had modernized technologically, economically, and socially, and, in doing so, had altered the natural-human system on numerous scales and dimensions (Thomas, Barnes, and Szuba 2007). The pace, scale, drivers, and implications of this change reflect the complexity of the natural-human system on the Eastern Shore, and serve an intellectually tractable example of biocomplexity, where the interplay between biological life and the physical environment transacts at multiple spatial and temporal scales, is characteristically difficult to predict, and must be studied both as a whole and piece by piece (Elser and Steuerwalt 2001).

Because of the interconnectedness of man and environment, Lacitignola (2007) argues that the analysis of socio-ecological systems, such as the Easter Shore of Virginia, requires "an integrated assessment of ecological, social, and economic factors." Put simply, study that is limited to traditional physical features—biological, chemical, and otherwise—does not reflect the entire spectrum of system properties in a human-dominated world. In response to this awareness, this paper examines the effects of this period of great change on the natural-human system through the complementary perspectives of historical records, systems modeling, and isotope geochemistry. The integration of these often separate disciplines (encompassing history, economics, sociology, chemistry, ecology, and systems modeling) enriches our understanding of the complex system and the reciprocal influences of people and the environment that so greatly affected system dynamics.

Human History

Set at the interface of terrestrial and estuarine systems, inhabitants of the Eastern Shore of Virginia in the late 19th century relied heavily on the seemingly inexhaustible resources of the natural system to support their existence. Burell et al. (1972), for example, asserts that the fishing business of the Eastern Shore is probably the oldest industry in Virginia, providing ample food and income to Eastern Shore fishermen since the earliest settlements in the 1620s. Similarly, agricultural life was ubiquitous, but focused largely on raising enough crops and livestock to feed people and farm animals, although a nominal amount of farm products reached regional markets and generated enough income to offset some costs of farming operations.

Between 1880 and 1920, however, a host of technological advances arose that led to dramatic changes in the natural-human system. Some of these changes were new innovations for the time including, for example, improvements in fertilizer use. Although soil on the Eastern Shore had always been productive (and supported by natural fertilizers), farm land was now being rejuvenated by larger amounts of burned oyster shells as well as the Magothy Bay bean (*Cassia chamaecrista*), which was commonly recognized to be a good soil builder. Moreover, commercial fertilizers, largely guano and nitrate deposits from the Caribbean and South America, were also used in considerable amounts (Bailey 1911). By 1919, in fact, farmers on the Eastern Shore reported substantial expenditures on fertilizer products, making them the second highest farming expense behind land and buildings (exceeding even the costs of hired labor). And although the Eastern Shore represented only 1.34% of farmed land in Virginia, it consumed over 19% of all fertilizer in the state (U.S. Census 1925).

Other technologies were not new in their own right, but only in the sense that they became available to people on the Eastern Shore for the first time. The most obvious example of this was the arrival of the railroad line down the crest of the peninsula in 1884, decades after railroads had marched west across the rest of the nation. The rail line changed both the local and national perspectives of inhabitants of the Shore. Village life that once was centered on the bay- and sea-side wharves was relocated to towns that arose around the twenty-eight train depots down the peninsula. But in addition to this change in local geography and culture, the greater effect of the rail line was the connection it offered the Shore to national economic markets. Rail transportation in refrigerated cars soon enabled the rapid delivery of Eastern Shore fruits, vegetables, and seafood to New York in twelve hours, Boston in 20 hours, and Montreal in 30 hours (Thomas, Barnes, and Szuba 2007). This access to national markets changed farming on the Eastern Shore in dramatic ways. For example, although oats and corn had been profitable from the 1840s to the 1880s, the extension of the railroads from the Eastern cities into the fertile lands of the West so cheapened the commodities that Eastern Shore farmers could no longer sell their "staple" crop in Baltimore, Philadelphia, and New York (Nock 1900). They responded by planting white and sweet potatoes in an effort to become more profitable. In 1870, less than 300,000 bushels of sweet potatoes were produced in Accomac and Northampton counties, whereas by 1900 over 2.5 million bushels were harvested on route to a peak of nearly 4.2 million by 1920. During the same period, Irish potato production increased from 159,346 bushels (1870) to more than 1.2 million in 1900 and over 7.5 million in 1920 (U.S. Census 1870-1920). Market opportunity also influenced the intensity of estuarine harvest (and overharvest), contributing to substantially depleted oyster stocks by the late 19th century as well as dramatic shifts in finfish catches. Oyster harvests in the Chesapeake Bay, for example, decreased from close to 125,000,000 pounds in 1880 to 50,000,000 in 1920 and continued a downward trend throughout the balance of the 20th century (Cronin 1986).

The emergence and pace of these changing technologies and market factors contributed to making the people on the Eastern Shore relatively wealthy. Between 1870 and 1920 the average value of farmland rose from \$15 to \$197 per acre in Northampton County and \$16 to \$137 in Accomac (compared to an average of \$55 per acre in the state of Virginia). Moreover, Accomac boasted the highest per capita income of any non-urban county in the United States in 1910 and Northampton and Accomac had the highest crop value per acre in the nation in 1919 (Thomas, Barnes, and Szuba 2007). While access to national markets fueled much of these gains, farmers used technology to increase productivity as well—Eastern Shore farms yielded 29.1 bushels of corn per acre in 1919 compared to 7.9 in 1880 (a 368% increase in productivity). Similar gains were seen in Irish potatoes (a 300% increase), sweet potatoes (a 294% increase), and oats (587% increase), although fewer acres of oats were being planted in response to market pressures. Interestingly, total acreage planted on the Shore did not change substantially at any point between 1880 and 1920 (ranging from 128,775 to 140,562) (National Agricultural Statistics Services 1840-1970).

These technological and market changes fueled many decisions on the Eastern Shore regarding the use of "their" natural terrestrial and estuarine resources. In some cases, early conservation efforts were undertaken to preserve oyster stocks (e.g., surveys of private and public grounds) and wood for barrel making (because it was less expensive to make barrels than to buy them). Having acknowledged these endeavors, the era more is more accurately recognized as ushering in a new business model for family farming with a focus on profitability rather than subsistence and sustainability.

Stable Isotope Geochemistry

Stable isotope geochemistry is a powerful tool in the study of natural systems (Peterson and Fry 1987; Lajtha and Michener 1994; and others). Isotopes are especially valuable as proxy records when direct instrumental or observational records are not otherwise available, as often occurs when examining past systems (Pasternack et al. 2000) or when linking or tracing source materials and dynamic processes (Harrigan et al. 1989; MacAvoy et al. 2001; Wayland and Hobson 2001; and numerous others). In fact, a wide range of biogeophysical and ecological research has relied on stable isotope geochemistry to identify and quantify source materials, sedimentation patterns, substrate characteristics, food sources, vegetation, and geomorphology over recent, historical, and prehistorical periods (Engstrom 1985; Marcus et al. 1991; et al. 2000; Jackson et al. 2001; Christiansen et al. 2002).

Stable isotopes have been particularly valuable research tools with respect to establishing and assessing critical terrestrial-estuarine linkages in the Chesapeake Bay watershed, as well as other biogeophysical processes that influence the physical properties and ecological dynamics of the Bay. Horrigan et al. (1990), for example, relied on stable isotopes to confirm the seasonal cycling of nitrogen in the Chesapeake Bay and Russell et al. (1998) used stable isotopes to identify organic and inorganic sources of nitrogen in wet deposition that contribute to eutrophication. Jackson et al. (2001) examined sedimentation, pollen, seeds, diatoms, and geochemistry in sediment cores to reconstruct the ecological history of the Chesapeake Bay watershed over the past 2,000 years and concluded that environmental and biological fluctuations since European settlement were greater than pre-settlement rates of change. Other evidence suggests that environmental disturbance due to nutrient influx from the terrestrial system did not become substantial until the late 18th century, and that the recurring, yet periodic, eutrophication and anoxia deep in the Bay were apparent by the early 19th century (Zimmerman and Canuel 2000).

More recently, Fulford (2007) presents compelling evidence that the Chesapeake Bay has suffered from a long history of eutrophication that has led to increased phytoplankton biomass (Kemp et al. 2005), decreased water clarity (Gallegos 2001), increases in the severity and geographic extent of seasonal hypoxia (Breitburg 1990, Boicourt 1992, Hagy et al. 2004), and decreases in submerged aquatic vegetation (Kemp et al. 1983; Orth and Moore 1983; Orth et al. 2002)—all with substantial implications on the natural-human system.

These and other studies have extended our understanding of climatic and anthropogenic impacts on the Chesapeake Bay well beyond the availability of historic records (Cooper and Brush 1993) and raised awareness of the potentially concurrent effects of both climate and man on the Chesapeake Bay system (Malone et al. 1986; Malone 1992; Curtin et al. 2001; Jackson et al. 2001 and others). Stable isotopes have also helped researchers to identify links between terrestrial land use (e.g., fertilizer use), eutrophication, and anoxic conditions, and the subsequent transformation of the estuarine food web from primarily metazoan driven to bacterially driven.

Systems Modeling

Systems modeling, by definition, attempts to simplify complexity to a level that is appropriate for describing systems and advancing our understanding of system dynamics (Shugart 1998). Environmental modeling has traditionally relied nearly exclusively on biogeophysical data to identify system (model) components, processes, and parameters. Cerco (1995), for example, created a mathematical model to examine trends in Chesapeake Bay eutrophication based largely on nutrient load data and hydrodynamic processes. Similarly, Crouch et al. (2008) produced an interactive model that assessed physical properties such as wind speed and direction to evaluate circulation patterns in the Bay, and Stow and Scavia (2009) used a similar approach to model bottom water hypoxia. At a more integrated systemic level, Linker et al. (2000) describe efforts by the Chesapeake Bay Program to develop cross-media models that incorporate watershed inputs (comprised of a non-point source submodel, river submodel, and hydrology submodel), estuarine dynamics (focused on water quality), and airshed processes for transporting atmospheric nitrogen emissions. It is hoped that these types of geophysical models will inform both science and policy—potentially influencing resource use choices and helping to reduce nutrient and sediment load delivery into the Bay.

Although there is great value in this approach to modeling, these physical features do not represent the entire spectrum of system properties in a human-dominated world. In this study, numerous sources of socio-economic data are integrated into system models to improve our understanding of the natural-human dynamic. More specifically, these models incorporate detailed demographic, agricultural, fishing, and economic/market data from, for example, the U.S. Population Census, the U.S. Agricultural Census, corollary fishing reports, economic/market reports, and other sources. These rich data records inform the science behind the modeling effort and greatly improve our understanding of both the natural and anthropogenic aspects of these systems.

The interactions between natural and human systems produce particularly complex dynamics that can, perhaps, be best analyzed through coupled natural–human systems models. These types of models generally attempt to account for interactions between human stakeholders and the natural landscape, interactions among the human stakeholders, and the responses of those human stakeholders to perceived changes in the natural environments (Acevedo et al 2008). On the Eastern Shore of Virginia, system complexity is illustrated through the history of tension between farming and fishing, each of which contributed substantially to the region's once flourishing socio-economic system. While "improvements" in agricultural and transportation technologies were vital to the production and sale of commercial crops on the Eastern Shore, increases in farming intensity contributed substantially to the transformation of the estuary benthos and food web—having profound implications on finfish and shellfish harvests (compounded by overfishing) which, in turn, had devastating effects on the economic viability of those watermen and communities that depended on Bay productivity for their livelihoods. These processes proved to be environmentally devastating to the Chesapeake Bay ecosystem as well.

Due to advances in computing power, the development of better modeling tools, and improvements in our understanding of biogeophysical and anthropogenic processes, systems science has recently begun to quantitatively describe the behavior of complex natural-human systems (Adger 2000; Casagrandi and Rinaldi 2002; Abel and Stepp 2003; Jannsen and Ostrom 2006; and many others). This assessment of the rich and complicated natural-human system on the Eastern Shore of Virginia begins with a review of human history, is corroborated by stable isotope evidence, and explored in depth through detailed systems modeling (Figure 4.2). Such an investigation of the historical Eastern Shore of Virginia system allows us to examine the complex processes that connect terrestrial and estuarine systems, the intended and unintended consequences of human actions, and many of the pressing questions facing the study of biocomplexity and natural-human systems.

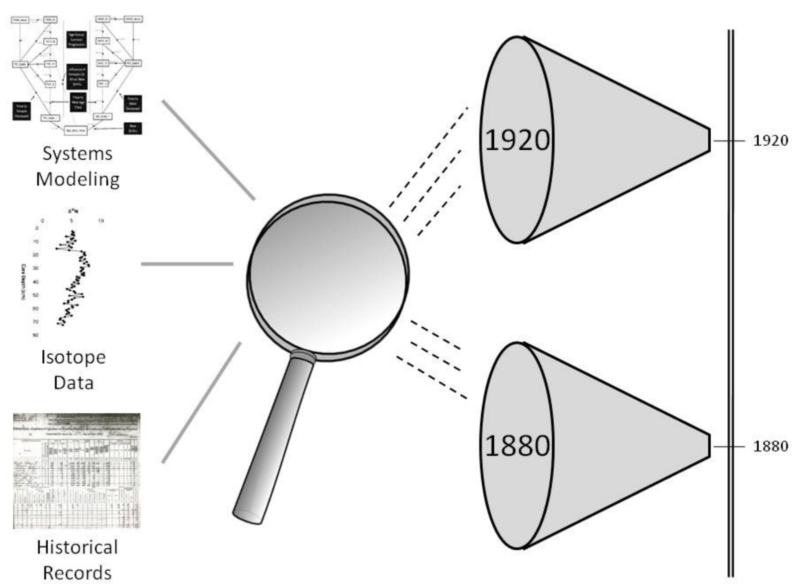


Figure 4.2. Historical records, isotope data, and systems modeling are individually powerful analytical tools but, in combination, greatly amplify our understanding of system dynamics.

Methodology

Historical Data

Historical data for this study reflect a wide range of primary and secondary sources, but focused substantially on data available from the 1880 U.S. Census and the 1920 U.S. Census, including numerous reports derived from these Census collections (e.g., 1880 Census Report on Mortality and Vital Statistics and the Census Abridged Life Tables for 1919-1920). Publications from the U.S. Commission of Fish and Fisheries (1871-1903) and Reports of the U.S. Commissioner of Fisheries (1919-1925) were also of great value. Data were identified in these national collections and/or derived for the Franktown Magisterial District, a politically defined geophysical unit in northern Northampton County on the Eastern Shore of Virginia. According to the Census Descriptions of Geographic Subdivision and Enumeration Districts, 1830-1950, Franktown included all of the area between the Accomac County boundary (to the north) and the Eastville Township boundary (to the south). Hog Island was also included in the District, as was the road dividing Franktown Township and Eastville Township (Turman 1964) (Figure 4.3).

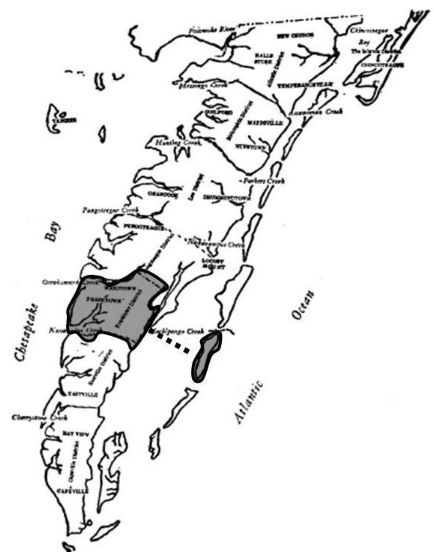


Figure 4.3. The Franktown Enumeration District (shaded) lies entirely within Northampton County, includes Hog Island, and is bounded by Accomac County to the north and the Eastville Township line to the south. After Turman (1964).

Coring and Isotope Methods

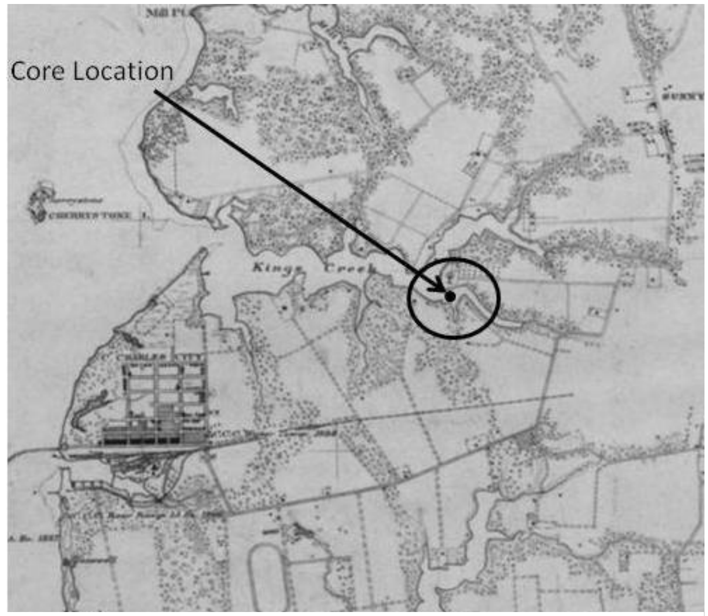


Figure 4.4. A sediment core was retrieved for carbon and nitrogen isotope analysis from King's Creek, a bayside tidal creek in Northampton County, north of Cape Charles at latitude 37° 16’ 47 N and longitude 075° 59’ 29 W. Image from the U.S. Department of Commerce and Labor (1904) Coast and Geodetic Survey: Eastern Shore of the Chesapeake Bay (Butlers Bluff to the Gulf), Plane Table Survey Register No. 2676.

A sediment core was retrieved from King’s Creek, a bayside tidal creek on the Eastern Shore of Virginia (latitude 37° 16’ 47 N and longitude 075° 59’ 29 W) (Figure 4.4). Cores were extracted using 10 cm diameter plexiglass tubing fitted to a piston coring apparatus. Upon extraction, the cores were kept cool until returned to laboratories at the University of Virginia for carbon and nitrogen isotope analysis. Following removal from the core tube, the sediments were cut into 1 cm sections. Outer perimeters of each section were excised to remove any portion of the sample potentially disturbed physically by the coring operation. Each sample was dried at 40ºC and ground into a fine powder. Once dry, 40% HCl acid was added to each sample to remove carbonate. The samples were redried at 40ºC and analyzed for isotope compositions using a GV OPTIMA stable isotope ratio mass spectrometer (IRMS) connected to a Carlo Erba elemental analyzer (EA).

Stable isotope findings are normally reported as delta (δ) values, which are presented in terms of per mil (‰). Delta values represent the difference between the sample and the relevant international standard, in this case PDB-V for carbon and atmospheric nitrogen (N_2) for nitrogen. Delta values are determined using the following equation:

$$[(R_{SAMPLE} - R_{STANDARD})/R_{STANDARD}][1000] = \delta‰$$

where the R value represents the ratio of the heavier isotope to the lighter isotope. For carbon, the R value is the ratio of $^{13}C/^{12}C$ and for nitrogen, it represents the ratio of $^{15}N/^{14}N$.

Systems Modeling Methods

The Natural-Human System–Eastern Shore of Virginia model (NHS-ESVA) is a single model of the natural-human system on the Eastern Shore of Virginia that has been parameterized to reflect two different time periods (1880 and 1920) in the history of the Franktown Enumeration District in Northampton County (Figure 4.3). NHS-ESVA is comprised of a human demographic model and four linked submodels that simulate energy balances, human population dynamics, terrestrial land use and harvest, estuarine harvest, critical technological and economic components influencing farming and fishing activities, and the links between terrestrial and estuarine systems (Figure 4.5). The model reflects and incorporates detailed demographic, agricultural, fishing, and economic/market data from the U.S. Population Census, and corollary reports such as Census Agricultural Reports, Census Fishery Industries Reports, Census Reports on Mortality and Vital Statistics, Census Reports on Statistics of Wages, and other primary sources of historical data.

NHS-ESVA: 1880 refers to a version of the model parameterized with 1880 data. NHS-ESVA:1920 refers to a version of the same model parameterized to reflect the 1920 system. The two models are structurally identical, with the only difference being the data used to parameterize them (i.e., data that reflect the1880 system versus data that reflect the 1920 system). All monetary values in NHS-ESVA: 1920 are converted to U.S. Dollars (1880) by means of a consumer price index adjustment to facilitate comparison with NHS-ESVA:1880 values.

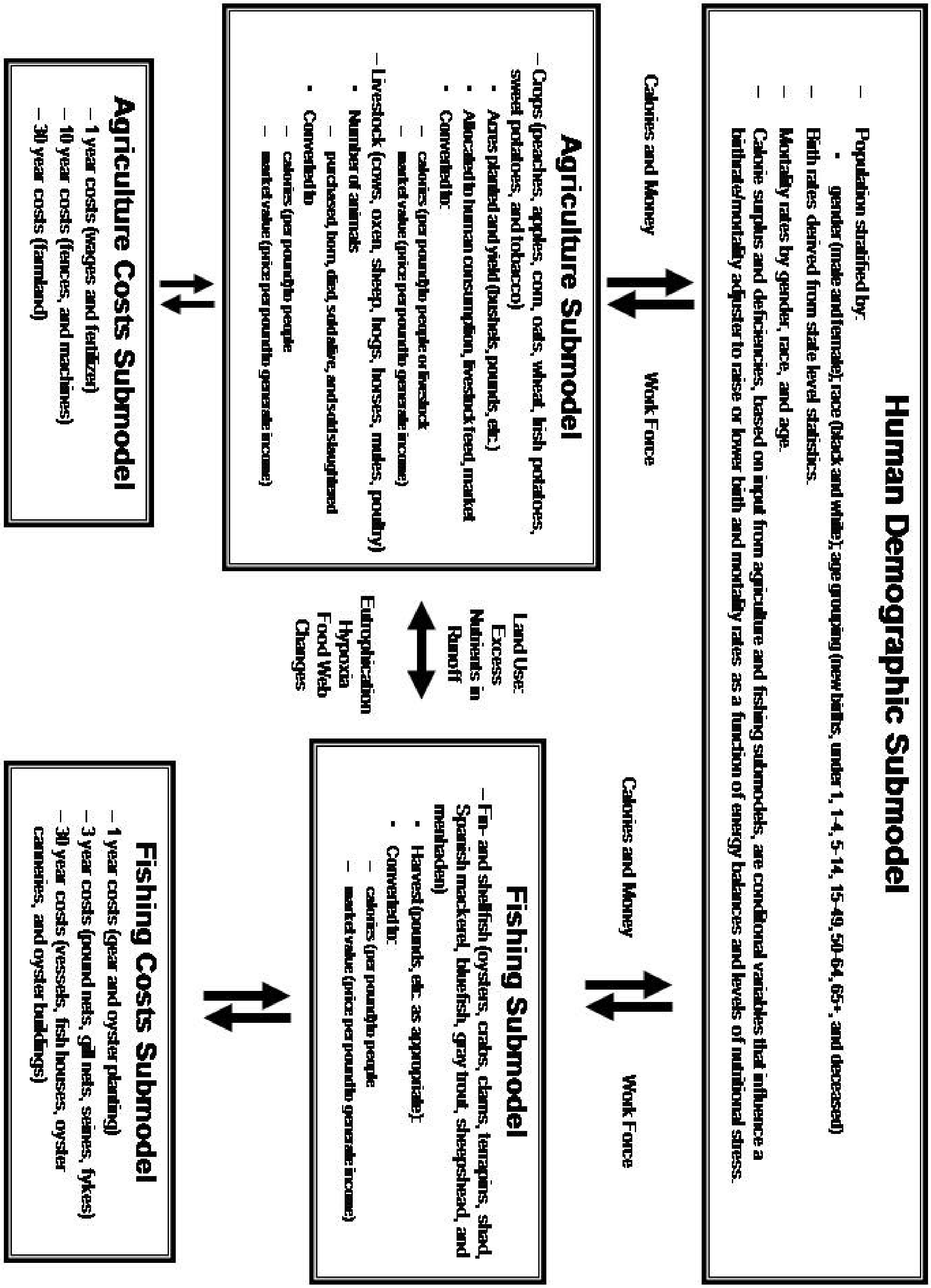


Figure 4.5. Conceptual overview of the NHS-ESVA model as more thoroughly described in Chapter 3. The model incorporates a human demographic model and four linked submodels that simulate terrestrial land use and agricultural productivity (farming), farming costs, estuarine productivity (fishing), and fishing costs.

As more thoroughly described in Chapter 3, NHS-ESVA was created using ModelMaker Version 4.0, a windows-based object-oriented modeling program commonly applied to many areas of modeling science, including environmental science, ecology, chemistry, sociology, and economics. Modelmaker enables users to conceptualize and design systems that include compartments, flows, variables, conditional and unconditional components, dependent and independent event triggers, random number generators, lookup (data) tables, and other useful tools found in many modeling programs. More information about this commercial product is available from Cherwell Scientific Ltd. (http://modelkinetix.com).

It is important to note that the models constructed in this study are explanatory rather than predictive in nature. While many models currently represented in peer-reviewed literature are designed to forecast system dynamics over time, models in this study are designed to describe system properties and dynamics in great detail at specific historical points in time (i.e., 1880 and 1920). For example, prior to 1884, there was not a railroad line connecting the Eastern Shore and its agricultural products and estuarine harvests to external markets in significant volume beyond Baltimore, Maryland to the north and Norfolk, Virginia to the south. This limitation is reflected in the 1880 model, which is appropriate and necessary to understand system dynamics at that time, but it also makes the analytical tool antiquated as a descriptor of the natural-human system after 1884 once the railroad had been established on the Eastern Shore. In contrast, the 1920 model reflects the prominent role the railroad played in connecting Eastern Shore agricultural and estuarine products to far-reaching geographic markets—because it is specifically the economic vitality of those pre-depression 1920 markets and 1920 agricultural and fishing technologies that drove Eastern Shore land use decisions, conservation efforts, and, by extension, changes to biogeophysical components and processes in both terrestrial and estuarine settings. While this time-specific limitation restricts the predictive power of the NHS-ESVA model, it provides a richer and more detailed description of system properties and dynamics during those specific historical periods. Thus, although NHS-ESVA:1880 and NHS-ESVA:1920 are structurally identical and, therefore, comparable, the models are not presented as tools to forecast or predict system dynamics. NHS-ESVA can, however, be parameterized for other time periods on the Eastern Shore of Virginia (or other geographic settings at terrestrial-estuarine interfaces) to assess the impact of, for example, new farming and fishing technologies, the abrupt transition from early 19th century boom markets to a 1930 depression market, or the growing awareness of resource scarcity that influenced land use and estuarine conservation decisions in the latter part of the 20th century.

Results and Discussion

NHS-ESVA:1920 was used to simulate 200 years (time steps) of natural-human system dynamics on the Eastern Shore of Virginia in the same manner described in Chapter 3 for NHS-ESVA:1880. Many of the results of the initial simulations of NHS-ESVA:1920 are strikingly similar to findings from the NHS-ESVA:1880 model. For example:

- ✓ Figure 4.6 – In the absence of explicitly structured carrying capacity limitations such as nutritional stress, the human populations (all races and genders) simulated in NHS-ESVA:1920 and NHS-ESVA:1880 appear to grow exponentially based purely on birth and mortality statistics from the U.S. Census for the respective years. Note that the actual starting population in 1920 (5,109) was nearly double the initial 1880 population (2,610).
- ✓ Figure 4.7 – As seen in NHS-ESVA:1880, the 1920 population shows more black people (2,759) than white people (2,350) under initial conditions, but differences in

birth rates and mortality rates for the two races result in the white population surpassing the black population within about 70 years.

- ✓ Figure 4.8 – As was the case with the 1880 simulation, the nutritional needs of the increasing human population in the NHS-ESVA:1920 simulation are not met by calorie production allocated for human consumption from farming and fishing.

With respect to calorie demand and production, a population will decrease when the demand for food calories exceeds total calorie production unless: (1) calories are imported; (2) large numbers of the growing population emigrate beyond system boundaries (effectively still a decline in the population within the system); or (3) reproduction rates decrease and/or mortality rates increase (e.g., nutritional stress leads to starvation, decreased fertility, or both). Because NHS-ESVA represents a closed system with respect to calorie importation and population mobility, nutritional stress is introduced as a carrying capacity mechanism for the human population (Hobel and Culhane 2003). Figure 4.9 demonstrates how black, white, and total population growth is altered (in contrast with Figure 4.6) by the application of nutritional stress on birth and mortality rates in NHS-ESVA:1920. Figure 4.10 illustrates the calorie demand and availability data that fuel these dynamics, while Figure 4.11 presents the same data as a ratio of human calorie demand to farming and fishing calorie production allocated to human consumption. Nutritional stress is triggered as this ratio approaches and exceeds 1.0 (i.e., as calorie demand approaches and exceeds supply, birthrates decrease, and mortality rates increase).

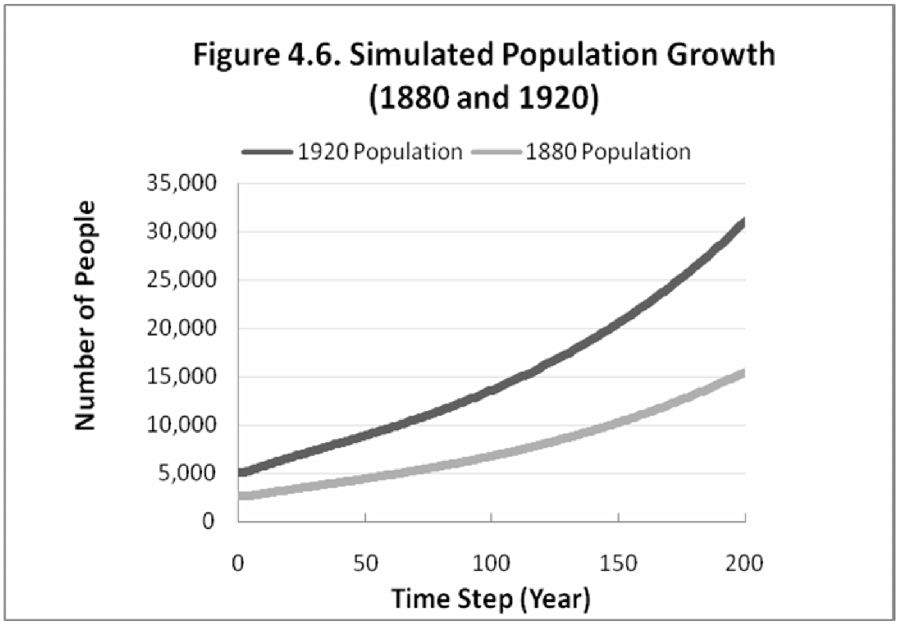


Figure 4.6. In the absence of carrying capacity limitations, human population growth appears to increase exponentially as initially simulated in NHS-ESVA:1880 and NHS-ESVA:1920.

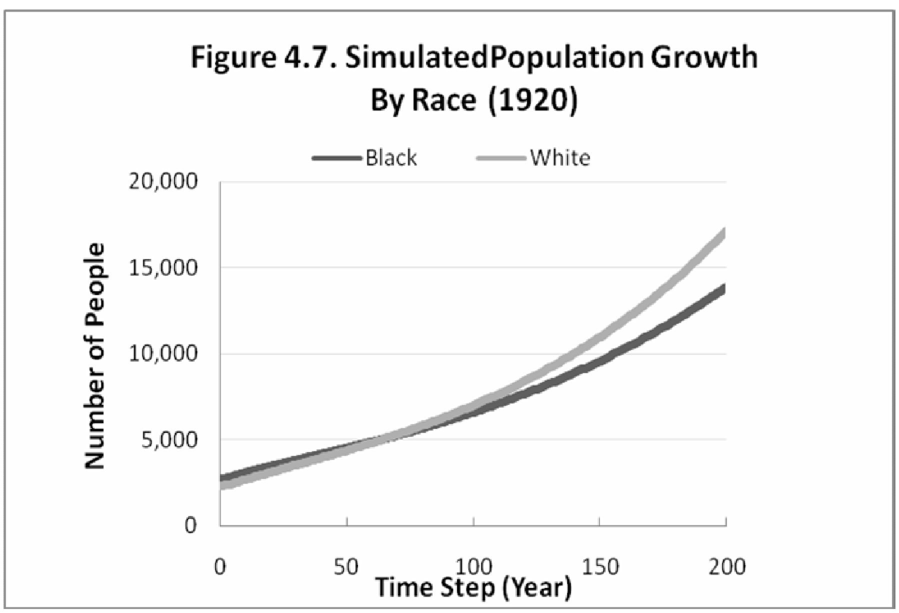


Figure 4.7. Population growth, by race, during the initial simulation of NHS-ESVA:1920. As occurred in the NHS-ESVA:1880 simulation, the white population eventually surpassing the black population based solely on published birth and mortality rates.

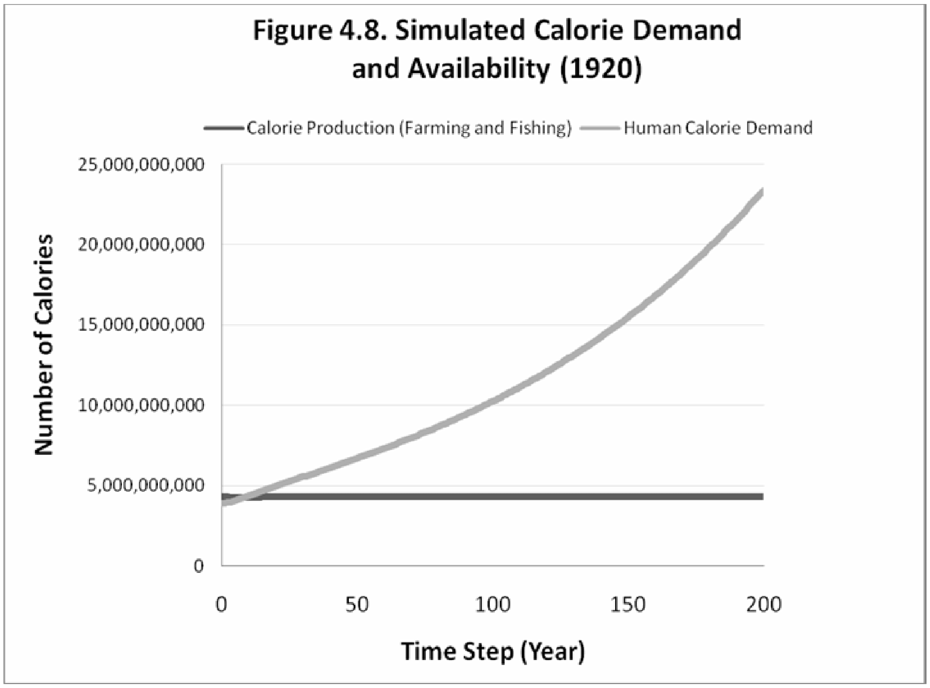


Figure 4.8. The nutritional demands of the growing human population quickly exceed calorie production allocated to human consumption from farming and fishing activities in NHS-ESVA:1920.

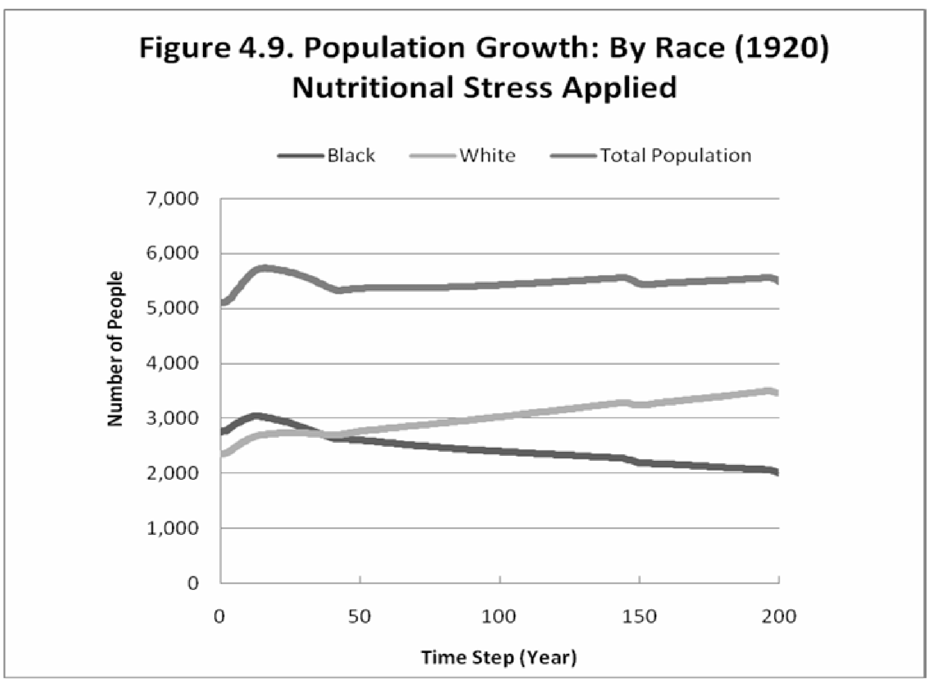


Figure 4.9. The effects of nutritional stress on human population dynamics, by race and total population in NHS-ESVA:1920.

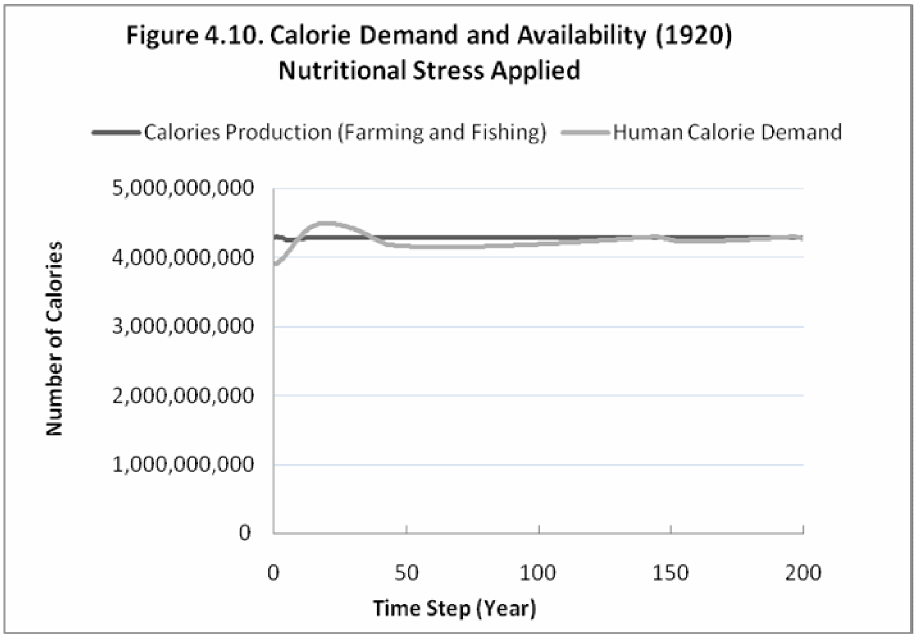


Figure 4.10. Nutritional stress decreases birthrates and increases mortality rates. Thus, as calorie demand approaches or exceeds calorie production allocated to human consumption, members of the population die and/or reproduce less which, in turn, decreases future calorie demand because of smaller populations.

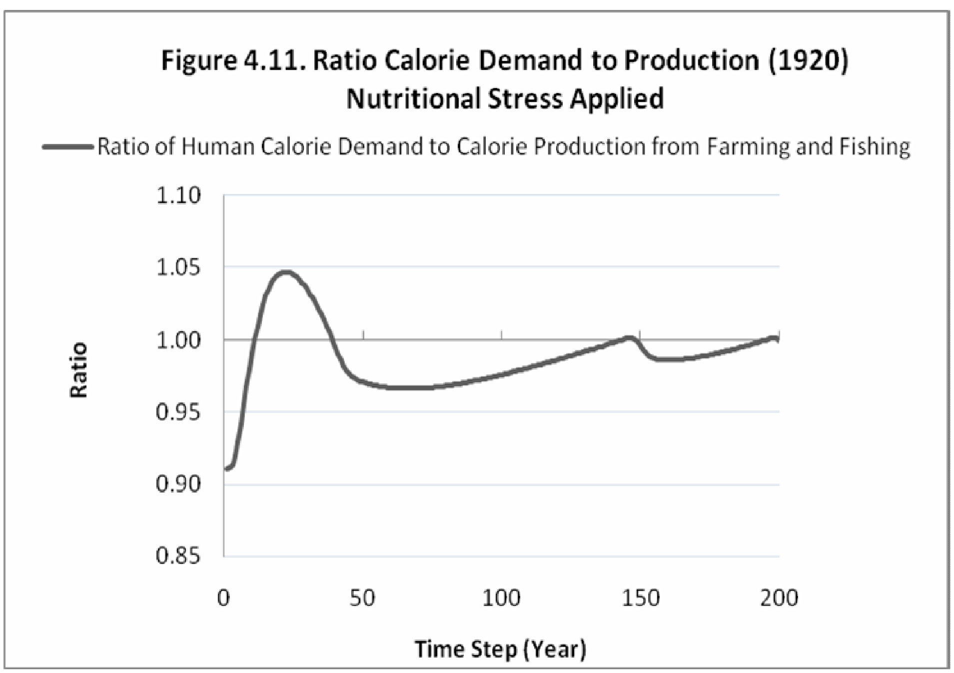


Figure 4.11. The ratio of human calorie demand to calorie production allocated to human consumption following the introduction of nutritional stress in NHS-ESVA:1920.

Until this point in the simulations, calorie production allocated to human consumption has remained constant—based on 1920 data, a total of 4,291,772,959 calories were produced for human consumption, 3,898,163,990 calories (90.84%) from farming with the remaining 393,608,969 attributable to fishing. Because the denominator in the ratio of human calorie demand to calories produced (i.e., calorie production) increases or decreases in NHS-ESVA as a function of farming or fishing productivity, changes in harvests determine the size of the human population that can be supported. For example, improvements in farming technology, such as fertilizer use, increased productivity substantially between 1880 and 1920: Eastern Shore farms yielded 7.9 bushels of corn per acre in 1880 compared to 29.1 in 1920 (a 368% increase in productivity) while similar gains were seen in Irish potatoes (a 300% increase) and sweet potatoes (a 294% increase) (National Agricultural Statistics Services 1840-1970).

As similar three-fold increases in productivity are simulated in NHS-ESVA:1920, the number of calories generated from farming increases as a step function to reflect these improvements in farming technology. While overfishing in the late 19th century contributed substantially to decreased estuarine harvests, fishing yields also decreases as a function of increased fertilizer use because of then-unknown linkages between the terrestrial system and the estuary system by means of increases in surface runoff and nutrient loads leading to eutrophication and, ultimately, benthic anoxia and changes in the food web. Despite this decrease in estuarine production, fertilizer effects on farm production result in a substantial increase in calorie production allocated for human consumption (Figure 4.12) and support a larger human population (Figure 4.13). Note, however, that a new population limit (carrying capacity) appears to have been established in the 1920 system at just under 20,000 people because technology (fertilizer)-driven increases in calorie production were only introduced three times in the simulation and human calorie demand eventually reached this calorie availability boundary. A similar, though lower, limit was reached in the 1880 simulation.

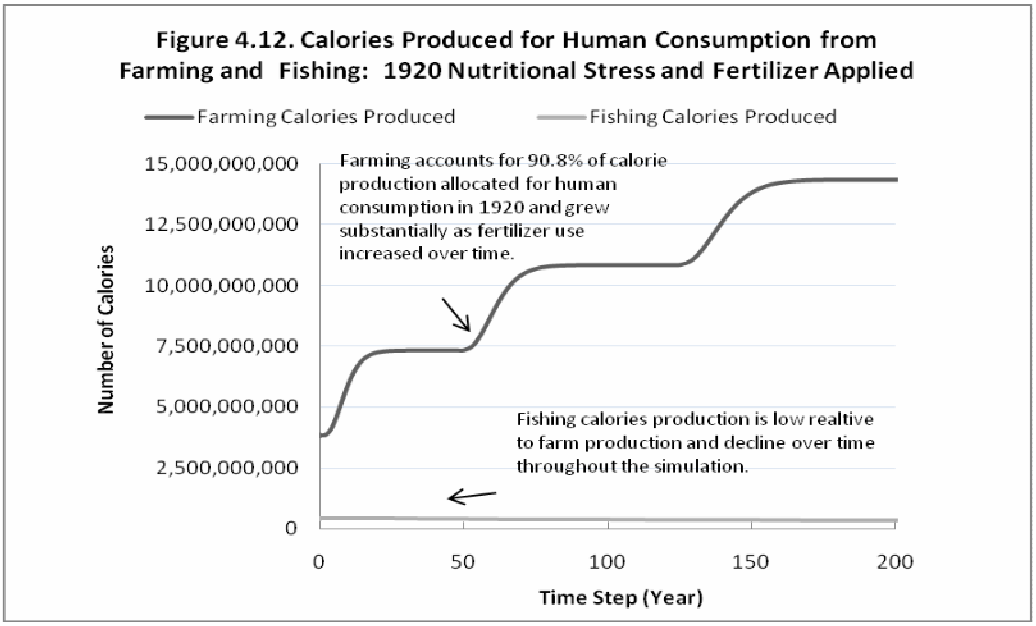


Figure 4.12. Calorie production dynamics after increases in fertilizer use as a step function over time (simulating a new technological advance). Fertilizer improvements increase farm harvest but decrease fish harvests due to damaging effects on estuarine water quality, habitat, and food web dynamics.

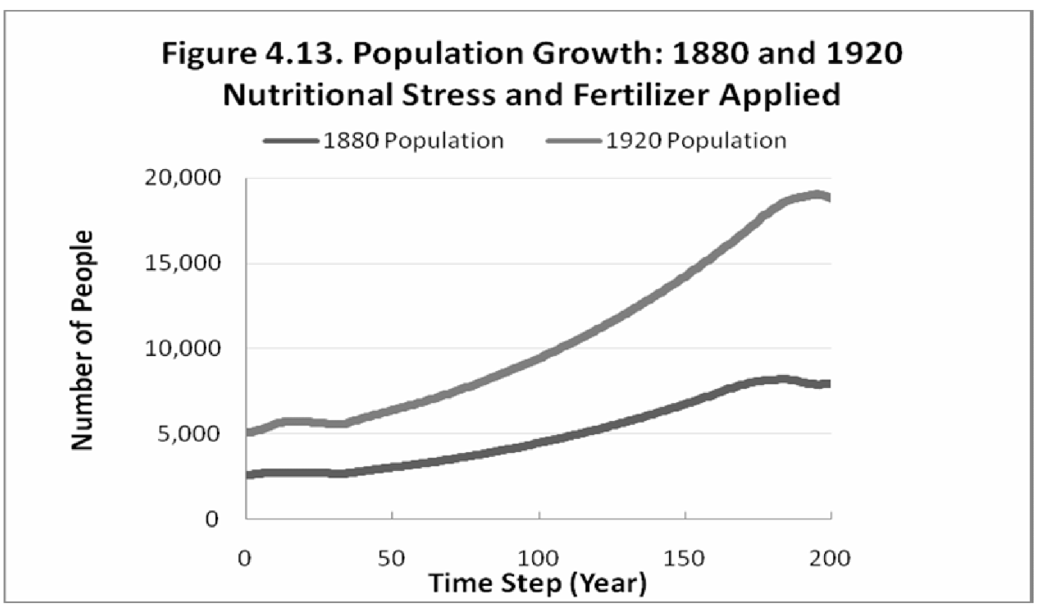


Figure 4.13. Human populations increased in both the 1880 and 1920 system simulations as a function of increased calorie availability due to improved farming technology (e.g., fertilizer use). In absolute terms, the 1920 system was able to support nearly twice as many people as the 1880 system.

Increases in farm productivity also had profound implications on farming economics. While fertilizer use increased farming costs, income grew at even greater levels and net profitability increased substantially. Figure 4.14 demonstrates these increases as well as declines in fishing profits as a function of the damaging effects on the estuarine benthos from fertilizer use. By 100 years into the 1920 simulation (following the third increase in productivity attributable to improved farming technologies), farming income represent 99.5% of system profits. Note that all financial data are reported in terms of 1880 U.S. Dollars to facilitate comparison with NHS-ESVA:1880 simulations. Actual farming net profits in 1920 USD (rather than 1880 conversions) were $1,329,000 in 1920 (the base year in the model) and exceeded $7,500,000 at the peak of technology (fertilizer) enhancement.

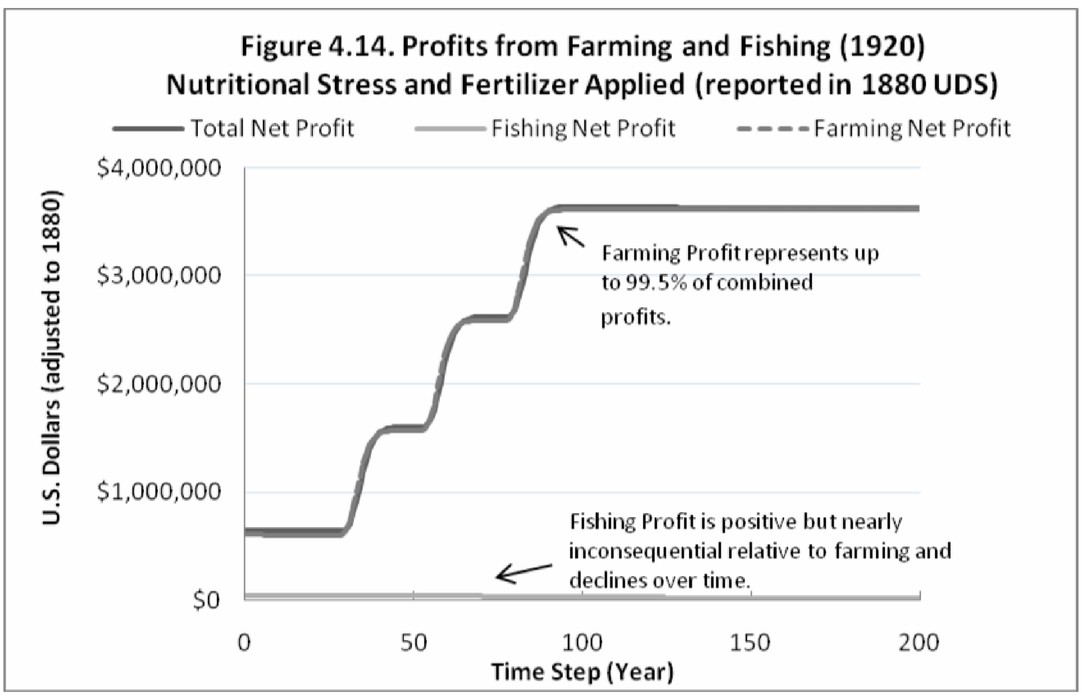


Figure 4.14 shows that farming was responsible for up to 99.5% of profits in the 1920 system. These data are reported in terms of 1880 U.S. Dollars to facilitate comparison with NHS-ESVA:1880 simulations.

In stark contrast, Figure 4.15 shows that farming yielded a net financial loss in the 1880 system even with fertilizer enhancement, offset only by fishing profits (and the avoidance of human and livestock food expenses). Because of increases in overall farm production, more harvest could be allocated to market in 1920 than in 1880 without triggering nutritional stress in the human population. Figure 4.16 simplifies the comparison of 1880 and 1920 economics, showing large differences in system profitability between the two time periods.

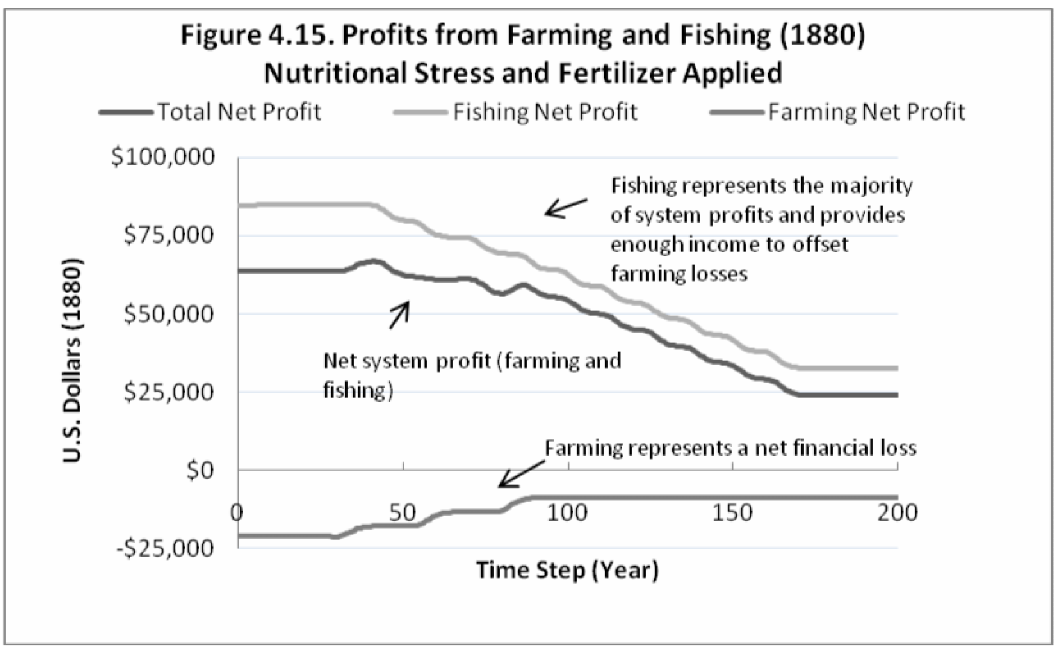


Figure 4.15. demonstrates that in 1880 farming resulted in a net financial loss, offset by modest fishing profits (and substantial calorie production).

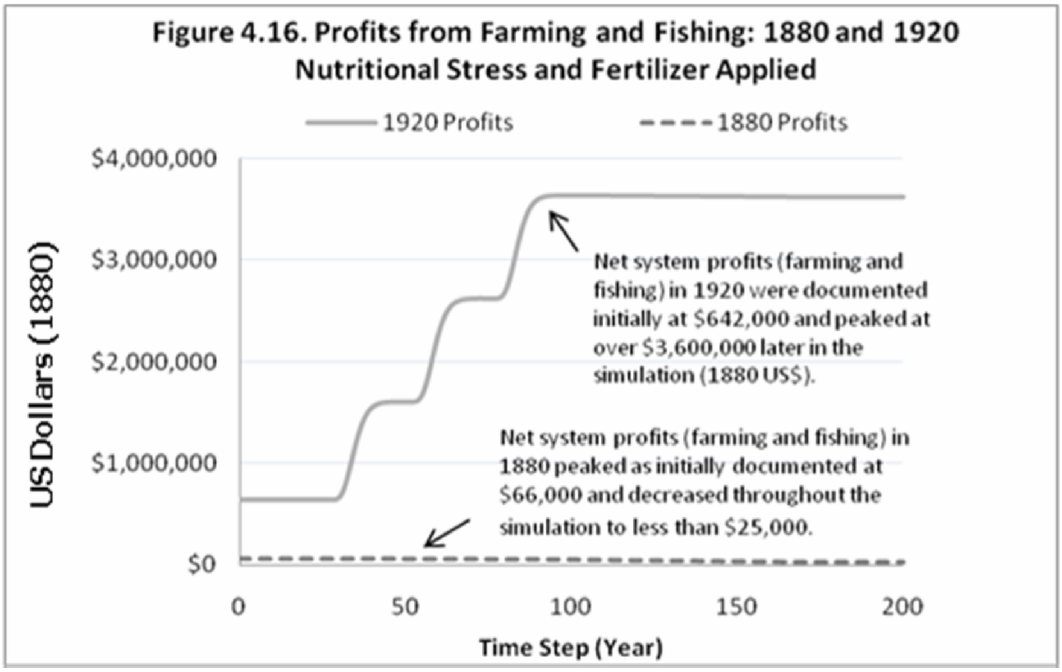


Figure 4.16 shows substantial differences in farming and fishing economics in 1880 and 1920 (see also Figure 4.14 and Figure 4.15). Total system profits in 1880 peaked at $66,000 and decreased throughout the 200 year simulation to less than $25,000. The 1920 system started at $642,000 in profits and increased during the simulation to over $3,600,000 (both reported in 1880 U.S. Dollars).

Isotope data corroborate findings from these historical research and system modeling results. Figure 4.17 shows carbon and nitrogen isotope data for a 72 cm sediment core taken from King’s Creek, a bayside tidal creek in Northampton County (37° 16’ 47 N and 075° 59’ 29 W). These data are interpretable based on the principle of superposition, which implies that, absent disturbance of sedimentary layers, time since deposition increases with core depth (i.e., deeper sediment layers represent older deposits). Accepting sedimentation rates in the lower Chesapeake Bay at 0.22 cm yr^{-1} over the past 200 years (and 0.02 cm yr^{-1} before that) (Cooper and Brush 1993), this 72 cm core then represents the period from 2006 (the top layer from the year the core was extracted) until well before the turn of the 19th century at 72 cm.

Figure 4.17. Carbon and Nitrogen Isotope Composition in Sedimentary Layers of an Eastern Shore Tidal Creek Core (King's Creek)

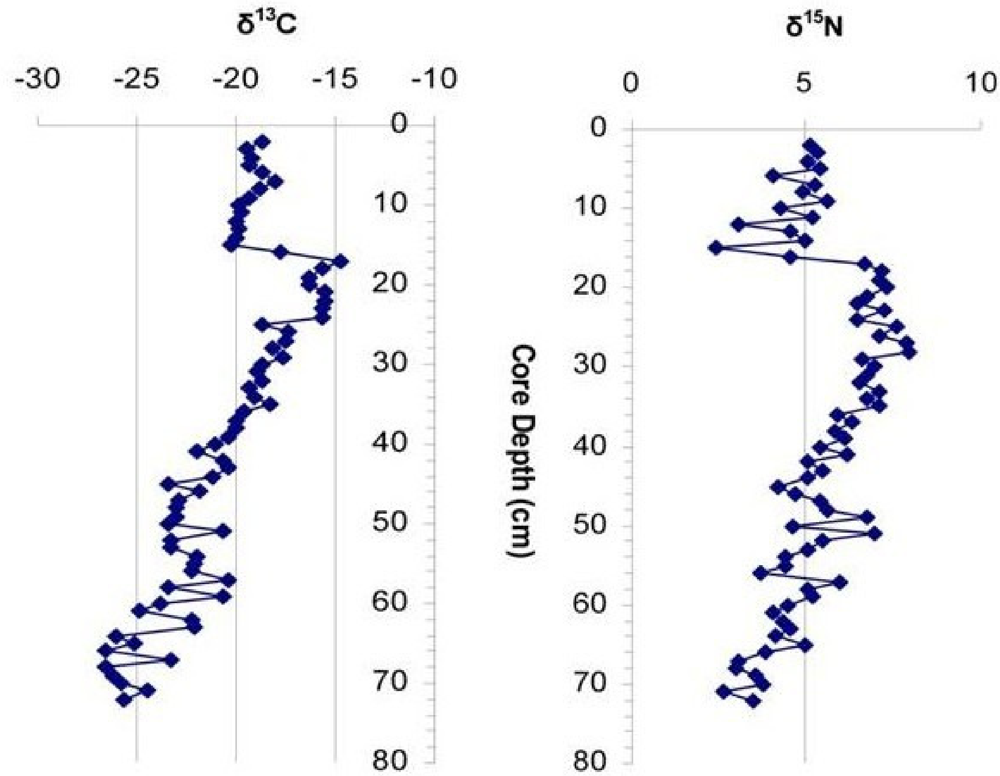
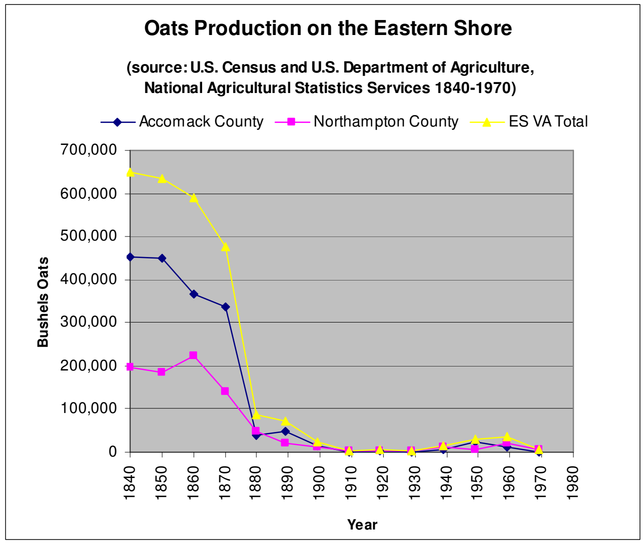


Figure 4.17. Carbon and nitrogen isotope data from a sediment core retrieved from King's Creek, a bayside tidal creek in Northampton County (37° 16' 47 N and 075° 59' 29 W). Periods of isotopic enrichment and depletion strongly corroborate historical data describing system dynamics throughout the 19th and 20th centuries.

$\delta^{13}C$ becomes progressively enriched from the base of the core (72 cm depth) to about 23 cm from the surface (1900) and stays this way until 15 cm from the surface (1938). This signature can be used to infer the presence and relative proportions of C_4 and C_3 photosynthetic plants (Fry et al. 1978), with the C_4 photosynthetic pathway characteristically in the range of –8 to –18 ‰ and the C_3 photosynthetic pathway between –20 to –30 ‰ (Fogel and Cifuentes 1993). Using these ranges, Figure 4.17 shows a record of predominance of C_3 crops that slowly becomes more enriched with C_4 plants until peak C_4 presence between 1900

(23 cm at 0.22 cm yr^{-1}) and 1938 (15 cm), followed by another period of relative depletion (although not as severe). Figure 4.18 presents historical crop data that show the same trend—a predominance of oats (a C_3 plant) decreasing precipitously through the late 19th century and being replaced by corn (a C_4 plant) with a peak in corn production from 1900 through 1940. The substantial presence of other C_3 crops, such as Irish and sweet potatoes, helps to retain the blended signature of –20 ‰ from 40 cm depth to the top of the core (other than during the C_4 corn peak described above). Interestingly, the increase in corn production reported for 1970 is also apparent in the localized enrichment from 8 to 6 cm below the surface (1970-80).



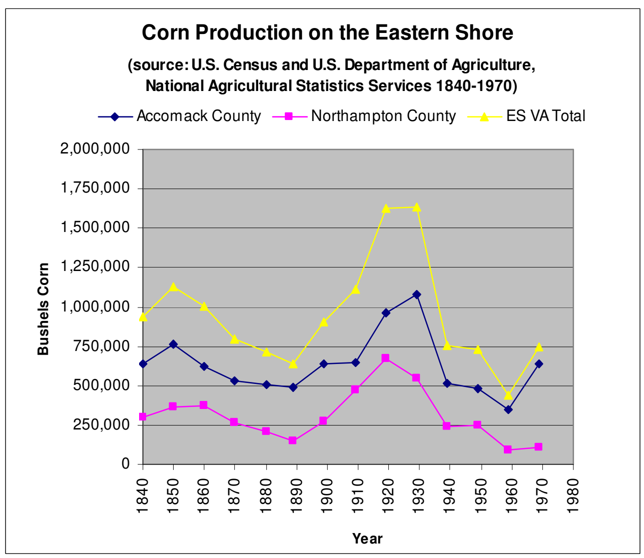


Figure 4.18. δ^{13}C corroborate historical records showing that oat production on the Eastern Shore never recovered following the decline after the Civil War. Corn production also declined following the war and was not to increase again substantially until the turn of the century. Source: U.S. Census and the U.S. Department of Agriculture, National Agricultural Statistics Service, 1840-1970.

Nitrogen isotopes for the same core also reflect values that are consistent with historical land use records for the Eastern Shore. Agricultural soils generally have ^{15}N values of between +3 and +12 ‰ (Macko and Ostrom 1994), whereas human wastewater is more enriched

(+10 to +20 ‰) (McClelland et al. 1997). Most modern commercial fertilizers have a ^{15}N value of 0 ‰ (i.e., there is no fractionation during the Haber process that converts atmospheric N to ammonium) (Fogel and Cifuentes 1993; Macko and Ostrom 1994) although they can commonly range from –3 to +3 ‰ (McClelland et al. 1997). $\delta^{15}N$ values begin at +2.6 ‰ at the core base and trend toward more enriched values (and a peak of +7.9 ‰) at a depth of about 20 cm (1915). This progression is consistent with agricultural soils in general and a fertilizer technology prior to the discovery of the Haber process in 1909 (Hager 2008). The signal is also likely increasingly influenced by human waste in the surface runoff as the population on the Eastern Shore increased through 1930 (Figure 4.19). At 18 cm (1925), there is a sharp depletion in the $\delta^{15}N$ signal from +7‰ to +4‰, which is consistent with the introduction of nitrogen fertilizer produced by the Haber process when commercially factories first appeared in the United States in the early 1920s (Sheridan 1979).

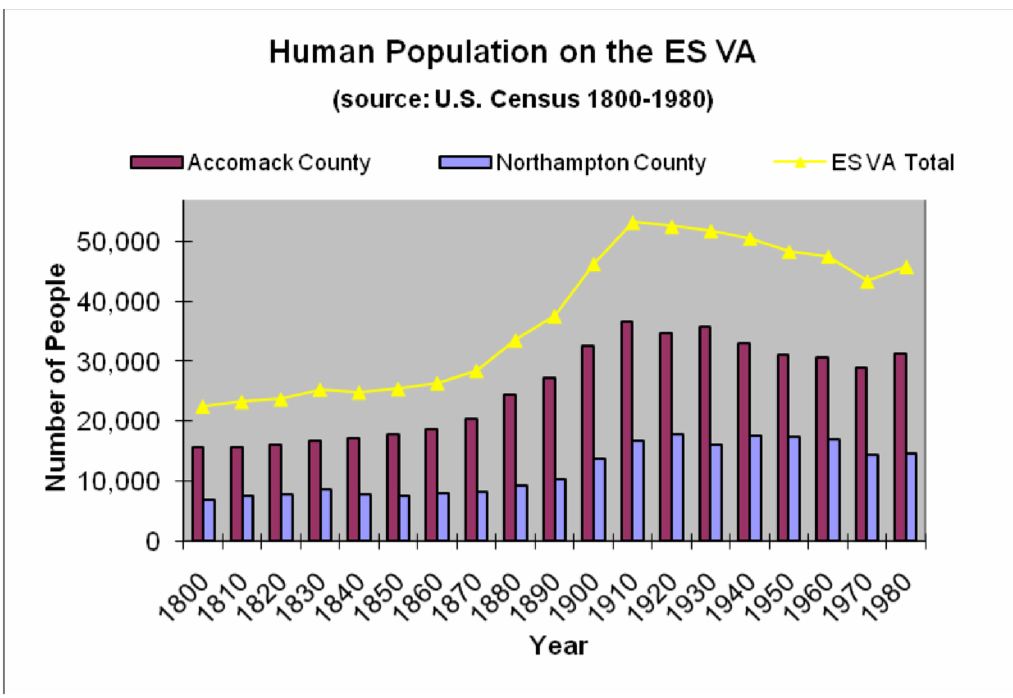


Figure 4.19. The period between 1880 and 1910 represented the highest rate of growth in the human population in recorded history on the Eastern Shore. The population peaked in 1910 and was followed by a slow decline throughout most of the 20th century.

Synthesis

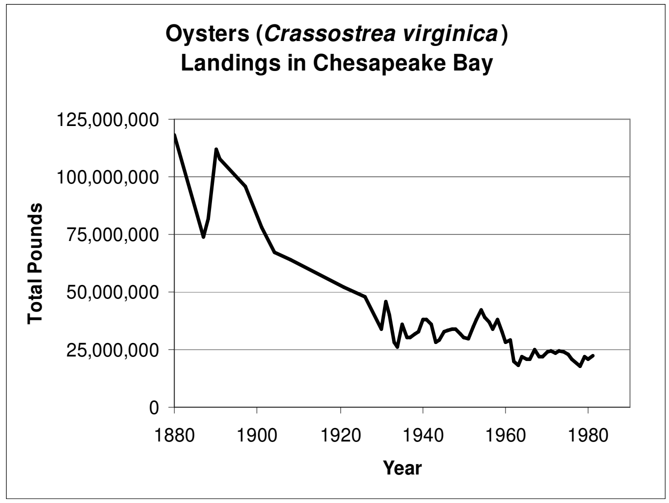


Figure 4.20. Historical landings of oysters (*Crassostrea virginica*) in the Chesapeake Bay, 1880-1981. After Cronin (1986).

The period between 1880 and 1920 was, indeed, a time of great change on the Eastern Shore of Virginia. During this window, the human population increased by 75%, advances in transportation technology (e.g., the railroad) connected the previously isolated peninsula to national economic markets, and advances in farm technology (e.g., fertilizer) improved agricultural productivity by upwards of 300% for many important crops. By 1920, harvests of the most prized catch from the Chesapeake Bay, the Virginia Oyster, was already deep in decline (Figure 4.20); yet, Northampton and Accomac counties boasted the highest value of crop per acre in the nation.

The NHS-ESVA:1880 simulation and the historical data used to parameterize it (as well as isotope data that corroborate its findings) describe a system of subsistence farming supported financially by fishing income. To be sure, agricultural efforts generated enough calories to feed the people and livestock, but farms operated at a net financial loss. Farm production certainly helped to defray costs of purchasing food, but the economics of farming in this manner were not sustainable without another source of income—and on the Eastern Shore in 1880, this source was fishing.

In contrast, historical data and simulation output for 1920 suggests that a new economic model had arisen on the Eastern Shore, driven nearly entirely by profits from farming. In fact, during the forty year window between 1880 and 1920, "family farming" appears to have been transformed into "family businesses." The number of farms on the Shore peaked in 1920, although their size was at its smallest in recorded history (Figure 4.21). Similarly, by 1920 fertilizer expenditures had surpassed labor costs—and a period of intense farming and agricultural productivity marked the times. "Back in 1907," a railroad official was quoted in the a 1919 issue of the Eastern Shore's local newspaper, *The Peninsula Enterprise*, "we used to get a little chill of joy up and down our spinal columns if we could see a million barrels of white potatoes promised at harvest, if we don't get 3,000,000 barrels now we feel sick" (Dean 1919). While data for the 1880 simulation show farm *losses* of $20,859, farming was generating a *profit* of $1,329,000 (or $606,000 in 1880 U.S. Dollars to facilitate comparison between periods).

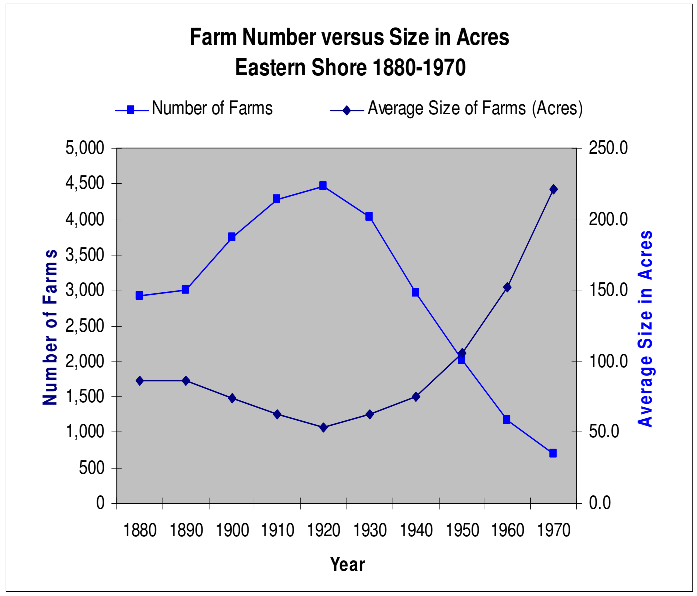


Figure 4.21. The number of farms on the Eastern Shore peaked in 1920, but farm size was at its lowest in recorded history.

Fishing economics, however, had taken another path. In 1880, fishing profits (before costs) approached $85,000 prior to decreasing in the NHS-ESVA:1880 simulation as a function of fertilizer use and overfishing. By 1920, historical data for the model showed profits of only $35,377 (in 1880 Dollars). Whereas 1880 fishing profits had underwritten farm losses and served as the primary source of income in the system, they represented less than 6 % of income in 1920 and decreased to less than 0.5% throughout the NHS-ESVA:1920 simulation. Fish harvest weight had not decreased dramatically, but the species being caught (e.g., menhaden) were not nearly as valuable at market as oysters had been 40 years earlier.

Conclusions

> *The economic history of the Eastern Shore has been greatly affected by both its natural characteristics and its location. Each has and good and bad effects, with the very advantages carrying with them serious disadvantages in a bewildering juxtaposition. For instance, the sea and bay provide a boundless resource of commercially desirable species; yet in these days of the dominance of terrestrial transportation, they lead to isolation from major markets in the area.*
>
> ― Burrel et al. 1972

The social, economic, and natural history of the Eastern Shore of Virginia did, indeed, reflect a bewildering juxtaposition of advantages and disadvantages resulting from its geographically location, which simultaneously isolates its people and yet provides them with an abundance of natural resources.

The Natural-Human System: Eastern Shore of Virginia (NHS-ESVA) model is presented as a tool for helping to clarify some of the relationships between people and their environment. It integrates historical records, isotope data, and systems modeling to explore the intended and unintended consequences of human activity within the natural-human system. Through the use of structurally identical models that are parameterized for different time periods during a particularly intense window of change (1880 and 1920), NHS-ESVA describes the impact of advances in transportation (e.g., the railroad) and farming (e.g., fertilizer use) technologies on system dynamics. This explanatory model enables in-depth analysis and description of system properties and process which, hopefully, can contribute to larger-scale biogeophysical models of the Chesapeake Bay watershed and enlighten policy and personal choices for resource use.

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Chapter 5. Extending Ecosystem Theory to Include Economic Information and Market Forces in Natural-Human Systems: A Case Study of the Eastern Shore of Virginia in 1880 and 1920

Abstract

Ecosystems have traditionally been defined based on spatial boundaries that enclose interacting biotic and abiotic entities in "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit" (Watson and Zakri 2003). This paper proposes an extension of the ecosystem concept to incorporate intangible, but critically important, aspects of human information sharing that factor substantially into system dynamics. An example of this type of information exchange occurred in a geographically isolated natural-human system on the Eastern Shore of Virginia between 1880 and 1920. In this example, the natural-human system was substantially affected by human awareness of external markets for agricultural commodities—and although there was no physical flow of materials with distant economic competitors, information about competition in a shared marketplace had profound implications on crop selection, farming intensity, and system dynamics. These "externalities", which might not be considered a part of an ecosystem by traditional geographic and material-transport definitions, nonetheless, had a significant effect on both the biotic and abiotic components of the ecosystem—and raise the question of whether it may be necessary to extend the definition of the ecosystem concept to include information that guides human decisionmaking.

The Ecosystem Concept

In an effort to keep ecological study tractable, researchers have traditionally endeavored to set geographical or physical boundaries on their study sites. Components and processes that existed within these boundaries would be considered a part of the system and studied either experimentally or observationally. Alternatively, features outside the system would not be considered. For example, a study of biogeographics might look at a lizard population on an island but, by definition, consider all lizards not living on the island to be outside of the system and, therefore, beyond of the scope of the study. Thus, even though lizards might be living on other islands, the system of study is considered "closed" for practical purposes at the physical border between the island and the surrounding water. Similarly, although heat or hours of daylight might affect the dynamics of the lizard population on the island and, therefore, be explicitly addressed in the study, the source of that heat and light energy (the sun) would not be considered to any great extent other than as manifested by the arrival of sunlight to the island. Setting such biogeophysical and intellectual boundaries often makes sense and, in many cases, is the only realistic way to study a system without becoming overwhelmed by the countless connections between one set of components and process and the rest of the systems in the universe.

One concept used by ecologist to set reasonable boundaries on systems of study is the "ecosystem." Shugart (1998) traces the concept's origins back to the Greek naturalist and philosopher Theophrastus (c. 370 to 285 BC) and, more recently, Möbius' "biocoenosis" (1877), Forbes' "microcosm (1897), and Dokuchaev's "biogeocoenosis" (1889), prior to the first use of the term "ecosystem" by A.G. Tansley in 1935. Since that time, Lindeman (1942), Odum (1953), and others have extended the definition of an ecosystem, which has more recently been defined as "a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit" (Watson and Zakri 2003). Abel and Stepp (2003) contributed to the advancement of the term with a focus on an enduring controversy associated with ecosystem concept—geographical size: asserting that an ecosystem can be "any size so long as organisms, physical environment, and interactions can exist within it...[It can] therefore be as small as a patch of soil supporting plants and microbes; or as large as the entire biosphere of the Earth."

The wide range of scales at which systems interact has further complicated the recent evolution of the ecosystem concept. Elser and Steuerwalt (2001) define "biocomplexity" as the "complex interplay between biological life and the physical environment [that] transacts at multiple spatial and temporal scales, is characteristically difficult to predict, and must be studied both as a whole and piece by piece." The intricacy, depth, and density of such a concept invites new ways of viewing system properties and dynamics and, in a human dominated world, requires the incorporation of social, economic, and cultural aspects of human activity in addition to strictly, and more traditionally studied, biogeophysical components of natural systems (Vitousek et al. 1997).

Economics and Ecosystems

Since its emergence as a field of study, a primary goal of ecology (particularly in its early stages) has been to understand the rational use and development of natural resources, sometimes referred to as "natural capital" or the "economy of nature" (DiCastri 2000). Similarly, modern economics traces its origins to the natural sciences when early thinkers began deliberating the many dimensions of natural resource use, management, and efficiency (Norgaard 2000). Thus, it is not surprising that economics has long been recognized as a factor in ecological and systems study (e.g., Odum et al. 1959), but properly accounting for man's place in nature beyond traditional foci on resource extraction has been a great challenge (Kangas 2004). Anthropogenic activities, including farming, fishing, manufacturing, pollution, and urbanization, have radically transformed "natural" landscapes and exerted profound effects on the structure and function of ecosystems (Millenium Ecosystem Assessment 2003).

Precisely because of the interconnectedness of man and environment, Lacitignola (2007) argues that the analysis of socio-ecological systems requires "an integrated assessment of ecological, social, and economic factors." Chapter 3 and Chapter 4 present just such an approach to studying natural-human system dynamics on the Eastern Shore of Virginia, a unique geophysical location and social structure set at the interface of terrestrial and estuarine systems and, perhaps, best defined by is its proximity to, and dynamic relationship with, both the Chesapeake Bay and the Atlantic Ocean. The product of this research is the Natural Human Systems: Eastern Shore of Virginia (NHS-ESVA) model, an analytical tool that integrates historical data (e.g., U.S. Census records), isotope analysis, and systems modeling to clarify some of the complex relationships between people and their environment, terrestrial and estuarine systems, and biotic and abiotic processes on the geographically isolated peninsula. NHS-ESVA was used to explore the intended and unintended consequences of human activity within the natural-human system during two different time periods that represent a particularly intense window of change (1880 and 1920). It examines the impact of advances in farming technologies (e.g., fertilizer) that greatly multiplied agricultural productivity as well as the introduction of new transportation technologies (e.g., the railroad) that, for the first time, enabled the rapid delivery of Eastern Shore fruits, vegetables, and seafood to markets in New York in twelve hours, Boston in 20 hours, and Montreal in 30 hours (Thomas, Barnes, and Szuba 2007). This access to national markets changed farming on the Eastern Shore in dramatic ways. For example, although oats had been profitable from the 1840s to the 1880s, the extension of the railroads from the Eastern cities into the fertile lands of the West so cheapened the commodity that Eastern Shore farmers could no longer sell their “staple” crop in Baltimore, Philadelphia, and New York (Nock 1900). They responded by planting white and sweet potatoes in an effort to become more competitive. In 1870, less than 300,000 bushels of sweet potatoes were produced in Accomac and Northampton counties, whereas by 1900 over 2.5 million bushels were harvested on route to a peak of nearly 4.2 million by 1920. During the same period, Irish potato production increased from 159,346 bushels (1870) to more than 1.2 million in 1900 and over 7.5 million in 1920 (U.S. Census 1870-1920).

The economic incentive driving land use decisions on the Eastern Shore were substantial: Between 1870 and 1920 the average value of farmland rose from $15 to $197 per acre in Northampton County and $16 to $137 in Accomac (compared to an average of $55 per acre in the state of Virginia). Moreover, Accomac boasted the highest per capita income of any non-urban county in the United States in 1910 and Northampton and Accomac had the highest crop value per acre in the nation in 1919 (Thomas, Barnes, and Szuba 2007). While access to national markets via the railroad fueled much of these gains, farmers used fertilizer and other technologies to greatly increase productivity—Eastern Shore farms yielded 29.1 bushels of corn per acre in 1919 compared to 7.9 in 1880 (a 368% increase in productivity). Similar gains were seen in Irish potatoes (a 300% increase) and sweet potatoes (a 294% increase). Finally, and not insignificantly, this period of increased farming intensity was tightly linked with changing dynamics in the Chesapeake Bay. Although not authoritatively established until late in the 20th century, the introduction of European land use practices (i.e., deforestation, plough pans, fertilizer use, erosion, and runoff), generated greater freshwater discharge (Bosch and Hewlitt 1982), sedimentation rates (Pasternack et al. 2001), and nutrient loads from fertilizers in surface runoff (Cerco et al. 2002). The consequences to the estuary include increases in eutrophication, turbidity, vertical stratification, and benthic anoxia, thereby transforming the benthos from a metazoan to microbially dominated food web (Cooper 1995).

Clearly, the Eastern Shore of Virginia had few or no tangible links with Midwestern farmers (i.e., no materials flowed directly between the two regions), yet sharing a marketplace in the large Eastern cities led directly to competition-driven land use decisions on the peninsula and, as described above, less directly (but significantly nonetheless) to ramifications on the estuarine system as well.

Extending the Ecosystem Concept

Assessing natural-human system dynamics demands not only an understanding of the biogeophysical components of the system, but also relevant human dimensions (both impacts and responses), including population growth, resource consumption, land use decisions, and technological advances (Raven 2002). Failure to account for these capacities can lead to exaggerated or otherwise faulty appraisals of system dynamics. For example, Malthus' famous 1798 prediction of imminent and recurring vice and misery facing human societies (war, famine, and disease) was predicated on the assumption that "population increases in a geometric ratio… while the means of subsistence increases in an arithmetic ratio" (Landry 2001). This assertion famously fails to account for human capacity to think—i.e., to alleviate misery through laws (e.g., land use), social standards (e.g., sanitation), and technological advances (e.g., enhanced productivity through improved farming practices). In a similar way, a comprehensive understanding of land use decisions on the Eastern Shore between 1880 and 1920 (and ever since) demands an awareness of the information about market competition that informed decisions by individual farmers. The ramifications of using this information (e.g., changing crop selection and farming intensity) not only affected the terrestrial system, but also had an impact on estuarine properties and processes.

Stepp et al. (2003) advocate consideration of these types of "remarkable properties" of human ecosystems, including the integration of belief systems, into ecological analysis. The history of the Eastern Shore of Virginia is presented here as an intellectual tractable example of how such an intangible concept can have a substantial impact natural-human system dynamics. Other examples of human thoughts leading to activities that modify the structure and function of ecosystems include: (1) globalization that integrates the flow of trade, capital, labor, and information as well as the policies that facilitate such flow in the form of reduction of barriers on trade, financial transactions, and migration (Aggarwal 2006); and (2) sustainability initiatives that modify resource extraction and use to reflect beliefs about the balance between the current use of natural resources and the preservation of resources for future use (Lambin 2005).

Conclusions

Most researchers believe that the future impact of human activity is both global and increasing (e.g., Western 1998; Kareiva 2007; and numerous others). Vitousek et al. (1997) contribute to such a claim when highlighting the degree of human influence on the environment. For example, between one-third and one-half of the Earth's land surface has been transformed by human action; the carbon dioxide concentration in the atmosphere has increased by nearly 30 percent since the beginning of the Industrial Revolution; more atmospheric nitrogen is fixed by anthropogenic activity than by all natural terrestrial sources combined; more than half of all accessible surface fresh water is used by people; and about one-quarter of the bird species on Earth have been driven to extinction. Lash (2001) adds that one half of the world's jobs depend on fisheries, forests, or small-scale agriculture, yet two-thirds of the world's fisheries are being harvested beyond sustainability, forest loss is accelerating, and soil degradation is widespread and worsening. Other "side effects" of human activities include simplified food webs, homogenized landscapes, and high nutrient inputs and imbalances. By these and other standards, it is clear that we live on a human-dominated planet. In fact, Kareiva et al. (2007) assert that there is no longer such thing as nature untouched by human influence and, perhaps more disquieting, Western (1998) argues that such human modification of ecosystems will have tremendous effects on natural systems and biological life and may, in fact, largely determine the future course of evolution.

In other words, the information that guides human activity is a critical component of a human dominated and richly complex Earth system. Just as ecosystems change, so too should our definition of the ecosystem concept. Extending the definition to include information that guides human decisionmaking is simply the acceptance of yet another dimension and scale of ecosystem study.

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Chapter 6. NHS-ESVA (1880 and 1920): Summary, Implications, and Next Steps

Introduction and Overview

This investigation of complexity examines people as a critical component of the natural system on the Eastern Shore of Virginia during a period of intense technological, social, and environmental change: 1880 - 1920. During this 40 year period, socio-economic pressure in the form of farming and fishing practices placed substantial stress on the terrestrial and estuarine systems. These successive time periods are also characterized by the use of distinctive (and advancing) human technologies which, in practice, affected the intensity and scale of anthropogenic pressure on the system and, in theory, contributed to system dynamics that potentially transcended conventional scales of social and environmental study. The most obvious example of this transformation was the arrival of the railroad down the spine of the peninsula in 1884. This significant transportation technology connected Eastern Shore agricultural products and estuarine harvests to markets throughout the vast majority of the United States, and changed both the local and national perspectives of inhabitants of the Shore. The emergence and pace of changing technologies framed the selection of the two time periods modeled in this study, with a goal of reflecting different technology regimes that contributed uniquely to the natural-human systems in 1880 and 1920.

Overcoming barriers to interdisciplinary study is vital to the study of complex natural-human systems (Lele and Norgaard 2005; Norgaard and Baer 2005) because the interconnectedness of man and environment demands “an integrated assessment of ecological, social, and economic factors” (Lacitignola 2007). In addition to reflecting biogeophysical data characteristic of traditional environmental modeling efforts, this project incorporates highly detailed demographic, agricultural, fishing, and economic/market data from the U.S. Census of Agriculture and the U.S. Population Census in both 1880 and 1920. It also relies on a wide range of corrollary historical sources for data and descriptions of socio-economic dynamics during the period of study. These data are the foundation of this analysis and serve as an example of overcoming the challenges of identifying empirical data when studying complex systems as described by Brown et al. (2008).

As such, this assessment of the rich and complex natural-human system on the Eastern Shore of Virginia:

- ✓ begins with a review of human history;
- ✓ is advanced by stable isotope evidence; and
- ✓ is explored in depth through detailed systems modeling (Figure 6.1)

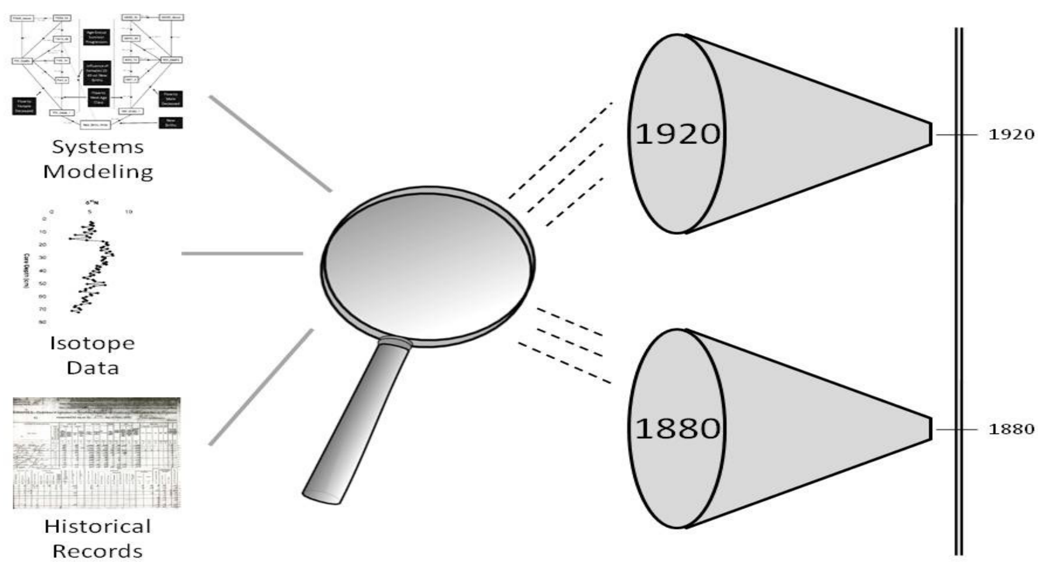

Figure 6.1. Historical records, isotope data, and systems modeling are individually powerful analytical tools but, in combination, greatly amplify our understanding of system dynamics.

More specifically, in this study, the natural-human system on the Eastern Shore of Virginia is characterized, quantified, and simulated via a multiple commodity model structure parameterized with historical, ecological, and physical data that enable the simulation of system dynamics in 1880 and 1920. The Natural-Human System - Eastern Shore of Virginia (NHS-ESVA) model was parameterized for 1880 (NHS-ESVA:1880) and 1920 (NHS-ESVA:1920) for the Franktown Enumeration District, a politically defined geophysical unit in northern Northampton County, Virginia (Figure 6.2). The NHS-ESVA model simulates energy balances, human population dynamics, terrestrial land use and harvest, estuarine productivity, critical technological and economic components influencing farming and fishing activities, and links between terrestrial and estuarine systems on the Eastern Shore of Virginia (Figure 6.3).

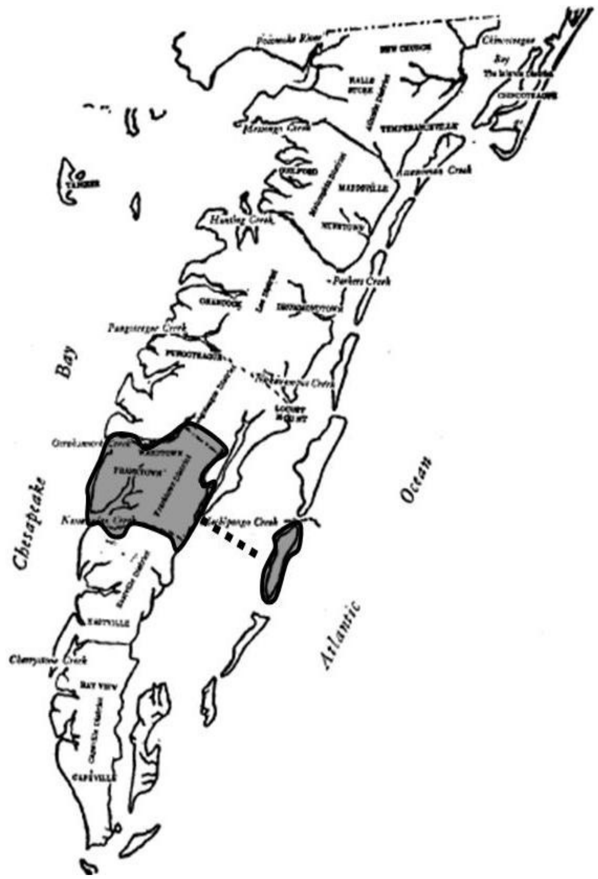

Figure 6.2. The Franktown Enumeration District (shaded) lies entirely within Northampton County, includes Hog Island, and is bounded by Accomack County to the north and the Eastville Township line to the south. After Turman (1964).

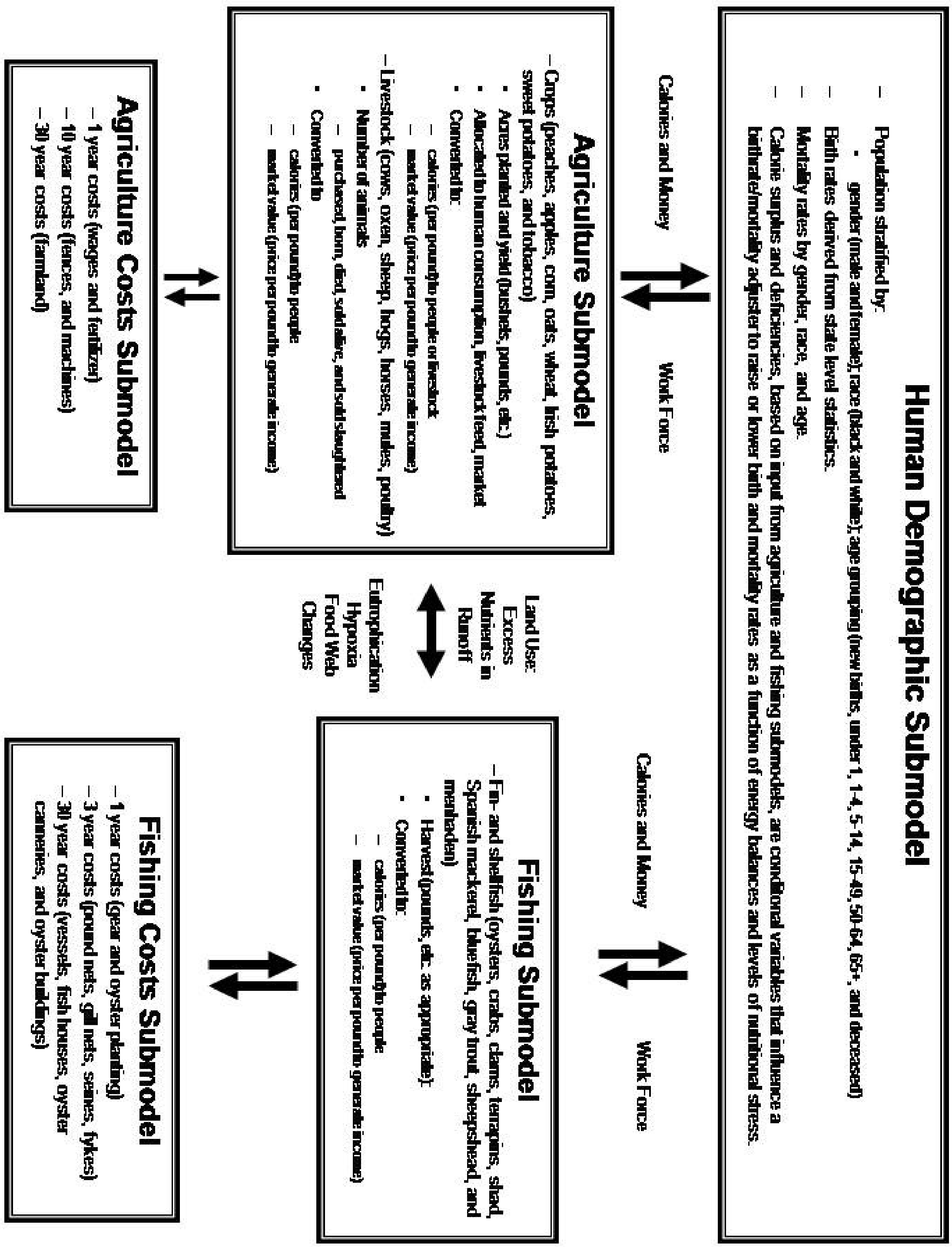

Figure 6.3. Conceptual overview of the NHS-ESVA model as more thoroughly described in Chapter 3. The model incorporates a human demographic model and four linked submodels that simulate terrestrial land use and agricultural productivity (farming), farming costs, estuarine productivity (fishing), and fishing costs.

Research Approach Conclusions

Tables 6.1 – 6.3 document the findings of this research relative to its original objectives, key questions, and hypothesis.

Table 6.1. Study Objectives

Study Objectives	Summary of Analysis
1) To characterize, quantify, and model the natural-human system on the Eastern Shore of Virginia in 1880 and 1920 via a single multiple commodity model structure. a. To parameterize the multiple commodity model with historical, ecological, and physical data that accurately depict the 1880 time period/technology regime. b. To parameterize the multiple commodity model with historical, ecological, and physical data that accurately depict the 1920 time period/technology regime.	ACCOMPLISHED NHS-ESVA represents a single model structure that, when parameterized by time period/technology regime (1880 and 1920), characterizes, quantifies, and simulates complex dynamics of the natural-human system on the Eastern Shore of Virginia. Methods for constructing and parameterizing NHS-ESVA:1880 and NHS-ESVA:1920 are discussed in Chapter 3 and Chapter 4, with supporting documentation about data sources presented in Appendix A and Appendix B. Source code is provided in Appendix C and Appendix D.
2) To simulate system dynamics during these two time periods (represented by the years 1880 and 1920). a. To assess system properties for the 1880 period/technology regime. b. To assess system properties for the 1920 period/technology regime. c. To compare and contrast 1880 and 1920 periods/technology regimes.	ACCOMPLISHED The findings of the NHS-ESVA:1880 and NHS-ESVA:1920 model simulations are presented in Chapter 3 and Chapter 4.
3) To establish an isotopic signature of the Eastern Shore as recorded in sediment cores from a bayside tidal creek. a. To assess whether this isotopic record is consistent with model simulation findings as well as our historical understanding of system dynamics.	ACCOMPLISHED Carbon and nitrogen isotope data and analysis are presented in Chapter 4.

Table 6.2. Key Questions

Key Questions	Summary of Analysis
1) For each time period/technology regime simulated by the multiple commodity model: a. Is the natural-human system in the Eastern Shore of Virginia stable and/or heading toward an equilibrium trajectory? b. Does the introduction of advancing technologies change system stability or equilibrium trajectories? c. If the system is stable, how, and to what degree, does the system demonstrate resistance to change (i.e., the system's internal inertia relative to external perturbations)? d. If the system is stable, how, and to what degree, does the system demonstrate resilience following change (i.e., the time required to return to its original state after being disturbed)?	A. Although the human population plateaus upon the application of nutritional stress, there is no evidence that the system is stable with respect to human population, farm production, estuarine harvests, or profitability. B. Findings and analysis from NHS-ESVA demonstrate how changing technologies (e.g., the introduction of the railroad in 1884 and the intensification of fertilizer use) lead to substantially different system dynamics. C & D. There was no evidence of stability, so these questions were not assessed.
2) How, and to what degree, do measured system properties vary between advancing time periods/technological regimes, as assessed by comparing output from models parameterized for 1880 and 1920?	Findings from the 1880 and 1920 simulations are presented in Chapters 3 and 4. With respect to particularly critical system properties, simulations show that: (1) 1880 calorie production for human consumption is more than doubled in the 1920 system. (2) 1880 profits were driven by fishing while farming activities were a net financial loss; 1920 system profits are driven nearly exclusively by farming and demonstrate an increase over the 1880 simulation by an order of magnitude.
3) What is the geochemical signature of the study catchment as established by sediment cores from a tidal creek in the study area? a. What is the $\delta^{13}C$ record in the sediments? b. What is the $\delta^{15}N$ record in the sediments? c. Are these data consistent with model simulations and our historical understanding of system dynamics?	A. $\delta^{13}C$ becomes progressively enriched from core base to 23 cm from the surface (1900) and stays this way until 15 cm (1938), which suggests C_3 crop predominance (e.g., oats) that slowly becomes more enriched with C_4 plants (e.g., corn) until peak C_4 presence between 1900 and 1938. B. $\delta^{15}N$ values begin at +2.6 ‰ at the core base and become more enriched to +7.2 ‰ until about 20 cm (1915). At 18 cm (1925), there is a sharp depletion in the $\delta^{15}N$ signal from +7‰ to +4‰. C. As discussed in Chapter 4, both carbon and nitrogen corroborate historical data and model simulations.

Table 6.3. Hypotheses

Hypotheses	Summary of Analysis
$H1_o$: The 1880 simulation will demonstrate system stability with respect to human populations, estuarine harvests, and farm productivity.	Rejected: Although human population plateaus upon the application of nutritional stress, there is no evidence that the system is stable with respect to human population, farm production, estuarine harvests, or profitability.
$H2_o$: The 1920 simulation will demonstrate system stability with respect to human populations, estuarine harvests, and farm productivity.	Rejected: Although human population plateaus upon the application of nutritional stress, there is no evidence that the system is stable with respect to human population, farm production, estuarine harvests, or profitability.
$H3_o$: The introduction of advancing technologies will not change measures of system stability.	Because system stability was not indicated, this hypothesis could not be assessed.
$H4_o$: Both time period/technology regime simulations (represented by the years 1880 and 1920) will produce similar measures of stability, regardless of the time period and technological advances.	Because system stability was not indicated, this hypothesis could not be assessed.
$H5_o$: The $\delta^{13}C$ record in the tidal creek core sediments will not change significantly with respect to time (core depth).	Rejected: The $\delta^{13}C$ record was interpreted to change over time (core depth) in a meaningful manner.
$H6_o$: The $\delta^{15}N$ record in the tidal creek core sediments will not change significantly with respect to time (core depth).	Rejected: The $\delta^{15}N$ record was interpreted to change over time (core depth) in a meaningful manner.

Janssen and Ostrum (2006) describe the difficulty of collecting and analyzing data about social systems over time and present four criteria for evaluating efforts to do so. These criteria are appropriate for assessing the value of the NHS-ESVA model:

(1) *Is the model plausible given our understanding of the processes?* NHS-ESVA was developed based on a large body of historical data—more than 55,000 individual data points and over 300 aggregate items from the U.S. Census of Agriculture and the U.S. Population Census in 1880 and 1920. These data were self-reported to Census enumerators by the people living, farming, and fishing in the system during the period of study. Interpretation of these data are enhanced by a deep and thorough review of additional historical resources that describe many facets of the time periods of study. In turn, historical data are corroborated by isotope data for the study setting, which increases confidence in the interpretation of findings and conclusions. As such, conclusions from model simulations that extend our understanding of system dynamics appear to be credible and defensible.

(2) *Can we understand why the model is doing so well?* Confidence in NHS-ESVA simulation results is based largely on confidence in the quality of the data used to construct and parameterize the model. As described above, the model relies heavily on U.S. Census data, which Moceri et al. (2001) recognize to be a source of high quality socioeconomic data from historical periods dating as far back as 1920 and earlier. The model also reflects detailed data and information from a wide range of research perspectives (e.g., human history, economics, stable isotope geochemistry, ecology, and systems modeling) which, when integrated via model simulations, provides a rich and broad perspective through which to assess system dynamics and properties.

(3) *Did we derive a better understanding of our empirical observations?* Census data used in this study have been available to researchers for decades. While many historians have used Census data to study a wide range of socio-economic topics, the understanding of these pieces of data is enriched tremendously through the integrative power of the NHS-ESVA model. Simulations presented in this study have helped to improve our understanding of the complex dynamics of the natural-human system in a way that cannot realistically be accomplished through the analysis of individual data elements in Census records.

(4) *Does the behavior of the models coincide with the understanding of the relevant stakeholders about the system?* The strongly interdisciplinary approach to this project permits a wide range of dynamic processes to be incorporated into the construction and interpretation of NHS-ESVA simulations, including features from traditionally independent disciplines such as ecology, hydrology, geography, isotope geochemistry, history, demographics, and economics—all integrated through the use of advanced systems modeling. Although additional perspectives may be incorporated in greater detail in future applications of NHS-ESVA, the existing model reflects a broad spectrum of relevant research and stakeholder perspectives.

Summary of Project Findings

Findings from historical research that help to frame the interpretation of NHS-ESVA simulation results include:

- ✓ The period between 1880 and 1920 was a time of great change on the Eastern Shore of Virginia
    - o the human population increased by 75%
    - o advances in transportation technology (e.g., the railroad in 1884) connected the previously isolated peninsula to national economic markets
    - o advances in farm technology (e.g., the intensity of fertilizer use) improved agricultural productivity during the 40 year period of study by upwards of 300% for many important crops
    - o by 1920, substantial declines had already been realized for the harvest of the most prized catch from the Chesapeake Bay, the Virginia Oyster

As described in much greater detail in Chapter 3 and Chapter 4, some of the major conclusions of the NHS-ESVA simulations for 1880 and 1920 include:

- ✓ With respect to the NHS-ESVA:1880 simulation:
    - o agricultural efforts generated enough calories to feed the people and livestock
        - nutritional stress had disproportionate effects on white and black populations
    - o farms operated at a net financial loss, eventually reaching -$8,700 annually in the 200 year simulation
        - farm production defrayed costs of purchasing food, but the economics of farming were not sustainable without another source of income

- despite evidence of overfishing prior to 1880, fish harvests were the primary source of system profits, approaching $32,000 in the simulation

✓ With respect to the NHS-ESVA:1920 simulation:

- calories for human consumption from agricultural production more than doubled between the 1880 and 1920 simulations—generating enough calories to fully support the human population and farm livestock, while still allowing farmers to send a greater percentage of their harvests to market
- a new economic model was established on the Eastern Shore, driven nearly entirely by farming profits, which exceeded $3,600,000 (in 1880 USD) in the 200 year simulation
  - family farming had become family business (and business was good)
- fishing profits declined to just over $11,000 (in 1880 USD) in the simulation due to pressures from estuarine habitat loss (i.e., terrestrial-estuarine coupling), as well as overfishing and declining market prices

But perhaps the greatest change on the Eastern Shore of Virginia between 1880 and 1920 was the introduction of the railroad down the spine of the peninsula in 1884—connecting the Eastern Shore culture as well as its farming and fishing commodities to Delmar, Delaware, and, by extension, the rest of the nation. Historical records describe great changes on the Eastern Shore following the arrival of the railroad including, for example, village life that once was centered on the bay- and sea-side wharves was relocated to towns that arose around the 28 train depots down the peninsula. Moreover, the products of the region's farming and fishing harvest could now be transported to large northeastern markets quickly and in great quantity (e.g., to New York in 12 hours, Boston in 20 hours, and Montreal in 30 hours)

(Thomas, Barnes, and Szuba 2007). Historical data and NHS-ESVA model simulations show that this advance in transportation technology appears to have provided a market that drove increasingly intense farming practices (including, for example, increased fertilizer use) which had significant direct and indirect effects on system dynamics. While unknown (at the time) terrestrial-estuarine couplings resulted in habitat loss and decreased fishery production in the Chesapeake Bay over time (compounded by overfishing), farm production and profitability increased tremendously. With respect to system economics, for example, the 1920 system generated increases in income by more than an order of magnitude relative to the 1880 system. Moreover, the primary source of income in 1880 had been fishing, which had supported otherwise unsustainable losses from farming. By 1920, farming was the primary source of income. Thus, a comparison of the 1880 and 1920 system simulations shows not only great change in the magnitude of production, but also an exchange of the primacy of farming and fishing in driving economic productivity.

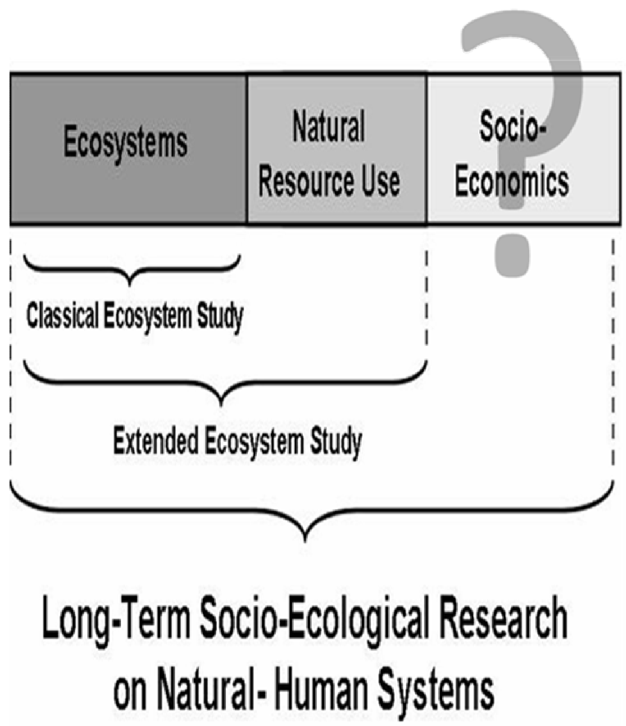

Figure 6.4. This work incorporates socio-economic data into ecosystem study to create a model of the coupled natural-human system—answering a challenge from Haber et al. (2006) to the scientific community and serving as an example of the analytical potential of this type of interdisciplinary study.

Implications

Haber et al. (2006) challenged the scientific community to extend systems research beyond traditional foci of ecology and natural resource use and to incorporate socio-economic components (Figure 6.4). This call to broaden the scope of systems study is not achieved when socio-economic data is simply added to biogeophysical models but, rather, when it is fully integrated as necessary to incorporate humans as critical components of the natural-human system—as accomplished in NHS-ESVA.

In addition to responding to Haber's challenge, this work achieves many of the goals set forth by the National Science Foundation for its biocomplexity research initiative. More specifically, and quite significantly, NHS-ESVA accomplishes the following goals stated by NSF for advancing the study of the complex dynamics of coupled natural and human systems (http://www.nsf.gov/about/budget/fy2007/pdf/9-NSF-WideInvestments/39-FY2007.pdf):

- ✓ synthesize environmental knowledge across disciplines, subsystems, time and space;
- ✓ discover new methods, models, theories, and conceptual and computational strategies for understanding complex environmental systems;
- ✓ develop new tools and innovative applications of new and existing technologies for cross-disciplinary environmental research;
- ✓ integrate human, societal, and ecological factors into investigations of the physical environment;
- ✓ improve science-based forecasting capabilities and enhance research on decision-making and human environmental behaviors; and
- ✓ advance a broad range of infrastructure to support interdisciplinary environmental activities such as collaborative networks, information systems, research platforms, international partnerships, and education activities that enhance and diversify the future environmental workforce.

While the specific findings about the natural-human system on the Eastern Shore are important to improving our understanding of dynamics in the Chesapeake Bay watershed, NHS-ESVA can also be applied to other settings at the interface of terrestrial-estuarine/marine/aquatic settings. After all, many properties, dynamics, and trends discerned about the natural-human system on the Eastern Shore of Virginia during the course of this research apply throughout the modern natural-human landscape across the planet, which faces comparable issues, such as:

- ✓ one-half of the world's jobs depend on fisheries, forests, or small-scale agriculture, yet two-thirds of the world's fisheries are being harvested beyond sustainability, forest loss is accelerating, and soil degradation is widespread and worsening (Lash 2001)

- ✓ commonly recognized consequences of human activities include homogenized landscapes, simplified food webs, and elevated nutrient inputs and imbalances (Kareiva et al. 2007)

Another substantial implication of this work is the example that the interdisciplinary NHS-ESVA model can become to researchers currently engaged in more traditionally focused academic study. If the research community is to address key questions arising from the growing awareness of complex dynamics in the natural-human system, it will, as Haber et al. (2006) contend, demand the integration of biogeophysical and historical data to reconstruct past system states—because past ecological conditions, social structures, and historical events undoubtedly influence current structures and functions of socio-ecological systems.

Future Directions of Study

As Cale, O'Neill, and Shugart (1983) correctly point out, desirable models are sufficiently applicable over a range of "ecological problems." In other words, when suitably constructed and parameterized, good models have the potential to generate and integrate useful information for multiple settings. Although NHS-ESVA is currently parameterized specifically to describe the Eastern Shore of Virginia in 1880 and 1920, this limitation is based on data input rather than model construction. In other words, the core structure of the NHS-ESVA model could be applied to other time periods as well as other natural-human systems set at the interface between terrestrial and estuarine or marine settings. For example, historical evidence suggests that technological and socio-economic change on the Eastern Shore in the period between 1930 and 1950 may be a rich avenue for additional analysis using the NHS-ESVA model (Figure 6.5).

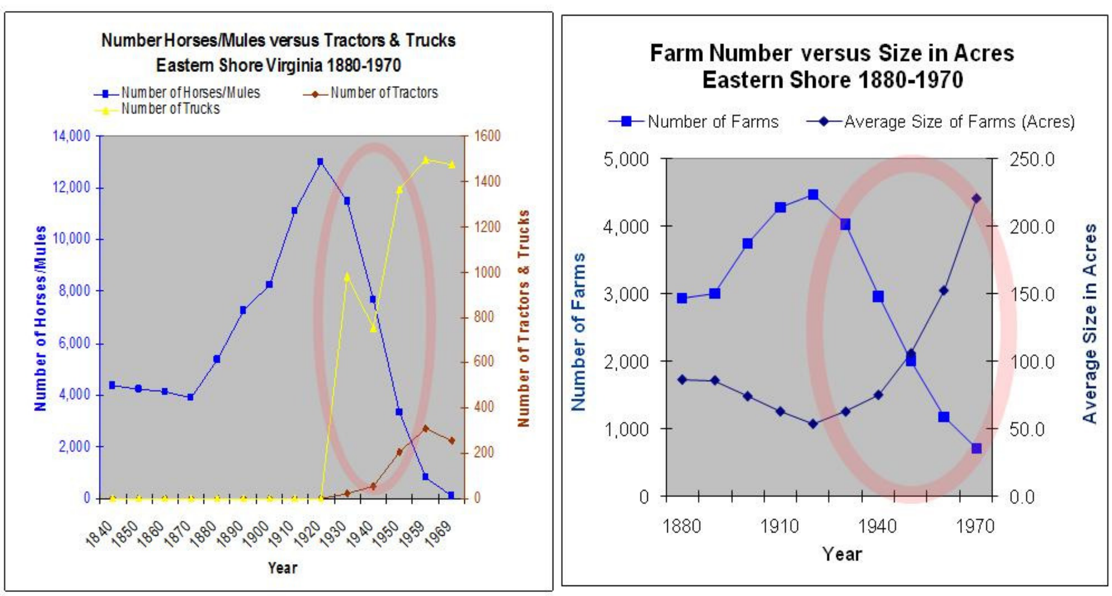

Figure. 6.5. Historical data suggest that the period between 1930 and 1950 may prove to be another time of great change on the Eastern Shore of Virginia with respect to technology (e.g., the introduction of Route 13 up the spine of the peninsula and the use of tractors and trucks for farm work) as well as changing economic markets (the Great Depression) and its effects on farm life (foreclosure and consolidation). The NHS-ESVA model could be applied to this time period/technology regime to study system dynamics.

Although not presented in this research, other potential avenues for using NHS-ESVA to extend analysis of the natural-human system on the Eastern Shore include: (1) long and short-term variability often characteristic of natural systems (e.g., in the form of climate change and cyclically "good" and "bad" fish harvests); (2) extreme events that arise periodically (e.g., the outbreak of disease affecting humans, agricultural crops, fish, or shellfish); (3) long and short-term conservation efforts (e.g., replanting sea grasses and other efforts to improve the health and habitats of the Chesapeake Bay); and (4) additional sensitivity analyses to identify the implications of small or large changes to model parameters (e.g., birthrates, mortality rates, and market prices).

It should also be noted that the structure and focus of the NHS-ESVA model may be improved during future study. For example, NHS-ESVA incorporates the degradation of the Chesapeake Bay benthos due to increased nutrient loads in the water column (e.g., from increased terrestrial fertilizer use), but it does not account for all sources of nitrogen that contribute to the process, including human waste water (sewage) and atmospheric deposition. Similarly, NHS-ESVA makes no formal distinction between Bay dynamics at its upper and lower reaches, although seasonal benthic anoxia occurs at much higher rates and over larger areas in the upper reaches that are closer to inflow from the Susquehanna River. Future versions of the model, or future efforts to integrate NHS-ESVA with other models of the Chesapeake Bay system (e.g., Cerco 1995; Linker et al. 2000; Crouch et al. 2008; and Stow and Scavia 2009), may address these issues more explicitly and incorporate other components of water quality, nutrient input, and related biogeophysical dynamics.

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Appendix A. Data Sources and Values for the 1880 Model of the Natural-Human System on the Eastern Shore of Virginia

Agriculture Data

The following is a description of 1880 U.S. Census of Agriculture procedures and practices as originally described by the U.S. Department of the Interior (1883).

> *The statistics of agriculture in a United States census are obtained through the personal visitation by the enumerators of population to each and every farm, in succession, within their respective districts. Required information is obtained on a farm-schedule, just as the returns of population are made upon a distinctively family-schedule. The data obtained do not embrace any operations connected with the soil that are not carried on through the occupation and cultivation of a farm in the usual sense of the term—thus excluding the production of meat, hides, and wool, through the grazing of cattle and sheep over extensive ranges of public or private lands.*
>
> *A canvas of the agricultural interests of a country through a farm-to-farm visitation has advantages and disadvantages. Each farmer, "whether intelligent or ignorant," becomes a census reporter with the assistance of a skilled census enumerator, who may generally be relied upon to check gross errors of intention or inadvertence. One of the primary benefits of farm-to-farm canvassing and interviews with proprietors is that these farmer knows the main facts relating to his own land and the operations upon it far better than can be conjectured in a general way by even the most accomplished agricultural statistician; and even if the farmers of any region feel no indisposition to tell the truth, the aggregation of their individual statements will yield a result far more closely approaching the facts than any enumerator's estimate.*
>
> *It should be noted that if every bit of planted land, however small, \were enumerated, the figures would lose all significance whatsoever. Given the impracticalities of enumerating the potato patch, tilled at odd hours by the factory hand, or the vegetable garden of the village shopkeeper, lawyer, or blacksmith, it is imperative to impose some definition upon the word "farm."*

According to the U.S. Department of the Interior (1883), the definition of a farm used by enumerators was:

> *Farms, for the purpose of the agricultural schedule, include all considerable nurseries, orchards, and market-gardens, which are owned by separate parties, which are cultivated for pecuniary profit, and employ as much as the labor of one able-bodied workman during the year. Mere cabbage and potato patches, family vegetable gardens, and ornamental houses, not constituting a portion of a farm for general agricultural purposes, will be excluded. No farm will be reported of less than three acres, unless five hundred dollars' worth of produce has actually been sold off from it during the year. The latter proviso will allow the inclusion of many market-gardens in the neighborhood of large cities, where, although the area is small, a high state of cultivation is maintained and considerable values are produced. A farm is what is owned or leased by one man and cultivated under his care. A distant wood-lot or sheep-pasture, even if in another subdivision, is to be treated as a part of the farm; but wherever there is a resident overseer, or a manager, there a farm is to be reported.*

From 1850-1880, a separate agricultural census of was made at the same time as the population census, and the farm records are available on microfilm at the National Archives Building in Washington, DC (700 Pennsylvania Avenue, NW, Washington, DC 20408-0001).

The 1880 U.S. Census of Agriculture was the first to use multiple enumerators and to be completed in only one month (June). Ten farms were recorded on each page of the agricultural census schedule. The order of the farms within each district represents a systematic inventory within the enumeration district by the census taker. Farms in close geographical proximity within an enumeration district are generally close together in the census records as well. For each farm, the enumerator recorded data in 101 columns as describe in table A.1.

Table A.1. Descriptions of Column Headings in the Enumeration Schedule of the 1880 Agricultural Census (after Moore 2003)

Column Number	Column Short Label	Full Explanation
Of the Person who Conducts this Farm		
1	Farm Operator Name	The operator is usually the same as the head of family in the population census. The alphabetical index following the data includes all names in col. 1.
Tenure		
2	Owner	Tenure = (O) owns the land
3	Rents for Fixed Money Rental	Tenure = (R) rents for cash
4	Rents for Shares of Products	Tenure = (S) rents for share of farm production
Acres of Land		
Improved		
5	Tilled	Area (in acres) of tilled land, including fallow and grasses in rotation.
6	Permanent meadows	Area (in acres) of permanent meadows, permanent pastures, orchard, and vineyard.
Unimproved		
7	Woodland and Forest	Area (in acres) of wetland and forest.
8	Other	Area (in acres) of other unimproved land, including old fields not growing trees
Farm Value		
9	Farm Land	Value (in dollars) of farm, including land, fences, and buildings (housing and outbuildings).
10	Farm Machinery	Value (in dollars) of farming implements and machinery.
11	Livestock	Value (in dollars) of Livestock
Fences		
12	Fence Cost	Cost (in dollars) of building and repairing fences.
13	Fertilizer Cost	Cost (in dollars) of fertilizers purchased.
Labor		
14	Wages	Amount (in dollars) paid for wages, including value of room and board.
15	Weeks Hired Labor	Weeks of hired labor upon the farm (and dairy) excluding housework.
16	Estimated Value of All Farm Production	Value (in dollars) of all farm production (sold, consumed, or on hand).

Grass Lands		
Acreage		
17	Mown	Grassland (in acres) mowed.
18	Not Mown	Grassland (in acres) not mown.
Products Harvested		
19	Hay	Tons of hay harvested.
20	Clover Seed	Bushels of clover seed harvested..
21	Grass Seed	Bushels of grass seed harvested;.
22	Horses	Number of horses, all ages, on hand.
23	Mules	Number of mules and asses on hand
Neat Cattle and their Products		
24	Working Oxen	Number of working oxen on hand.
25	Milk Cows	Number of milk cows on hand.
26	Other Cattle	Number of other cattle, all ages, on hand.
27	Calves Dropped	Number of calves dropped.
28	Cows Purchased	Number of cattle purchased.
29	Cows Sold Living	Number of live cattle sold.
30	Cows Slaughtered	Number of cattle slaughtered.
31	Cows Died	Number of cattle that died, strayed, and stolen not recovered.
32	Milk	Gallons of milk sold or sent to butter and cheese factories.
33	Butter	Pounds of butter made on the farm.
34	Cheese	Cheese made on the farm.
Sheep		
35	Sheep	Number of sheep and lambs on hand.
36	Lambs Dropped	Number of lambs dropped.
37	Sheep Purchased	Number of sheep and lambs purchased.
38	Sheep Sold Living	Number of sheep and lambs sold living.
39	Sheep Slaughtered	Number of sheep and lambs slaughtered.
40	Killed by Dogs	Number of sheep and lambs killed by dogs.
41	Died of Disease	Number of sheep and lambs that died of disease.
42	Died of Stress of Weather	Number of sheep that died of weather stress.
43	Fleeces	Number of fleeces clipped.
44	Wool	Weight (pounds) of fleeces.

Swine		
45	Hogs	Number of swine on hand.
Poultry		
46	Barnyard Poultry	Number of adult barnyard poultry (chickens, turkeys, and ducks) on hand.
47	Other Poultry	Number of other adult poultry on hand.
49	Eggs	Number (in dozens) of eggs produced.
Cereals		
49	Barley Acres	Area (in acres) of barley farmed.
50	Barley Crop	Bushels of barley produced.
51	Buckwheat Acres	Area (in acres) of buckwheat farmed.
52	Buckwheat Crop	Bushels of buckwheat produced.
53	Indian Corn Acres	Area (in acres) of Indian corn farmed.
54	Indian Corn Crop	Bushels of Indian corn produced.
55	Oats Acres	Area (in acres) of oats farmed.
56	Oats Crop	Bushels of oats produced.
57	Rye Acres	Area (in acres) of rye farmed.
58	Rye Crop	Bushels of rye produced.
59	Wheat Acres	Area (in acres) of wheat farmed.
60	Wheat Crop	Bushels of wheat produced.
Pulse		
61	Canada Peas (Dry)	Bushels of Canada peas (dry) produced.
62	Beans (Dry)	Bushels of beans (dry) produced.
Fiber		
63	Flax in Crop	Area (in acres) of flax farmed.
64	Flax in Seed	Bushels of flax in seed.
65	Raw Flax	Tons of raw flax.
66	Fiber Flax	Pounds of flax fiber.
67	Hemp Acres	Area (in acres) of hemp farmed.
69	Hemp Crop	Tons of hemp produced.
Sugar		
69	Sorghum in Crop	Area (in acres) of sorghum farmed.
70	Sorghum Sugar	Pounds sugar produced.
71	Sorghum Molasses	Gallons molasses produced.
72	Maple in Crop	Area (in acres) of maple farmed.
73	Maple Sugar	Pounds maple sugar produced.
74	Maple	Gallons maple molasses produced.

	Molasses	
Broom Corn		
75	Broom Corn Acres	Area (in acres) of broom corn farmed.
76	Broom Corn Pounds	Pounds broom corn produced.
Hops		
77	Hops Acres	Area (in acres) of hops farmed.
78	Hops Crop	Pounds hops produced.
Potatoes (Irish)		
79	Potatoes (Irish) Acres	Area (in acres) of potatoes (Irish) farmed.
80	Potatoes (Irish) Crop	Bushels potatoes (Irish) produced.
Potatoes (Sweet)		
81	Potatoes (Sweet) Acres	Area (in acres) of potatoes (Sweet) farmed.
82	Potatoes (Sweet) Crop	Bushels potatoes (Sweet) produced.
Tobacco		
83	Tobacco Acres	Area (in acres) of tobacco farmed.
84	Tobacco Crop	Pounds tobacco produced.
Orchards		
Apple		
85	Apple Acres	Area (in acres) of apple farmed.
86	Apple Bearing Trees	Number of apple bearing trees.
87	Apple Bushels	Bushels of apples produced.
Peach		
88	Peach Acres	Area (in acres) of peach farmed.
89	Peach Bearing Trees	Number of peach bearing trees.
90	Peach Bushels	Bushels of peaches produced.
91	Total Value of Orchard Products	Total value (in dollars) of orchard products of all kinds sold or consumed.
Nurseries		
92	Nursery Acres	Area (in acres) of nurseries.
93	Nurseries	Value (in dollars) of all nursery products.

	Value	
Vineyards		
94	Vineyard Acres	Area (in acres) of vineyards.
95	Grapes Sold	Pounds of grapes sold.
96	Wine Made	Gallons of wine produced.
Market Gardens		
97	Value of Products Sold	Value (in dollars) of market garden products sold.
Bees		
98	Honey	Production (in pounds) of honey.
99	Wax	Production (in pounds) of beeswax.
Forest Products		
100	Amount of Wood Cut	Amount (in cords) of wood cut from forests.
101	Value of Forest Products	Total value (in dollars) of all forest products sold or consumed.

An enumeration district is a geographical area assigned to each census taker, usually representing a specific portion of a city or county. When the Bureau of the Census assigned areas for census takers to collect data, it divided counties, cities, towns, villages, Indian reservations, and even hospitals and jails into enumeration districts (ED). Heavily populated areas like major cities would have dozens or even hundreds of EDs while rural counties and places would have only a few. Each county was assigned a number, and each ED within it was then numbered consecutively (National Archives and Records Administration 2009).

The Franktown Magisterial District, in the county of Northampton and state of Virginia, was identified as Enumeration District #84 (Virginia) in the June 1880 U.S. Census of Agriculture. According to the *Census Descriptions of Geographic Subdivision and Enumeration Districts, 1830-1950*, John Addison, the enumerator, was based out of the Concord Wharf Post Office, west of Eastville along the Occohannock Creek. Franktown included all of the area between the Accomac County boundary (to the north) and the Eastville Township boundary (to the south). Hog Island was included, as was the road dividing Franktown Township and Eastville Township (Turman 1964) (Figure A.1).

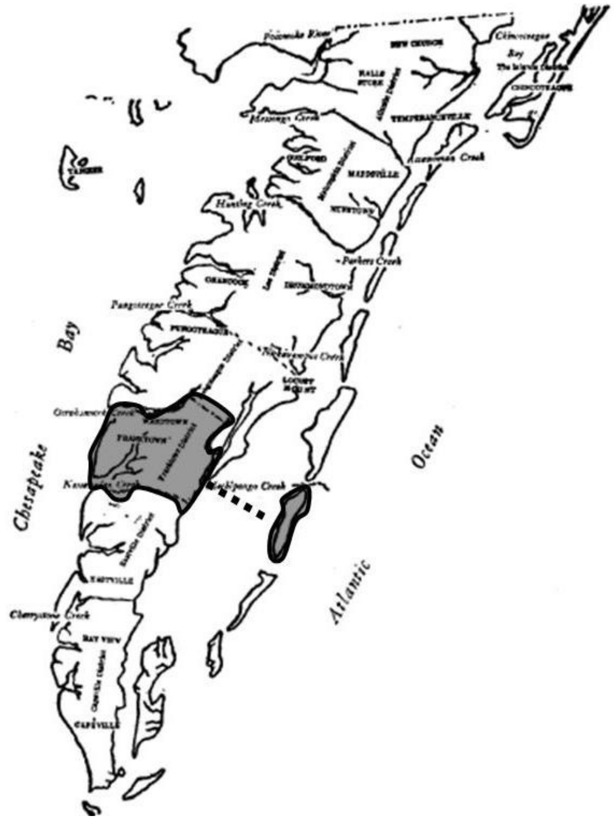
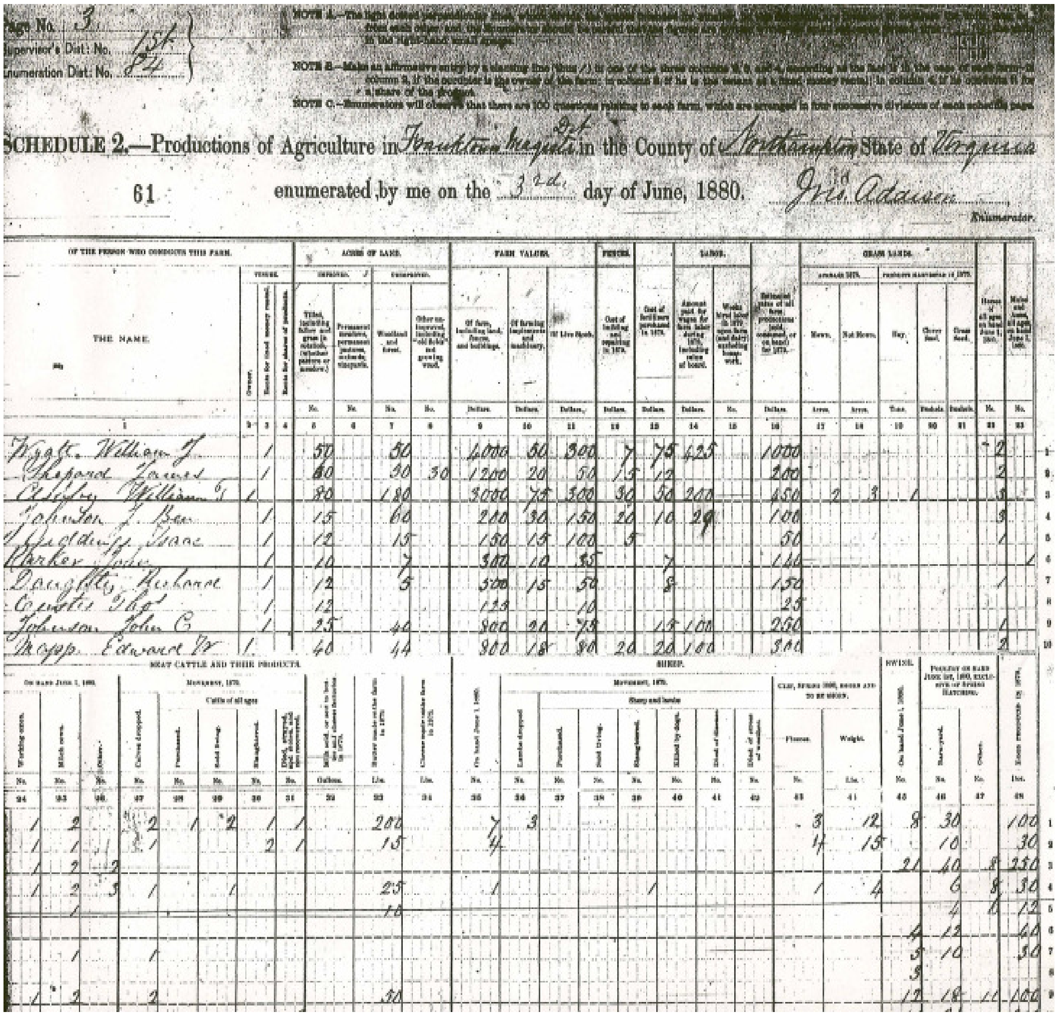


Figure A.1. The Franktown Enumeration District (shaded) is set entirely within Northampton County, includes Hog Island, and is bounded by Accomac County to the north and the Eastville Township line to the south. After Turman (1964).

The 1880 Census of Agriculture reports a total of 118,517 farms in Virginia, a 60.5% increase over the 1870 Census of Agriculture, at which time 73,849 farms were reported in Virginia. Nationally, there was a 73.7% increase in the number of farms between 1880 and 1870. Total farm acreage in Virginia during this same period increased by only 9.3%. This larger increase in number and smaller increase in area suggest movement in the direction of more, but smaller, farms which is consistent with socioeconomic norms of the period: a father (farmer) divided his farm to be inherited by each of his sons.



Page No. 3
Supervisor's Dist: No. 1st
Enumeration Dist: No. 84

SCHEDULE 2.—Productions of Agriculture in Franktown Magisterial Dist in the County of Northampton State of Virginia

61 enumerated by me on the 3rd day of June, 1880. Jno. Addison, Enumerator.

The Name (1)	Owner (2)	Rents for fixed money rental (3)	Rents for shares of products (4)	Tilled (5)	Permanent meadows, pastures, orchards, vineyards (6)	Woodland and forest (7)	Other unimproved (8)	Of farm, including land, fences, and buildings (9)	Of farming implements and machinery (10)	Of live stock (11)	Cost of building and repairing in 1879 (12)	Cost of fertilizers purchased in 1879 (13)	Amount paid for wages for farm labor during 1879 (14)	Weeks hired labor (15)	Estimated value of all farm productions for 1879 (16)	Mown (17)	Not mown (18)	Hay (19)	Clover seed (20)	Grass seed (21)	Horses (22)	Mules and asses (23)
Wyatt, William J.		1		50		50		4000	50	300	7	75	425		1000						2	
Shepard, James		1		60		30	30	1200	20	50	15	12			200						2	
Ashby, William T.	1			80		180		3000	75	300	30	50	200		450	2	3	1			3	
Johnson, J. Ben		1		15		60		200	30	150	20	10	29		100						3	
Widdup, Isaac		1		12		15		150	15	100	5				50						1	
Parker, John		1		10		7		300	10	35		7			100							
Doughty, Richard		1		12		5		500	15	50		8			150						1	
Custis, Thos		1		12				125		10					25							
Johnson, John C.		1		25		40		800	20	75		15	100		250						1	
Kopp, Edward W.	1			40		44		800	18	80	20	20	100		300						2	

Figure A.2. Copy of an original return from the 10th U.S. Census (1880), Schedule 2 Productions of Agriculture during the year ending 1880, for the Franktown Enumeration District, Northampton County, Virginia. Each name represents the operator of a farm. Data cells reflect responses to each of the items listed in table A.1 above. These returns were copied from microfiche (T1132, Roll #27) at the U.S. National Archives, 700 Pennsylvania Avenue, NW, Washington, DC 20408-0001.

The Franktown Enumeration District (Northampton County) contains records for 225 farms. Eighty-four were owner occupied (37.3%), 91 were rented for cash (40.4%), and 50 were rented for a share of farm production (22.2%). Thus, farms in the Franktown Enumeration District (Figure A.1) accounted for 28.8% of the total farms in Northampton County (781) and 7.7% of the farms on the entire Eastern Shore of Virginia (2,926) in 1880.

These farms managed a total of 22,904 acres, or 48.4% of the 47,227 acres of farmed land in Northampton County, and 17.4% of the 131, 387 acres farmed on the entire Eastern Shore. Of this, 11, 382 acres were classified by the farmer and enumerator as "improved" and 11,522 acres as "unimproved." The land was further identified as 10,069 acres tilled, including fallow land and grasses in rotation and 1,313 acres in permanent meadows, permanent pastures, orchard, and vineyard. 10,372 acres were recognized as wetland or forest, while another 1,150 acres were designated as "other," including old fields not growing trees. The mean size of these farms was 101.7 acres, which is larger than the mean farm size on the entire Eastern Shore at that time (86.6 acres), likely attributable to several particularly large farms that may have skewed the statistic. As evidence of this assertion, the ten largest farms accounted in themselves for 3,274 acres (averaging 327.4 acres) or 14.3% or the total land managed by the 225 farms in the enumeration district. This assertion is warranted even when acknowledging that the ten smallest farms in the district averaged only 7.4 acres.

The average farm value, including all land, housing, and outbuildings, was $1,627, again perhaps skewed by the large farms, one of which was valued at $12,000. The average value for machinery and equipment reported by 225 farms was only $31.60, with most farms reporting less than $10 worth of machinery. Livestock value totaled $39,828 or $177 per farm in the enumeration district. These farms reported an average of $19.40 spent building and repairing fences that year and another $35.60 per farm on fertilizer purchases.

The estimated value of all farm production (sold, consumed, or on hand) was $67,938 for the 225 farms, or just over $300 per farm on average. This value was derived from a wide range of products produced, harvested, slaughtered, consumed, or sold on the farms as described below.

A total of 6,388 acres of corn were planted on 223 of the 225 farms (averaging 28.7 acres per farm and ranging from 2 to 110 acres). These efforts yielded 50,780 bushels (averaging 227.7 bushels per farm and ranging from 15 to 1,200 bushels). Additionally, 1,715 acres of wheat were planted on 68 farms, yielding 9,060 bushels (averaging 133.2 bushels per farm and ranging from 8 to 650). Only three farms planted a combined total of 9 acres of wheat, producing 117 bushels, and making it inconsequential to Eastern Shore productivity.

Grassland farming, including hay and clover, was practically inconsequential in the Franktown Enumeration District, with only one farm reporting production of these crops from a total of 6 planted acres. Several other crops were included in the 1880 U.S. Census of Agriculture but not reported grown in the Franktown enumeration district. These included cereals (barley, buckwheat, and rye), pulses (pea and beans), broom corn, hops, maples sugar, grapes, and fibers such as flax and hemp. Two acres of sorghum were harvested on a single farm to produce 130 gallons of molasses. One farm produced 30 pounds of honey and 3 pounds of wax from beekeeping. And although they peak of tobacco farming on the Eastern Shore had long since passed, six farms planted 15 acres and produced 1,975 pounds.

In contrast, the agricultural census shows that Irish and sweet potatoes were grown in great quantity. In 1880, 212 farms planted 707 acres of Irish potatoes, yielding 33,845 bushels, or nearly 160 bushels per farm (ranging from 2 to 900). Another 622 acres were planted with sweet potatoes, which produced 37,030 bushels (an average of 174.7 bushels, ranging from 12 to 1,300, on the 212 farms with a crop).

With respect to orchards, 24 farms managed a total of 1,481 apple trees on 57 acres. The largest apple orchard covered 200 acres and the smallest 10 acres. A total of 1,578 bushels of apples were produced. Likewise, 3,432 peach trees were harvested from 46 acres on 22 farms, producing 1,202 bushels. The total value of these orchard products was $1,013. The only other arboreal production identified in the agricultural census stemmed from wood cut from forests, which was reported at a value of $4,548.

With respect to livestock, the 212 farms owned 427 horses and 52 mules, presumably as working animals. Seventy-nine (79) working oxen were reported on 68 farms and 370 milk cows were reported on 183 farms, which likely provided dairy products for use by the farmer and family, as evidenced by a total of only 226 gallons of milk sold or sent to butter and cheese factories from the entire enumeration district Pre-20th century dairy statistics for Virginia estimate that each milk cow produces about 147 gallons of milk per year, suggesting that approximately 54,000 gallons of milk were produced but not sold on these farms. Likewise, on average three gallons of good milk made one pound of butter during this time (Cylcopedia of Households 1881). Thus, the 4,796 pounds of butter that were reported produced on the farms accounts for roughly 14,400 gallons of milk, with the remainder likely consumed in another manner (except for home use, no cheese was produced). Farmers owned another 331 other (beef) cows and bulls as well. 272 calves were dropped and 33 were purchased compared to 84 sold living, 57 slaughtered, and 41 that died during the enumeration year.

Thirty-seven farms owned a total of 431 sheep, including one farm with 63. In addition to 124 lambs dropped during the enumeration year, 22 were purchased, 11 sold living, 9 slaughtered, 45 killed by dogs, 20 died from disease and 38 from weather stress. These sheep produced 245 fleeces weighing 933 pounds for market. A total 2,243 hogs were reported on 211 of the 225 farms in the district (an average of 10.6 hogs per farm reporting hogs with a minimum of one and a maximum of 47 hogs on a single farm). Barnyard poultry, including chickens, turkeys, and ducks, were reported on 222 of the 225 farms in the district. The number ranged from 2 to 100 with an average of 17.7 per farm for a total of 3,917. An additional 842 “other” adult poultry were reported. Total egg production was 17,280 dozen (207,360 individual eggs). The Cylcopedia of Households (1881) estimates that poultry produce 88 eggs per individual per year, which is consistent with the population and production when accounting for the fact that some of the adult poultry are males.

Fishing Data

> *In addition to its agricultural interests, the [Eastern Shore] bears a peculiar relation to the salt water, and many of the inhabitants, having no interesting the land, are largely dependent upon the fisheries for a livelihood, while a considerable percentage of the farmers give more or less attention to fishing, oystering, and clamming at periods of the year when their crops do not require their attention.*
>
> — G.B. Goode, 1887

On February 9, 1871, the U.S. Congress established a federal Commission of Fish and Fisheries, mandating that it study “the causes for the decrease of commercial fish and aquatic animals in U.S. coastal and inland waters, to recommend remedies to Congress and the states, and to oversee restoration efforts.” For the next thirty years, the Commission deployed its research vessels on the nation's rivers, lakes and oceans, trained fishery agents to document the catches, collaborate with scientists on biological and technical innovation, and establish fish hatcheries. The first fishing statistics for the Eastern Shore of Virginia were reported by the U.S. Commission of Fish and Fisheries in 1887 for the year 1880.

In this inaugural report, a special section was included on especially significant fishing regions throughout the nation. One such section focused on Virginia’s Northampton and Accomac counties. Evaluators described conditions on the Eastern Shore as lacking suitable transportation and, therefore, suitable markets. They also noted the plethora of part-time fishermen involved in Eastern Shore fishing activities, contributing to a total of 764 men engaged in shore fisheries in Accomac and Northampton counties. These fishermen employed 668 vessels, 17 pound-nets, 125 gill-nets, and 12 seines (Goode 1887).

Catch data for the Eastern Shore provided by the Commission for 1880 show harvests of 37,910 pounds of shad (*Clupea sapidissima*), 799,663 pounds of Spanish mackerel (*Cybium maculatuan*), 1,003,167 pounds of bluefish (*Pomatomus saltatrix*), 1,143,000 pounds of gray and salmon trout (*Cynoscion regalis* and *Cynoscion maculatus*), 411,000 pounds of sheepshead (*Archosargus probatocephalus*), and 1,512,399 pounds of other fish, referred to as "miscellaneous" in the 1880 Census, for a total of 4,893,729 pounds harvested in 1880. Additional harvests included 2,300 dozen (27,600 individuals) terrapins (*Malaclemys terrapin*), 8,000,000 individuals (27,500 bushels) of quahogs (*Mercenaria mercenaria*, the Atlantic round clam). The two counties also caught 15,876,000 menhaden (Census Bulletin No. 281, 1881).

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Appendix B. Data Sources and Values for the 1920 Model of the Natural-Human System on the Eastern Shore of Virginia

> *But for the sweet potato the Eastern Shore of Virginia and its people would not be by far what they are today. It has not only brought comforts, luxuries, wealth, and population, but to it more than to all the other resources combined perhaps is due the present enviable social, moral, and intellectual position of the people of this section. It has brought the money, and the money has made all of these other facts and conditions possible. It enhances all values, builds the highways, railroads, vessels, steamboats, stores, school-houses, churches, and homes of this country. It pays the teachers in the schools, the ministers in the pulpits, and the lawyers at the bar. It is the creator of banks and bankers, doctors and lawyers, preachers and teachers, and all trades and conditions of men are dependent upon it. It heals the sick, feeds the hungry and clothes the naked, and blesses all the land. It is true that this land is greatly favored in other natural advantages--its oysters, its fish, its fruit, its soil and its climate, all of which contribute to make this the favored spot of the country; but it cannot be denied that the sweet potato is the keystone to the arch upon which almost all else rests.*
>
> — N.W. Nock, 1900

The 1920 U.S. Federal Census was the fourteenth enumeration of the United States population, initiated on January 1, 1920. It included a detailed population survey, as well as collections concerning occupations, agriculture, irrigation, drainage, manufactures, and mines and quarries.

Agriculture Data

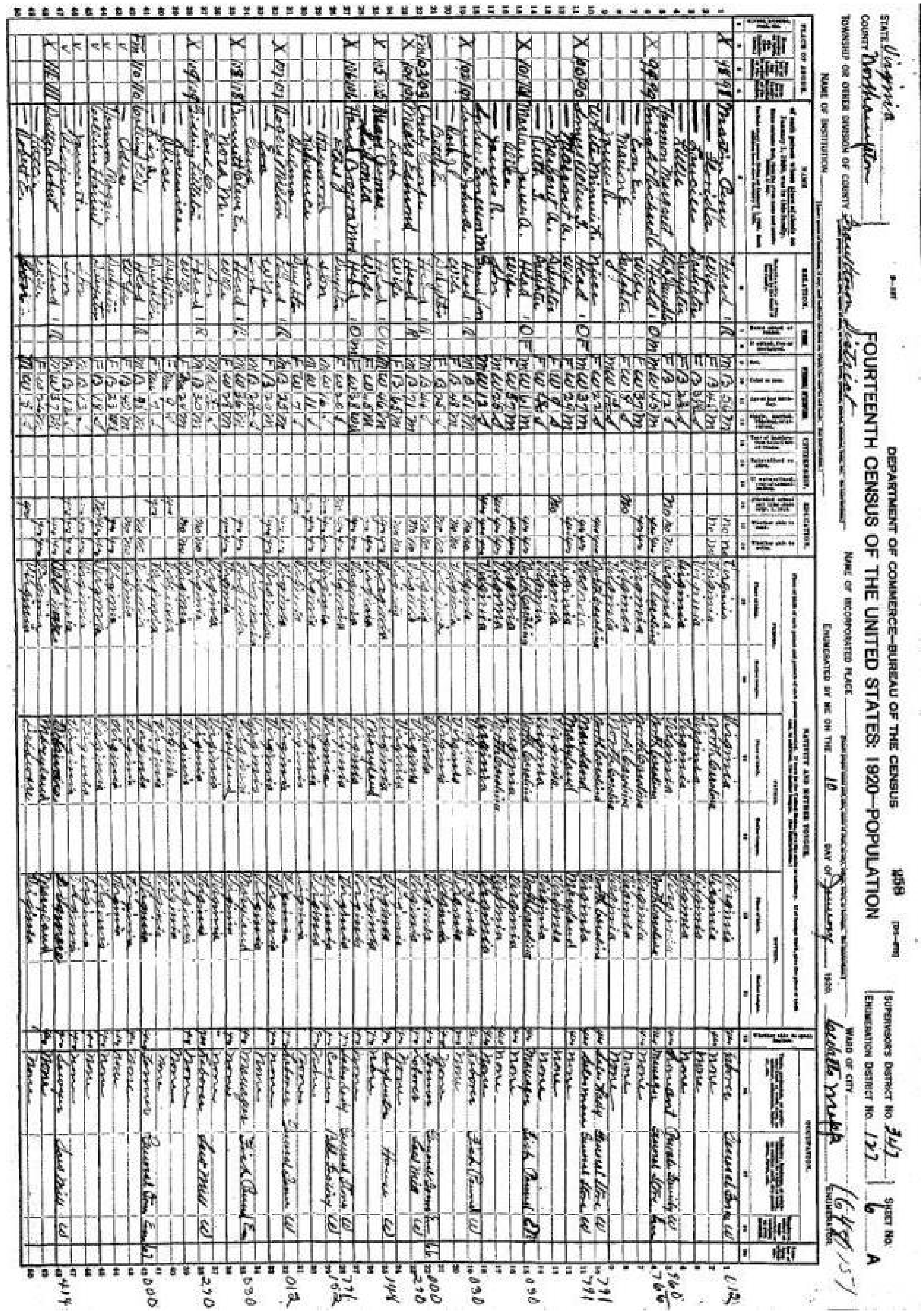
For the purposes of the 1920 Census, the definition of a farm used by enumerators was:

> *A "farm" for census purposes is all the land which is directly farmed by one person managing and conducting agricultural operations, either by his own labor alone or with the assistance of members of his household or hired employees. The term "agricultural operations" is used as a general term, referring to the work of growing crops, producing other agricultural*

> *products, and raising domestic animals, poultry, and bees. A "farm" is thus defines may consist of a single tract of land or of a number of separate and distinct tracts, and these several tracts may be held under different tenures, as where one tract is owned by the farmer and another tract is hired by him. When a landowner has one or more tenants, renters, croppers, or managers, the land operated by each is considered a "farm." In applying the foregoing definition, enumerators were instructed to report as a "farm" any tract of 3 or more acres used for agricultural purposes, and also any tract containing less than 3 acres which produced at least $250 worth of farm products in the year 1919, or required for its agricultural operations the continuous services of at least one person.*

An enumeration district is a geographical area assigned to each census taker, usually representing a specific portion of a city or county. When the Bureau of the Census assigned areas for census takers to visit when collecting information from residents, it divided counties, cities, towns, villages, Indian reservations, and even hospitals and jails into enumeration districts (ED). Heavily populated areas like major cities would have dozens or even hundreds of EDs while rural counties and places would have only a few or one. Each county was assigned a number, and each ED within it was then numbered consecutively (U.S. National Archives and Records Administration 2009).

Franktown Magisterial District, in the county of Northampton and state of Virginia, was identified as Enumeration District #127 (Virginia) in the Fourteenth Census of the United States, undertaken on January, 1, 1920. According to the *Census Descriptions of Geographic Subdivision and Enumeration Districts, 1830-1950*, Franktown included all of the area between the Accomac County boundary (to the north) and the Eastville Township boundary (to the south). Hog Island was included, as was the road dividing Franktown Township and Eastville Township (Turman 1964).



DEPARTMENT OF COMMERCE—BUREAU OF THE CENSUS

FOURTEENTH CENSUS OF THE UNITED STATES: 1920—POPULATION

Figure B.1. Copy of an original return from the 14th U.S. Census (1920) for the Franktown Enumeration District, Northampton County, Virginia. Each name represents an individual living in the Enumeration District during the census. Data cells reflect responses to each of the items listed in the population census.

72 AGRICULTURE—VIRGINIA.

COUNTY TABLE I.—FARMS AND FARM PROPERTY, 1920,

		THE STATE.			Accomac.	Albemarle.[1]	Alleghany.[2]	Amelia.	Amherst.
		Total.	White.	Colored.					
	ALL FARMS.								
1	Number of farms..1920	186,242	138,456	47,786	3,206	3,165	621	1,198	2,472
2	1910	184,018	135,904	48,114	2,977	2,741	574	1,250	2,317
3	1900	167,886	123,052	44,834	2,772	2,636	516	1,361	2,159
	All farmers classified by sex, 1920:								
4	Male...number..	176,214	131,438	44,776	3,174	2,917	581	1,134	2,368
5	Female...number..	10,028	7,018	3,010	32	248	40	64	104
	Color and nativity of all farmers, 1920:								
6	Native white...number..	136,874	136,874	...	2,070	2,294	599	590	1,582
7	Foreign-born white...number..	1,582	1,582	...	5	52	4	15	27
8	Negro and other nonwhite...number..	47,786	...	47,786	1,131	819	18	593	863
	All farms classified by size, 1920:								
9	Under 3 acres...number..	435	350	85	5	...	1	...	7
10	3 to 9 acres...number..	14,077	8,485	5,592	178	447	46	52	170
11	10 to 19 acres...number..	21,890	12,094	9,796	335	433	48	131	340
12	20 to 49 acres...number..	45,884	28,684	17,200	1,467	515	92	260	615
13	50 to 99 acres...number..	42,714	33,318	9,401	939	519	120	255	528
14	100 to 174 acres...number..	34,011	29,877	4,134	219	581	145	232	478
15	175 to 259 acres...number..	13,968	12,971	997	41	285	72	120	182
16	260 to 499 acres...number..	9,633	9,202	431	17	252	65	109	120
17	500 to 999 acres...number..	2,833	2,702	131	4	105	25	30	23
18	1,000 acres and over...number..	797	778	19	1	28	7	9	9
	LAND AND FARM AREA.								
19	Approximate land area, 1920...acres..	25,767,680	...	...	321,280	478,080	292,480	237,440	300,800
20	Land in farms..1920...acres..	18,561,112	16,297,693	2,263,419	156,788	388,941	95,795	151,286	232,867
21	1910...acres..	19,495,636	17,257,416	2,238,220	185,538	386,491	104,006	189,042	258,373
22	1900...acres..	19,907,883	17,678,765	2,229,118	190,861	396,624	110,328	193,183	241,685
23	Improved land in farms..1920...acres..	9,460,492	8,356,031	1,104,461	79,397	215,880	31,643	54,572	109,610
24	1910...acres..	9,870,058	8,758,850	1,111,208	83,116	226,830	32,699	66,031	123,307
25	1900...acres..	10,094,805	8,969,347	1,125,458	93,210	249,409	30,861	79,571	132,140
26	Woodland in farms, 1920...acres..	7,907,352	6,890,639	1,016,713	70,506	150,333	62,357	89,565	110,192
27	Other unimproved land in farms, 1920...acres..	1,193,268	1,051,023	142,245	6,885	22,728	1,795	7,149	13,065
28	Per cent of land area in farms, 1920	72.0	63.2	8.8	48.8	81.4	32.8	63.7	77.4
29	Per cent of farm land improved, 1920	51.0	51.3	48.8	50.6	55.5	33.0	36.1	47.1
30	Average acreage per farm, 1920	99.7	117.7	47.4	48.9	122.9	154.3	126.3	94.2
31	Average improved acreage per farm, 1920	50.8	60.4	23.1	24.8	68.2	51.0	45.6	44.3
	VALUE OF FARM PROPERTY.								
32	All farm property..1920...dollars..	1,196,555,772	1,077,230,705	119,325,067	24,175,791	28,189,780	3,332,156	6,720,227	10,893,876
33	1910...dollars..	625,065,383	570,316,476	54,748,907	12,544,530	14,945,561	2,092,552	3,042,322	5,620,605
34	1900...dollars..	323,515,977	298,986,961	24,529,016	5,947,816	7,438,312	1,255,215	1,644,931	2,779,658
35	Land in farms...1920...dollars..	756,354,277	682,763,115	73,591,162	16,858,117	15,632,226	2,041,470	4,155,644	6,506,536
36	1910...dollars..	394,658,912	362,105,272	32,553,640	8,657,019	8,432,964	1,332,080	1,751,214	3,138,688
37	1900...dollars..	200,615,080	186,133,370	14,481,710	3,947,030	4,143,410	824,870	917,900	1,637,720
38	Farm buildings..1920...dollars..	268,080,748	240,679,999	27,400,749	4,548,793	9,224,040	707,080	1,634,975	2,846,125
39	1910...dollars..	137,399,150	124,728,286	12,670,864	2,508,851	4,587,136	377,230	793,790	1,468,995
40	1900...dollars..	70,963,120	65,462,380	5,500,740	1,320,090	2,210,160	221,120	461,100	646,380
41	Implements and machinery..1920...dollars..	50,151,466	45,381,173	4,770,293	1,125,424	1,144,072	154,391	326,599	397,960
42	1910...dollars..	18,115,883	16,263,380	1,852,503	382,444	413,739	84,677	109,852	182,977
43	1900...dollars..	9,911,040	8,979,760	931,280	181,270	227,290	39,900	66,310	87,630
44	Live stock on farms..1920...dollars..	121,969,281	108,406,418	13,562,863	1,643,457	2,189,442	429,215	603,009	1,143,255
45	1910...dollars..	74,891,438	67,219,538	7,671,900	996,216	1,511,722	298,565	387,466	829,945
46	1900...dollars..	42,026,737	38,411,451	3,615,286	499,426	857,452	169,325	199,621	407,928
	Average values, 1920:								
47	All property per farm...dollars..	6,425	7,780	2,497	7,541	8,907	5,366	5,610	4,407
48	Land and buildings per farm...dollars..	5,501	6,670	2,113	6,677	7,853	4,426	4,834	3,783
49	Land alone per acre...dollars..	40.75	41.89	32.51	107.52	40.19	21.31	27.47	27.94

Figure B.2. Example of aggregated agriculture data presented in the 1920 Census for the state and counties of Virginia. Data categories (e.g., All Farms) and items within those categories (e.g., Number of Farms) are presented in the far left column (column #2). State level data appear in the middle (columns 3-5), and county level data appear for each county in alphabetical order in the remaining columns in succession (columns 6-10 in this example).

The 1920 Census Agricultural Report states that 72.03% of the total land area in Virginia was recognized as farm land. There were 186,242 farms in Virginia, a 1.21% increase over 1910 and a 57% increase over 1880. In spite of this slight increase in the number of farms, total land farmed in the state actually decreased 4.79% from 1910 to 1920 (19,495,636 versus 18,561,112 acres). This increase in farm number and decrease in farm area reflects property inheritance norms of the period in which a father (farmer) divided his farm to be inherited by each of his sons.

Northampton County, Virginia (the southern county on the Eastern Shore of Virginia) had 1,259 farms, 77.68% of which contained 99 or less acres. Total farmed area in Northampton County was 82,892 acres. 54.25% of farms were operated by tenants, while 44.72% of farms were operated by owners, and just over 1.03% by managers. The average value of a Northampton farm, including land, buildings, and property, was $14,433, more than double the state average of $6,425. Moreover, farm value per acre in Northampton County was $197.26, compared to $136.53 in Accomac and $55.19 for the state of Virginia.

The Franktown Enumeration District population of 5,109 represented 28.62% of the Northampton County total population of 17,852. This figure was used to calculate farming and fishing data that, in many cases, were reported at the county level rather than the enumeration district level. Thus, the Franktown District was calculated to have 360 farms over 43,775 acres, 23,723 of which were actively farmed at an average of 65.8 acres per farm.

A total of 6,589 acres of corn were planted. These efforts yielded 191,645 bushels (averaging 29.08 bushels/acre with a value of $1.85/bushel). Seventeen (17) acres of oats were planted with a yield of 529 bushels (an average of 30.83 bushels/acre with a value of $1.10/bushel). Wheat was planted on 110 acres and 1,763 bushels were harvested (15.96 bushels/acre at $2.34/bushel). Only 25 acres of rye were planted, producing 80 bushels (an average of 3.18 bushels/acre with a price of $1.80/bushel). Eleven acres of soy beans produced 60 bushels (5.20 bushels/acre at a price of $4.65/bushel). Nine acres of dry peas yielded 67 bushels (7.77 bushels/acre with a value of $4.25/bushel).

The great bulk of crop production came from potatoes. In 1920, 6,484 acres of Irish potatoes were planted and 929,562 bushels harvested (143.37 bushels/acre with a market value of $2.20/bushel). Similarly, 1.387 acres of sweet potatoes produced 242,309 bushels (174.65 bushels/acre at a price of $1.60/bushel).

With respect to fruits, 6 acres of strawberries produced 6.257 quarts with a market price of $0.20/quart. Farmers reported that 897 apple trees of bearing age generated 1.303 bushels at a price of $1.60/bushel, while there were 507 peach trees that produced 300 bushels at a price of $2.00/bushel. Similarly, 384 pear trees generated 1,090 bushels with a price of $1.60 and 68 plum trees produces 52 bushels of plums (and prunes) with an average price of $1.90/bushel. Cherry trees yielded 52 bushels with a value of $2.50/bushel. Finally, 56 grape vines produced 479 pounds of grapes with a value of $0.09/pound.

Of the 360 farms, 358 reported owning livestock, totaling 828 horses (valued at $85,415 or $103/animal), 527 mules (worth $87,001 or $165/animal), 33 beef cattle ($1,518 or $47/animal), 522 dairy cattle ($32,477 or $62/animal), 613 sheep ($6,967 or $11/animal), 2,553 swine ($33,629 or $13/animal), and 23,879 chickens and other poultry ($27,503 or $1.15/animal). With respect to livestock products, 66,904 gallons of milk and 20,162 pounds of butter were produced. Of this, 4,789 gallons of milk were sold at $0.36/gallon, as were 5,089 pounds of butter at $0.25 per pound. Additionally, 53,153 dozen eggs were laid with 26,673 dozen sold at $0.42/dozen. Finally, 440 sheep were shorn to generate 2,998 pounds of wool with a total value of $1,424.

Fishing Data

Catch data for the Eastern Shore provided by the U.S. Commissioner of Fisheries for the Fiscal Year 1922 (reporting data for the year 1920) show harvests by Northampton Country fisherman of 11,3630 pounds of shad (*Clupea sapidissima*) (valued at $2,258), 4,435 pounds of Spanish mackerel (*Cybium maculatuan*) (valued at $665), 101,538 pounds of bluefish

(*Pomatomus saltatrix*) (valued at $13,803), 1,813,120 pounds of gray and salmon trout (*Cynoscion regalis* and *Cynoscion maculatus*) (valued at $92,047), 825 pounds of sheepshead (*Archosargus probatocephalus*) (valued at $126), 12,025,500 pounds of menhaden (*Brevoortia tyrannus*) (valued at $23,894), and 2,900,400 pounds of other fish, referred to as "miscellaneous" (valued at $164,999), for a total of 19,285,847 pounds harvested (valued at $485,429). Additional harvests included 72,427 pounds of quahogs (*Mercenaria mercenaria*, the Atlantic round clam) (valued at $21,508), 1,672,181 pounds of oysters (*Crassostrea virginica*) (valued at $140,884), 664,151 pounds of hard crabs (*Callinectes sapidus*) (valued at $22,120), and 18,862 pounds of soft crabs (*Callinectes sapidus*) (valued at $3,125).

The same resource reports financial investment in the products of the fisheries for Northampton County, including $123,750 for 3 fishing vessels (steam), $19,20 on fishing vessel (steam) outfits, $16,300 on 18 transport vessels (gas), $5,125 on transport vessel (gas) outfits, $3,400 on 2 transport vessels (sail), $775 on transport vessel (sail) outfits, $43,795 on 68 power boats, $15,811 on 439 sail boats, $188,270 on 55 pound nets, $1,110 on 20 gill nets, $1,675 on 10 haul seines, $7,500 on 3 purse seines, $1,020 on hand lines, $1,191 on 292 tongs, rakes, etc., $780 on 106 scallop dredges, and $298,562 on fish houses and shore property.

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Appendix C. Parameters and Source Code for NHS-ESVA:1880

Source Code from ModelMaker4.0 File:

Main
Agriculture
compartment: Ag_CaloriesProduced Unconditional
dAg_CaloriesProduced/dt = -
NetCaloriestoPeople_Agric+Peach_toAgCaloriesProduced+Apples_toAgCaloriesProduced+Corn_toAgCalories+
Oats_toAgCaloriesProduced+Wheat_toAgCalProd+Pot_toAgCalProd+SwPot_toAgCalProd+Oxen_toAgCalProd
+OtherCow_toAgCalProd+MilkCows_toAgCalProd+Sheep_toAgCalProd+Hogs_toAgCalProd+Poultry_toAgCal
Prod+Eggs_toAgCalProd+Milk_toCalories+Butter_toCalories
Initial Value = 1677002285
compartment: Ag_CashMarket Unconditional
dAg_CashMarket/dt =
Tob_toCash+SwPot_toCash+Pot_toCash+Wheat_toCash+Oats_toCash+Corn_toCash+Apples_toCash+Peach_to
Cash+Oxen_toCash+OtherCows_toCash+MilkCow_toCash+Sheep_toCash+Milk_toMoney-
GrossAgMoneytoPeople-(MilkCow_PricetoPurchase*MilkCow_Purchased)-
(OtherCows_PricetoPurchase*OtherCow_Purchased)-(Oxen_PricetoPurchase*Oxen_Purchased)-
(Sheep_PricetoPurchase*Sheep_Purchased)
Initial Value = 7235.97
compartment: Ag_MoneyProduced Unconditional
dAg_MoneyProduced/dt = +GrossAgMoneytoPeople-GrossAgMoneyPeople2
Initial Value = 7235.97
compartment: Ag_MoneyTotal Unconditional
dAg_MoneyTotal/dt = -TotalRevenuesFarmers+(RandomNumber1sd4_Markets*GrossAgMoneyPeople2)
Initial Value = 7235.97
AgEconomics
compartment: AnnualCosts_Ag Unconditional
1Year
dAnnualCosts_Ag/dt = +WageCostsAnnual+FertilizerCostsAnnual-Annualized1YrCosts
Initial Value = 25935
flow: Annualized10YrCosts Unconditional
Flow from ShortCosts_Ag to TotalFarmingCosts
Annualized10YrCosts = ShortCosts_Ag
flow: Annualized1YrCosts Unconditional
Flow from AnnualCosts_Ag to TotalFarmingCosts
Annualized1YrCosts = AnnualCosts_Ag
flow: Annualized30YrCosts Unconditional
Flow from CapitalCosts_Ag to TotalFarmingCosts
Annualized30YrCosts = CapitalCosts_Ag
compartment: CapitalCosts_Ag Unconditional
30Years
dCapitalCosts_Ag/dt = +FarmCosts30Yr-Annualized30YrCosts
Initial Value = 1182
flow: FarmCosts30Yr Unconditional
Flow from FarmLand_Cost to CapitalCosts_Ag
FarmCosts30Yr = (1/30) * FarmLand_Cost
compartment: FarmLand_Cost Unconditional
dFarmLand_Cost/dt = 0
Initial Value = 35470
compartment: Fence_Cost Unconditional
dFence_Cost/dt = 0
Initial Value = 3122
flow: FenceCosts10Yr Unconditional
Flow from Fence_Cost to ShortCosts_Ag

FenceCosts10Yr = (1/10) * Fence_Cost
compartment: Fertilier_Cost Unconditional
dFertilier_Cost/dt = 5157+(1289*FertilizerUse_Annual)-FertilizerCostsAnnual
Initial Value = 5157
flow: FertilizerCostsAnnual Unconditional
Flow from Fertilier_Cost to AnnualCosts_Ag
FertilizerCostsAnnual = Fertilier_Cost
compartment: Machine_Cost Unconditional
dMachine_Cost/dt = 0
Initial Value = 6660
flow: MachineCosts10Yr Unconditional
Flow from Machine_Cost to ShortCosts_Ag
MachineCosts10Yr = (1/10) * Machine_Cost
compartment: ShortCosts_Ag Unconditional
10Years
dShortCosts_Ag/dt = +MachineCosts10Yr-Annualized10YrCosts+FenceCosts10Yr
Initial Value = 978
flow: TotalAnnualCostsFarming Unconditional
Flow from TotalFarmingCosts to TotalAnnualFarmingCostsfromSu
TotalAnnualCostsFarming = TotalFarmingCosts
compartment: TotalFarmingCosts Unconditional
dTotalFarmingCosts/dt = +Annualized1YrCosts+Annualized10YrCosts+Annualized30YrCosts-TotalAnnualCostsFarming
Initial Value = 28096
compartment: Wage_Costs Unconditional
dWage_Costs/dt = 0
Initial Value = 20778
flow: WageCostsAnnual Unconditional
Flow from Wage_Costs to AnnualCosts_Ag
WageCostsAnnual = Wage_Costs
compartment: Apple_Calories2 Unconditional
dApple_Calories2/dt = +(Apple_weightperbush*Calories_Apples*Apples_toCalories)-Apples_toAgCaloriesProduced
Initial Value = 2860093
flow: Apple_Sold Unconditional
Flow from Apples_bushels to Apples_Market
Apple_Sold = APercent_AgFood_toMarket * Apples_bushels
compartment: Apples_acres Unconditional
dApples_acres/dt = 0
Initial Value = 58
compartment: Apples_Animals Unconditional
dApples_Animals/dt = +Apples_toAnimals
Initial Value = 1160
compartment: Apples_bushels Unconditional
dApples_bushels/dt = (BperAcre_apples * CropEnhancementFactor* Apples_acres)+(BperAcre_apples * RandomNumber1sd_Crops* Apples_acres)-Apple_Sold-Apples_toAnimals-Apples_toPeople
Initial Value = 1578
compartment: Apples_Food Unconditional
dApples_Food/dt = +Apples_toPeople-Apples_toCalories
Initial Value = 252.48
compartment: Apples_Market Unconditional
dApples_Market/dt = +Apple_Sold-Apples_toMoney
Initial Value = 165.69
compartment: Apples_Money Unconditional
dApples_Money/dt = +(APPB_Apples*Apples_toMoney)-Apples_toCash
Initial Value = 203.8
flow: Apples_toAgCaloriesProduced Unconditional
Flow from C1 to Ag_CaloriesProduced
Apples_toAgCaloriesProduced = Apple_Calories2
flow: Apples_toAnimals Unconditional

Flow from Apples_bushels to Apples_Animals
Apples_toAnimals = APercent_AgFood_toAnimals * Apples_bushels
flow: Apples_toCalories Unconditional
Flow from Apples_Food to C1
Apples_toCalories = Apples_Food
flow: Apples_toCash Unconditional
Flow from Apples_Money to Ag_CashMarket
Apples_toCash = Apples_Money
flow: Apples_toMoney Unconditional
Flow from Apples_Market to Apples_Money
Apples_toMoney = Apples_Market
flow: Apples_toPeople Unconditional
Flow from Apples_bushels to Apples_Food
Apples_toPeople = APercent_AgFood_toPeople * Apples_bushels
flow: Butter_toCalories Unconditional
Flow from ButtertoCalories to Ag_CaloriesProduced
Butter_toCalories = ButtertoCalories
compartment: ButtertoCalories Unconditional
dButtertoCalories/dt = +(Butter_Calories*ButterTranstoCal)-Butter_toCalories
Initial Value = 15595156
flow: ButterTranstoCal Unconditional
Flow from MilkforButter to ButtertoCalories
ButterTranstoCal = MilkforButter
compartment: Corn_acres Unconditional
dCorn_acres/dt = 0
Initial Value = 6389
compartment: Corn_Animals Unconditional
dCorn_Animals/dt = +Corn_toAnimals
Initial Value = 37323
compartment: Corn_bushels Unconditional
dCorn_bushels/dt = (BperAcre_corn * CropEnhancementFactor* Corn_acres)+(BperAcre_corn * RandomNumber1sd_Crops* Corn_acres)-Corn_toPeople-Corn_Sold-Corn_toAnimals
Initial Value = 50780
compartment: Corn_Calories2 Unconditional
dCorn_Calories2/dt = +(Corn_weightperbush*Corn_calories*Corn_toCalories)-Corn_toAgCalories
Initial Value = 941258080
compartment: Corn_Food Unconditional
dCorn_Food/dt = +Corn_toPeople-Corn_toCalories
Initial Value = 8124.80
compartment: Corn_Market Unconditional
dCorn_Market/dt = +Corn_Sold-Corn_toMoney
Initial Value = 5331.90
compartment: Corn_Money Unconditional
dCorn_Money/dt = +(APPB_Corn*Corn_toMoney)-Corn_toCash
Initial Value = 2079.44
flow: Corn_Sold Unconditional
Flow from Corn_bushels to Corn_Market
Corn_Sold = APercent_AgFood_toMarket * Corn_bushels
flow: Corn_toAgCalories Unconditional
Flow from Corn_Calories2 to Ag_CaloriesProduced
Corn_toAgCalories = Corn_Calories2
flow: Corn_toAnimals Unconditional
Flow from Corn_bushels to Corn_Animals
Corn_toAnimals = APercent_AgFood_toAnimals * Corn_bushels
flow: Corn_toCalories Unconditional
Flow from Corn_Food to Corn_Calories2
Corn_toCalories = Corn_Food
flow: Corn_toCash Unconditional
Flow from Corn_Money to Ag_CashMarket
Corn_toCash = Corn_Money

flow: Corn_toMoney Unconditional
Flow from Corn_Market to Corn_Money
Corn_toMoney = Corn_Market
flow: Corn_toPeople Unconditional
Flow from Corn_bushels to Corn_Food
Corn_toPeople = APercent_AgFood_toPeople * Corn_bushels
flow: CostsofFarming Unconditional
Flow from ExpensesFarmingtoNegative to NetProfittoFarmers
CostsofFarming = ExpensesFarmingtoNegative
compartment: DeadAnimals Unconditional
dDeadAnimals/dt = +MilkCows_toDead+OtherCows_toDead+Oxen_toDead+Sheep_toDead
Initial Value = 0.0
compartment: Egg_Calories2 Unconditional
dEgg_Calories2/dt = +(Egg_Calories*Eggs_toCalories)-Eggs_toAgCalProd
Initial Value = 13478400
compartment: Eggs Unconditional
dEggs/dt = +(Poultry*53)-Eggs_toCalories
Initial Value = 207360
flow: Eggs_toAgCalProd Unconditional
Flow from Egg_Calories2 to Ag_CaloriesProduced
Eggs_toAgCalProd = Egg_Calories2
flow: Eggs_toCalories Unconditional
Flow from Eggs to Egg_Calories2
Eggs_toCalories = Eggs
compartment: ExpensesFarming Unconditional
dExpensesFarming/dt = +FarmingExpenses-tonegative
Initial Value = 28096
compartment: ExpensesFarmingtoNegative Unconditional
dExpensesFarmingtoNegative/dt = +(-1*tonegative)-CostsofFarming
Initial Value = -28096
flow: FarmingExpenses Unconditional
Flow from TotalAnnualFarmingCostsfromSu to ExpensesFarming
FarmingExpenses = TotalAnnualFarmingCostsfromSu
flow: GrossAgMoneyPeople2 Unconditional
Flow from Ag_MoneyProduced to Ag_MoneyTotal
GrossAgMoneyPeople2 = Ag_MoneyProduced
flow: GrossAgMoneytoPeople Unconditional
Flow from Ag_CashMarket to Ag_MoneyProduced
GrossAgMoneytoPeople = Ag_CashMarket
compartment: Hog_Pop Unconditional
dHog_Pop/dt = -Hogs_toHogs
Initial Value = 1000000
compartment: Hogs Unconditional
dHogs/dt = +Hogs_toHogs-Hogs_toCalories
Initial Value = 2243
compartment: Hogs_Calories Unconditional
dHogs_Calories/dt = +(Hog_Calories*Hogs_toCalories)-Hogs_toAgCalProd
Initial Value = 76934900
flow: Hogs_toAgCalProd Unconditional
Flow from Hogs_Calories to Ag_CaloriesProduced
Hogs_toAgCalProd = Hogs_Calories
flow: Hogs_toCalories Unconditional
Flow from Hogs to Hogs_Calories
Hogs_toCalories = .25*Hogs
flow: Hogs_toHogs Unconditional
Flow from Hog_Pop to Hogs
Hogs_toHogs = .25*Hogs
compartment: Milk Unconditional
Gallons
dMilk/dt = (MilkCow_GallonsPerCow*MilkCows)-MilktoPeople-MilktoButter-MilkforSale

Initial Value = 54390
flow: Milk_toCalories Unconditional
Flow from MilkCalories to Ag_CaloriesProduced
Milk_toCalories = MilkCalories
flow: Milk_toMoney Unconditional
Flow from MilkSold to Ag_CashMarket
Milk_toMoney = MilkSold
compartment: MilkCalories Unconditional
dMilkCalories/dt = +(Milk_Calories*MilktoPeople)-Milk_toCalories
Initial Value = 91643904
compartment: MilkCow_Dropped Unconditional
dMilkCow_Dropped/dt = +MilkCow_toDrop-MilkCowDropped_toMilkCow
Initial Value = 129
compartment: MilkCow_Money Unconditional
dMilkCow_Money/dt = +(MilkCows_PricePerSale*MilkCow_toMoney)-MilkCow_toCash
Initial Value = 837
compartment: MilkCow_Pop Unconditional
dMilkCow_Pop/dt = -MilkCow_toDrop-MilkCow_toPurchase
Initial Value = 100000000
compartment: MilkCow_Purchased Unconditional
dMilkCow_Purchased/dt = +MilkCow_toPurchase-MilkCowPurchased_toMilkCow
Initial Value = 16
flow: MilkCow_toCash Unconditional
Flow from MilkCow_Money to Ag_CashMarket
MilkCow_toCash = MilkCow_Money
flow: MilkCow_toDrop Unconditional
Flow from MilkCow_Pop to MilkCow_Dropped
MilkCow_toDrop = MilkCow_Dropped
flow: MilkCow_toMoney Unconditional
Flow from MilkCows_sold to MilkCow_Money
MilkCow_toMoney = MilkCows_sold
flow: MilkCow_toPurchase Unconditional
Flow from MilkCow_Pop to MilkCow_Purchased
MilkCow_toPurchase = MilkCow_Purchased
flow: MilkCowDropped_toMilkCow Unconditional
Flow from MilkCow_Dropped to MilkCows
MilkCowDropped_toMilkCow = MilkCow_Dropped
flow: MilkCowPurchased_toMilkCow Unconditional
Flow from MilkCow_Purchased to MilkCows
MilkCowPurchased_toMilkCow = MilkCow_Purchased
compartment: MilkCows Conditional
dMilkCows/dt =
 0 for MilkCows>676
 -MilkCows_toSold-MilkCows_toDied-
MilkCows_toSlaughtered+MilkCowDropped_toMilkCow+MilkCowPurchased_toMilkCow by default
Initial Value = 370
compartment: MilkCows_Calories2 Unconditional
dMilkCows_Calories2/dt = +(MilkCow_Calories*MilkCows_toCalories)-MilkCows_toAgCalProd
Initial Value = 10707231
compartment: MilkCows_died Unconditional
dMilkCows_died/dt = +MilkCows_toDied-MilkCows_toDead
Initial Value = 6
compartment: MilkCows_slaughtered Unconditional
dMilkCows_slaughtered/dt = +MilkCows_toSlaughtered-MilkCows_toCalories
Initial Value = 27
compartment: MilkCows_sold Unconditional
dMilkCows_sold/dt = +MilkCows_toSold-MilkCow_toMoney
Initial Value = 40
flow: MilkCows_toAgCalProd Unconditional
Flow from MilkCows_Calories2 to Ag_CaloriesProduced

MilkCows_toAgCalProd = MilkCows_Calories2
flow: MilkCows_toCalories Unconditional
Flow from MilkCows_slaughtered to MilkCows_Calories2
MilkCows_toCalories = MilkCows_slaughtered
flow: MilkCows_toDead Unconditional
Flow from MilkCows_died to DeadAnimals
MilkCows_toDead = MilkCows_died
flow: MilkCows_toDied Unconditional
Flow from MilkCows to MilkCows_died
MilkCows_toDied = MilkCows_died
flow: MilkCows_toSlaughtered Unconditional
Flow from MilkCows to MilkCows_slaughtered
MilkCows_toSlaughtered = MilkCows_slaughtered
flow: MilkCows_toSold Unconditional
Flow from MilkCows to MilkCows_sold
MilkCows_toSold = MilkCows_sold
compartment: MilkforButter Unconditional
lbs
dMilkforButter/dt = +MilktoButter-ButterTranstoCal
Initial Value = 4796
flow: MilkforSale Unconditional
Flow from Milk to MilkSold
MilkforSale = MilkSold_Perct * Milk
compartment: MilkSold Unconditional
dMilkSold/dt = +(APPG_Milk*MilkforSale)-Milk_toMoney
Initial Value = 13.56
flow: MilktoButter Unconditional
Flow from Milk to MilkforButter
MilktoButter = MilkButter_Perct * Milk
flow: MilktoPeople Unconditional
Flow from Milk to C1
MilktoPeople = MilkConsumed_Perct * Milk
flow: NetCaloriestoPeople_Agric Unconditional
Flow from Ag_CaloriesProduced to TotalCaloriesfromAgriculture
NetCaloriestoPeople_Agric = Ag_CaloriesProduced
flow: NetMoneytoPeopleAgric Unconditional
Flow from NetProfittoFarmers to NetMoneyfromAgric
NetMoneytoPeopleAgric = NetProfittoFarmers
compartment: NetProfittoFarmers Unconditional
dNetProfittoFarmers/dt = +TotalRevenuesFarmers+CostsofFarming-NetMoneytoPeopleAgric
Initial Value = -20859.54
flow: Oat_toCalories Unconditional
Flow from Oats_Food to C1
Oat_toCalories = Oats_Food
compartment: Oats_acres Unconditional
dOats_acres/dt = 0
Initial Value = 1715
compartment: Oats_Animals Unconditional
dOats_Animals/dt = +Oats_toAnimals
Initial Value = 6659
compartment: Oats_bushels Unconditional
dOats_bushels/dt = (BperAcre_oats * CropEnhancementFactor*Oats_acres)+(BperAcre_oats *
RandomNumber1sd_Crops*Oats_acres)-Oats_toPeople-Oats_Sold-Oats_toAnimals
Initial Value = 9060
compartment: Oats_Food Unconditional
dOats_Food/dt = +Oats_toPeople-Oat_toCalories
Initial Value = 1449.60
compartment: Oats_Market Unconditional
dOats_Market/dt = +Oats_Sold-Oats_toMoney
Initial Value = 951.30

compartment: Oats_Money Unconditional
dOats_Money/dt = +(APPB_Oats*Oats_toMoney)-Oats_toCash
Initial Value = 294.90
flow: Oats_Sold Unconditional
Flow from Oats_bushels to Oats_Market
Oats_Sold = APercent_AgFood_toMarket * Oats_bushels
flow: Oats_toAgCaloriesProduced Unconditional
Flow from C1 to Ag_CaloriesProduced
Oats_toAgCaloriesProduced = Oats_toCalories2
flow: Oats_toAnimals Unconditional
Flow from Oats_bushels to Oats_Animals
Oats_toAnimals = APercent_AgFood_toAnimals * Oats_bushels
compartment: Oats_toCalories2 Unconditional
dOats_toCalories2/dt = +(Oat_weightperbush*Oat_calories*Oat_toCalories)-Oats_toAgCaloriesProduced
Initial Value = 81827021
flow: Oats_toCash Unconditional
Flow from Oats_Money to Ag_CashMarket
Oats_toCash = Oats_Money
flow: Oats_toMoney Unconditional
Flow from Oats_Market to Oats_Money
Oats_toMoney = Oats_Market
flow: Oats_toPeople Unconditional
Flow from Oats_bushels to Oats_Food
Oats_toPeople = APercent_AgFood_toPeople * Oats_bushels
compartment: OtherCattle Conditional
dOtherCattle/dt =
0 for OtherCattle>605
-OtherCattleSold-OtherCattleDied-
OtherCattleSlaughtered+OtherCowDropped_toOtherCow+OtherCowPurchased_toOtherCow by default
Initial Value = 331
compartment: OtherCattle_sold Unconditional
dOtherCattle_sold/dt = +OtherCattleSold-OtherCows_toMoney
Initial Value = 36
flow: OtherCattleDied Unconditional
Flow from OtherCattle to OtherCows_died
OtherCattleDied = OtherCows_died
flow: OtherCattleSlaughtered Unconditional
Flow from OtherCattle to OtherCows_slaughtered
OtherCattleSlaughtered = OtherCows_slaughtered
flow: OtherCattleSold Unconditional
Flow from OtherCattle to OtherCattle_sold
OtherCattleSold = OtherCattle_sold
compartment: OtherCow_Calories2 Unconditional
dOtherCow_Calories2/dt = +(OtherCows_Calories*OtherCow_toCalories)-OtherCow_toAgCalProd
Initial Value = 9578631
compartment: OtherCow_Dropped Unconditional
dOtherCow_Dropped/dt = +OtherCow_toDrop-OtherCowDropped_toOtherCow
Initial Value = 115
compartment: OtherCow_Pop Unconditional
dOtherCow_Pop/dt = -OtherCow_toDrop-OtherCow_toPurchase
Initial Value = 100000000
compartment: OtherCow_Purchased Unconditional
dOtherCow_Purchased/dt = +OtherCow_toPurchase-OtherCowPurchased_toOtherCow
Initial Value = 14
flow: OtherCow_toAgCalProd Unconditional
Flow from OtherCow_Calories2 to Ag_CaloriesProduced
OtherCow_toAgCalProd = OtherCow_Calories2
flow: OtherCow_toCalories Unconditional
Flow from OtherCows_slaughtered to OtherCow_Calories2
OtherCow_toCalories = OtherCows_slaughtered

flow: OtherCow_toDrop Unconditional
Flow from OtherCow_Pop to OtherCow_Dropped
OtherCow_toDrop = OtherCow_Dropped
flow: OtherCow_toPurchase Unconditional
Flow from OtherCow_Pop to OtherCow_Purchased
OtherCow_toPurchase = OtherCow_Purchased
flow: OtherCowDropped_toOtherCow Unconditional
Flow from OtherCow_Dropped to OtherCattle
OtherCowDropped_toOtherCow = OtherCow_Dropped
flow: OtherCowPurchased_toOtherCow Unconditional
Flow from OtherCow_Purchased to OtherCattle
OtherCowPurchased_toOtherCow = OtherCow_Purchased
compartment: OtherCows_died Unconditional
dOtherCows_died/dt = +OtherCattleDied-OtherCows_toDead
Initial Value = 17
compartment: OtherCows_Money Unconditional
dOtherCows_Money/dt = +(OtherCows_PricePerSale*OtherCows_toMoney)-OtherCows_toCash
Initial Value = 749
compartment: OtherCows_slaughtered Unconditional
dOtherCows_slaughtered/dt = +OtherCattleSlaughtered-OtherCow_toCalories
Initial Value = 24
flow: OtherCows_toCash Unconditional
Flow from OtherCows_Money to Ag_CashMarket
OtherCows_toCash = OtherCows_Money
flow: OtherCows_toDead Unconditional
Flow from OtherCows_died to DeadAnimals
OtherCows_toDead = OtherCows_died
flow: OtherCows_toMoney Unconditional
Flow from OtherCattle_sold to OtherCows_Money
OtherCows_toMoney = OtherCattle_sold
compartment: Oxen Conditional
dOxen/dt =
 0 for Oxen>144
 -Oxen_toSold-Oxen_toDied-Oxen_toSlaughtered+OxenDropped_toOxen+OxenPurchased_toOxen by default
Initial Value = 79
compartment: Oxen_Calories2 Unconditional
dOxen_Calories2/dt = +(Oxen_Calories*Oxen_toCalories)-Oxen_toAgCalProd
Initial Value = 2286138
compartment: Oxen_died Unconditional
dOxen_died/dt = +Oxen_toDied-Oxen_toDead
Initial Value = 4
compartment: Oxen_Dropped Unconditional
dOxen_Dropped/dt = +Oxen_toDrop-OxenDropped_toOxen
Initial Value = 28
compartment: Oxen_Money Unconditional
dOxen_Money/dt = +(Oxen_PricePerSale*Oxen_toMoney)-Oxen_toCash
Initial Value = 179
compartment: Oxen_Pop Unconditional
dOxen_Pop/dt = -Oxen_toDrop-Oxen_toPurchase
Initial Value = 100000000
compartment: Oxen_Purchased Unconditional
dOxen_Purchased/dt = +Oxen_toPurchase-OxenPurchased_toOxen
Initial Value = 3
compartment: Oxen_slaughtered Unconditional
dOxen_slaughtered/dt = +Oxen_toSlaughtered-Oxen_toCalories
Initial Value = 6
compartment: Oxen_sold Unconditional
dOxen_sold/dt = +Oxen_toSold-Oxen_toMoney
Initial Value = 9
flow: Oxen_toAgCalProd Unconditional

Flow from Oxen_Calories2 to Ag_CaloriesProduced
Oxen_toAgCalProd = Oxen_Calories2
flow: Oxen_toCalories Unconditional
Flow from Oxen_slaughtered to C1
Oxen_toCalories = Oxen_slaughtered
flow: Oxen_toCash Unconditional
Flow from Oxen_Money to Ag_CashMarket
Oxen_toCash = Oxen_Money
flow: Oxen_toDead Unconditional
Flow from Oxen_died to DeadAnimals
Oxen_toDead = Oxen_died
flow: Oxen_toDied Unconditional
Flow from Oxen to Oxen_died
Oxen_toDied = Oxen_died
flow: Oxen_toDrop Unconditional
Flow from Oxen_Pop to Oxen_Dropped
Oxen_toDrop = Oxen_Dropped
flow: Oxen_toMoney Unconditional
Flow from Oxen_sold to Oxen_Money
Oxen_toMoney = Oxen_sold
flow: Oxen_toPurchase Unconditional
Flow from Oxen_Pop to Oxen_Purchased
Oxen_toPurchase = Oxen_Purchased
flow: Oxen_toSlaughtered Unconditional
Flow from Oxen to Oxen_slaughtered
Oxen_toSlaughtered = Oxen_slaughtered
flow: Oxen_toSold Unconditional
Flow from Oxen to Oxen_sold
Oxen_toSold = Oxen_sold
flow: OxenDropped_toOxen Unconditional
Flow from Oxen_Dropped to Oxen
OxenDropped_toOxen = Oxen_Dropped
flow: OxenPurchased_toOxen Unconditional
Flow from Oxen_Purchased to Oxen
OxenPurchased_toOxen = Oxen_Purchased
compartment: Peach_acres Unconditional
dPeach_acres/dt = 0
Initial Value = 47
compartment: Peach_Animals Unconditional
dPeach_Animals/dt = +Peach_toAnimals
Initial Value = 883
compartment: Peach_bushels Unconditional
dPeach_bushels/dt = (CropEnhancementFactor*BperAcre_peach * Peach_acres)+(RandomNumber1sd_Crops*BperAcre_peach * Peach_acres)-Peach_Sold-Peach_toPeople-Peach_toAnimals
Initial Value = 1202
compartment: Peach_Calories2 Unconditional
dPeach_Calories2/dt = +(Peach_weightperbush*Peach_calories*Peach_toCalories)-Peach_toAgCaloriesProduced
Initial Value = 1702032
compartment: Peach_Food Unconditional
dPeach_Food/dt = +Peach_toPeople-Peach_toCalories
Initial Value = 192.32
compartment: Peach_Market Unconditional
dPeach_Market/dt = +Peach_Sold-Peach_toMoney
Initial Value = 126.21
compartment: Peach_Money Unconditional
dPeach_Money/dt = +(APPB_Peach*Peach_toMoney)-Peach_toCash
Initial Value = 169.12
flow: Peach_Sold Unconditional
Flow from Peach_bushels to Peach_Market

Peach_Sold = APercent_AgFood_toMarket * Peach_bushels
flow: Peach_toAgCaloriesProduced Unconditional
Flow from Peach_Calories2 to Ag_CaloriesProduced
Peach_toAgCaloriesProduced = Peach_Calories2
flow: Peach_toAnimals Unconditional
Flow from Peach_bushels to Peach_Animals
Peach_toAnimals = APercent_AgFood_toAnimals * Peach_bushels
flow: Peach_toCalories Unconditional
Flow from Peach_Food to Peach_Calories2
Peach_toCalories = Peach_Food
flow: Peach_toCash Unconditional
Flow from Peach_Money to Ag_CashMarket
Peach_toCash = Peach_Money
flow: Peach_toMoney Unconditional
Flow from Peach_Market to Peach_Money
Peach_toMoney = Peach_Market
flow: Peach_toPeople Unconditional
Flow from Peach_bushels to Peach_Food
Peach_toPeople = APercent_AgFood_toPeople * Peach_bushels
compartment: Pot_Calories2 Unconditional
dPot_Calories2/dt = +(Potato_irish_weightperbush*Potato_irish_calories*Pot_toCalories)-Pot_toAgCalProd
Initial Value = 291770976
compartment: Pot_Food Unconditional
dPot_Food/dt = +Potato_toPeople-Pot_toCalories
Initial Value = 5415.20
compartment: Pot_Market Unconditional
dPot_Market/dt = +Potato_Sold-Pot_toMoney
Initial Value = 3553.73
flow: Pot_toAgCalProd Unconditional
Flow from C1 to Ag_CaloriesProduced
Pot_toAgCalProd = Pot_Calories2
flow: Pot_toCalories Unconditional
Flow from Pot_Food to C1
Pot_toCalories = Pot_Food
flow: Pot_toCash Unconditional
Flow from Potatoe_Money to Ag_CashMarket
Pot_toCash = Potatoe_Money
flow: Pot_toMoney Unconditional
Flow from Pot_Market to Potatoe_Money
Pot_toMoney = Pot_Market
flow: Potato_Sold Unconditional
Flow from Potatoes_bushels to Pot_Market
Potato_Sold = APercent_AgFood_toMarket * Potatoes_bushels
flow: Potato_toPeople Unconditional
Flow from Potatoes_bushels to Pot_Food
Potato_toPeople = APercent_AgFood_toPeople * Potatoes_bushels
compartment: Potatoe_Money Unconditional
dPotatoe_Money/dt = +(APPB_Potato_irish*Pot_toMoney)-Pot_toCash
Initial Value = 1243.80
compartment: Potatoes_acres Unconditional
dPotatoes_acres/dt = 0
Initial Value = 708
compartment: Potatoes_Animals Unconditional
dPotatoes_Animals/dt = +Potatoes_toAnimals
Initial Value = 25876
compartment: Potatoes_bushels Unconditional
dPotatoes_bushels/dt =
(BperAcre_potato_irish*CropEnhancementFactor*Potatoes_acres)+(BperAcre_potato_irish*RandomNumber1sd_Crops*Potatoes_acres)-Potato_toPeople-Potato_Sold-Potatoes_toAnimals
Initial Value = 33845

flow: Potatoes_toAnimals Unconditional
Flow from Potatoes_bushels to Potatoes_Animals
Potatoes_toAnimals = APercent_AgFood_toAnimals * Potatoes_bushels
flow: Poulltry_toCalories Unconditional
Flow from Poultry to Poultry_Calories2
Poulltry_toCalories = .5 * Poultry
compartment: Poultry Unconditional
dPoultry/dt = +Poultry_toPoultry-Poulltry_toCalories
Initial Value = 3917
compartment: Poultry_Calories2 Unconditional
dPoultry_Calories2/dt = +(Poultry_Calories*Poulltry_toCalories)-Poultry_toAgCalProd
Initial Value = 2087290
compartment: Poultry_Pop Unconditional
dPoultry_Pop/dt = -Poultry_toPoultry
Initial Value = 1000000000
flow: Poultry_toAgCalProd Unconditional
Flow from Poultry_Calories to Ag_CaloriesProduced
Poultry_toAgCalProd = Poultry_Calories2
flow: Poultry_toPoultry Unconditional
Flow from Poultry_Pop to Poultry
Poultry_toPoultry = .5 * Poultry
compartment: Sheep Conditional
dSheep/dt =
 0 for Sheep>842
 -SheepDied-SheepSlaughtered-SheepSold+SheepDropped_toSheep+SheepPurchased_toSheep by default
Initial Value = 431
compartment: Sheep_Calories2 Unconditional
dSheep_Calories2/dt = +(Sheep_Calories*Sheep_toCalories)-Sheep_toAgCalProd
Initial Value = 577837
compartment: Sheep_died Unconditional
dSheep_died/dt = +SheepDied-Sheep_toDead
Initial Value = 103
compartment: Sheep_Dropped Unconditional
dSheep_Dropped/dt = +Sheep_toDrop-SheepDropped_toSheep
Initial Value = 124
compartment: Sheep_Money Unconditional
dSheep_Money/dt = +(Sheep_PricePerSale*Sheep_toMoney)-Sheep_toCash
Initial Value = 33
compartment: Sheep_Pop Unconditional
dSheep_Pop/dt = -Sheep_toDrop-Sheep_toPurchase
Initial Value = 100000000
compartment: Sheep_Purchased Unconditional
dSheep_Purchased/dt = +Sheep_toPurchase-SheepPurchased_toSheep
Initial Value = 22
compartment: Sheep_slaughtered Unconditional
dSheep_slaughtered/dt = +SheepSlaughtered-Sheep_toCalories
Initial Value = 9
compartment: Sheep_sold Unconditional
dSheep_sold/dt = +SheepSold-Sheep_toMoney
Initial Value = 11
flow: Sheep_toAgCalProd Unconditional
Flow from C1 to Ag_CaloriesProduced
Sheep_toAgCalProd = Sheep_Calories2
flow: Sheep_toCalories Unconditional
Flow from Sheep_slaughtered to Sheep_Calories2
Sheep_toCalories = Sheep_slaughtered
flow: Sheep_toCash Unconditional
Flow from Sheep_Market to Ag_CashMarket
Sheep_toCash = Sheep_Money
flow: Sheep_toDead Unconditional

Flow from Sheep_died to DeadAnimals
Sheep_toDead = Sheep_died
flow: Sheep_toDrop Unconditional
Flow from Sheep_Pop to Sheep_Dropped
Sheep_toDrop = Sheep_Dropped
flow: Sheep_toMoney Unconditional
Flow from Sheep_sold to Sheep_Money
Sheep_toMoney = Sheep_sold
flow: Sheep_toPurchase Unconditional
Flow from Sheep_Pop to Sheep_Purchased
Sheep_toPurchase = Sheep_Purchased
flow: SheepDied Unconditional
Flow from Sheep to Sheep_died
SheepDied = 0.23577* Sheep
flow: SheepDropped_toSheep Unconditional
Flow from Sheep_Dropped to Sheep
SheepDropped_toSheep = Sheep_Dropped
flow: SheepPurchased_toSheep Unconditional
Flow from Sheep_Purchased to Sheep
SheepPurchased_toSheep = Sheep_Purchased
flow: SheepSlaughtered Unconditional
Flow from Sheep to Sheep_slaughtered
SheepSlaughtered = Sheep_slaughtered
flow: SheepSold Unconditional
Flow from Sheep to Sheep_sold
SheepSold = Sheep_sold
compartment: Sw_Potatoes_acres Unconditional
dSw_Potatoes_acres/dt = 0
Initial Value = 623
compartment: Sw_Potatoes_bushels Unconditional
dSw_Potatoes_bushels/dt =
(BperAcre_potatos_sw*CropEnhancementFactor*Sw_Potatoes_acres)+(BperAcre_potatos_sw*RandomNumber1
sd_Crops*Sw_Potatoes_acres)-SwPotato_toPeople-SwPotato_Sold-SwPotatoes_toAnimals
Initial Value = 37030
compartment: SwPot_Calories2 Unconditional
dSwPot_Calories2/dt = +(Potato_sweet_weightperbushel*Potato_sweet_calories*SwPot_toCalories)-
SwPot_toAgCalProd
Initial Value = 132952512
compartment: SwPot_Food Unconditional
dSwPot_Food/dt = +SwPotato_toPeople-SwPot_toCalories
Initial Value = 5924.80
compartment: SwPot_Market Unconditional
dSwPot_Market/dt = +SwPotato_Sold-SwPot_toMoney
Initial Value = 3888.15
flow: SwPot_toAgCalProd Unconditional
Flow from C1 to Ag_CaloriesProduced
SwPot_toAgCalProd = SwPot_Calories2
flow: SwPot_toCalories Unconditional
Flow from SwPot_Food to SwPot_Calories2
SwPot_toCalories = SwPot_Food
flow: SwPot_toCash Unconditional
Flow from SwPotatoe_Money to Ag_CashMarket
SwPot_toCash = SwPotatoe_Money
flow: SwPot_toMoney Unconditional
Flow from SwPot_Market to SwPotatoe_Money
SwPot_toMoney = SwPot_Market
flow: SwPotato_Sold Unconditional
Flow from Sw_Potatoes_bushels to SwPot_Market
SwPotato_Sold = APercent_AgFood_toMarket * Sw_Potatoes_bushels
flow: SwPotato_toPeople Unconditional

Flow from Sw_Potatoes_bushels to SwPot_Food
SwPotato_toPeople = APercent_AgFood_toPeople * Sw_Potatoes_bushels
compartment: SwPotatoe_Money Unconditional
dSwPotatoe_Money/dt = +(APPB_Potato_sweet*SwPot_toMoney)-SwPot_toCash
Initial Value = 1555.26
compartment: SwPotatoes_Animals Unconditional
dSwPotatoes_Animals/dt = +SwPotatoes_toAnimals
Initial Value = 27218
flow: SwPotatoes_toAnimals Unconditional
Flow from Sw_Potatoes_bushels to SwPotatoes_Animals
SwPotatoes_toAnimals = APercent_AgFood_toAnimals * Sw_Potatoes_bushels
compartment: Tob_Market Unconditional
dTob_Market/dt = +Tobacco_Sold-Tob_toMoney
Initial Value = 1975
flow: Tob_toCash Unconditional
Flow from Tobacco_Money to Ag_CashMarket
Tob_toCash = Tobacco_Money
flow: Tob_toMoney Unconditional
Flow from Tob_Market to Tobacco_Money
Tob_toMoney = Tob_Market
compartment: Tobacco_acres Unconditional
dTobacco_acres/dt = 0
Initial Value = 15
compartment: Tobacco_Money Unconditional
dTobacco_Money/dt = +(APPP_Tobacco*Tob_toMoney)-Tob_toCash
Initial Value = 276.50
compartment: Tobacco_pounds Unconditional
dTobacco_pounds/dt = (BperAcre_tobacco * CropEnhancementFactor*Tobacco_acres)+(BperAcre_tobacco * RandomNumber1sd_Crops*Tobacco_acres)-Tobacco_Sold
Initial Value = 1975
flow: Tobacco_Sold Unconditional
Flow from Tobacco_pounds to Tob_Market
Tobacco_Sold = Tobacco_pounds
flow: tonegative Unconditional
Flow from ExpensesFarming to ExpensesFarmingtoNegative
tonegative = ExpensesFarming
flow: TotalRevenuesFarmers Unconditional
Flow from Ag_MoneyTotal to NetProfittoFarmers
TotalRevenuesFarmers = Ag_MoneyTotal
compartment: Wheat_acres Unconditional
dWheat_acres/dt = 0
Initial Value = 9
compartment: Wheat_Animals Unconditional
dWheat_Animals/dt = +Wheat_toAnimals
Initial Value = 86
compartment: Wheat_bushels Unconditional
dWheat_bushels/dt = (BperAcre_wheat * CropEnhancementFactor*Wheat_acres)+(BperAcre_wheat * RandomNumber1sd_Crops*Wheat_acres)-Wheat_toPeople-Wheat_Sold-Wheat_toAnimals
Initial Value = 117
compartment: Wheat_Calories2 Unconditional
dWheat_Calories2/dt = +(Wheat_weightperbush*Wheat_calories*Wheat_toCalories)-Wheat_toAgCalProd
Initial Value = 1742083
compartment: Wheat_Food Unconditional
dWheat_Food/dt = +Wheat_toPeople-Wheat_toCalories
Initial Value = 18.72
compartment: Wheat_Market Unconditional
dWheat_Market/dt = +Wheat_Sold-Wheat_toMoney
Initial Value = 12.29
compartment: Wheat_Money Unconditional
dWheat_Money/dt = +(APPB_Wheat*Wheat_toMoney)-Wheat_toCash

Initial Value = 10.20
flow: Wheat_Sold Unconditional
Flow from Wheat_bushels to Wheat_Market
Wheat_Sold = APercent_AgFood_toMarket * Wheat_bushels
flow: Wheat_toAgCalProd Unconditional
Flow from C1 to Ag_CaloriesProduced
Wheat_toAgCalProd = Wheat_Calories2
flow: Wheat_toAnimals Unconditional
Flow from Wheat_bushels to Wheat_Animals
Wheat_toAnimals = APercent_AgFood_toAnimals* Wheat_bushels
flow: Wheat_toCalories Unconditional
Flow from Wheat_Food to C1
Wheat_toCalories = Wheat_Food
flow: Wheat_toCash Unconditional
Flow from Wheat_Money to Ag_CashMarket
Wheat_toCash = Wheat_Money
flow: Wheat_toMoney Unconditional
Flow from Wheat_Market to Wheat_Money
Wheat_toMoney = Wheat_Market
flow: Wheat_toPeople Unconditional
Flow from Wheat_bushels to Wheat_Food
Wheat_toPeople = APercent_AgFood_toPeople * Wheat_bushels
compartment: Wool Unconditional
2.16 lbs wool per sheep
dWool/dt = (APPP_Wool*2.16*Sheep)
Initial Value = 271
flow: Wool_toMarket Unconditional
Flow from Wool to Ag_CashMarket
Wool_toMarket = Wool
compartment: BayHealthDump Unconditional
dBayHealthDump/dt = +F16
Initial Value = 0.0
compartment: BayHealthFactor Conditional Global
dBayHealthFactor/dt =
  -.50-F16 for FertilizerUse_Aggregate>=450
  -.45-F16 for FertilizerUse_Aggregate>=400
  -.40-F16 for FertilizerUse_Aggregate>=350
  -.35-F16 for FertilizerUse_Aggregate>=300
  -.30-F16 for FertilizerUse_Aggregate>=250
  -.25-F16 for FertilizerUse_Aggregate>=200
  -.20-F16 for FertilizerUse_Aggregate>=150
  -.15-F16 for FertilizerUse_Aggregate>=100
  -.10-F16 for FertilizerUse_Aggregate>=50
  -.05-F16 for FertilizerUse_Aggregate>=25
  0-F16 by default
Initial Value = 0
compartment: BlackTotal Unconditional
dBlackTotal/dt = TotalPop_FB+TotalPop_MB-F24
Initial Value = 1421
compartment: CalDump Unconditional
dCalDump/dt = +toCalDump
Initial Value = 0.0
compartment: Calories_from_Ag_and_ChesBay Unconditional
dCalories_from_Ag_and_ChesBay/dt = +CaloriesfromFishing+TotalCaloriesfromAgric-toCalDump
Initial Value = 1949627154
flow: CaloriesfromFishing Unconditional
Flow from TotalCaloriesFromFishing to Calories_from_Ag_and_ChesBay
CaloriesfromFishing = TotalCaloriesFromFishing
Chesapeake
compartment: BAYCash_Market Unconditional

dBAYCash_Market/dt = -
GrossMoneytoPeople_Bay+Oysters_toBayCash+Clams_toBayCash+Crabs_toBayCash+Terps_toBayCash+Shad_toBayCash+SpMackeral_toBayCash+Bluefish_toBayCash+GrTrout_toBayCash+Sheepshead_toBayCash+OtherFish_toBayCash+Menhaden_toBayCash
Initial Value = 104298
compartment: BAYFood_CaloriesProduced Unconditional
dBAYFood_CaloriesProduced/dt = -
NetCaloriestoPeople+Oysters_toBayProd+Crabs_toBayProd+Clams_toBayProd+Terps_toBayProd+Shad_toBayProd+SpMackeral_toBayProd+Bluefish_toBayProd+GrTrout_toBayProd+Sheepshead_toBayProd+OtherFish_toBayProd
Initial Value = 272624869
compartment: Bluefish_Calories2 Unconditional
dBluefish_Calories2/dt = +(Calories_Bluefish*Bluefish_toCalories)-Bluefish_toBayProd
Initial Value = 20983009
compartment: Bluefish_Food Unconditional
dBluefish_Food/dt = +Bluefish_toFood-Bluefish_toCalories
Initial Value = 37470
compartment: BlueFish_Harvest Unconditional
dBlueFish_Harvest/dt = (BayHealthFactor*BluefishPool)+(RandomNumber1sd3_Fish*BluefishPool)-
Bluefish_toFood-Bluefish_toMkt
Initial Value = 189943
compartment: Bluefish_Market Unconditional
dBluefish_Market/dt = +Bluefish_toMkt-Bluefish_toMoney
Initial Value = 152474
compartment: Bluefish_Money Unconditional
dBluefish_Money/dt = +(BPPP_Bluefish*Bluefish_toMoney)-Bluefish_toBayCash
Initial Value = 3049
flow: Bluefish_toBayCash Unconditional
Flow from Bluefish_Money to BAYCash_Market
Bluefish_toBayCash = Bluefish_Money
flow: Bluefish_toBayProd Unconditional
Flow from Bluefish_Calories2 to BAYFood_CaloriesProduced
Bluefish_toBayProd = Bluefish_Calories2
flow: Bluefish_toCalories Unconditional
Flow from Bluefish_Food to Bluefish_Calories2
Bluefish_toCalories = Bluefish_Food
flow: Bluefish_toFood Unconditional
Flow from BlueFish_Harvest to Bluefish_Food
Bluefish_toFood = AFoodvsMarket_estuary * BlueFish_Harvest
flow: Bluefish_toMkt Unconditional
Flow from BlueFish_Harvest to Bluefish_Market
Bluefish_toMkt = (1-AFoodvsMarket_estuary) * BlueFish_Harvest
flow: Bluefish_toMoney Unconditional
Flow from Bluefish_Market to Bluefish_Money
Bluefish_toMoney = Bluefish_Market
compartment: BluefishPool Unconditional
dBluefishPool/dt = 0
Initial Value = 189943
compartment: Clam_Calories2 Unconditional
dClam_Calories2/dt = +(Clam_Calories*Clams_toCalories)-Clams_toBayProd
Initial Value = 1020951
compartment: Clam_Food Unconditional
dClam_Food/dt = +Clam_toFood-Clams_toCalories
Initial Value = 3039
compartment: Clam_Harvest Unconditional
dClam_Harvest/dt = (BayHealthFactor*ClamPool)+(RandomNumber1sd3_Fish*ClamPool)-Clam_toFood-
Clam_toMkt
Initial Value = 15403
compartment: Clam_Market Unconditional
dClam_Market/dt = +Clam_toMkt-Clams_toMoney

Initial Value = 12365
flow: Clam_toFood Unconditional
Flow from Clam_Harvest to Clam_Food
Clam_toFood = AFoodvsMarket_estuary * Clam_Harvest
flow: Clam_toMkt Unconditional
Flow from Clam_Harvest to Clam_Market
Clam_toMkt = (1-AFoodvsMarket_estuary) * Clam_Harvest
compartment: ClamPool Unconditional
dClamPool/dt = 0
Initial Value = 15403
compartment: Clams_Money Unconditional
dClams_Money/dt = +(BPPP_Clam*Clams_toMoney)-Clams_toBayCash
Initial Value = 618
flow: Clams_toBayCash Unconditional
Flow from Clams_Money to BAYCash_Market
Clams_toBayCash = Clams_Money
flow: Clams_toBayProd Unconditional
Flow from Clam_Calories2 to BAYFood_CaloriesProduced
Clams_toBayProd = Clam_Calories2
flow: Clams_toCalories Unconditional
Flow from Clam_Food to Clam_Calories2
Clams_toCalories = Clam_Food
flow: Clams_toMoney Unconditional
Flow from Clam_Market to Clams_Money
Clams_toMoney = Clam_Market
compartment: Crab_Calories2 Unconditional
dCrab_Calories2/dt = +(Crab_Calories*Crabs_toCalories)-Crabs_toBayProd
Initial Value = 12434831
compartment: Crab_Food Unconditional
dCrab_Food/dt = +Crab_toFood-Crabs_toCalories
Initial Value = 8933
compartment: Crab_Harvest Unconditional
dCrab_Harvest/dt = (BayHealthFactor*CrabPool)+(RandomNumber1sd3_Fish*CrabPool)-Crab_toFood-Crab_toMkt
Initial Value = 45284
compartment: Crab_Market Unconditional
dCrab_Market/dt = +Crab_toMkt-Crabs_toMoney
Initial Value = 36351
flow: Crab_toFood Unconditional
Flow from Crab_Harvest to Crab_Food
Crab_toFood = AFoodvsMarket_estuary * Crab_Harvest
flow: Crab_toMkt Unconditional
Flow from Crab_Harvest to Crab_Market
Crab_toMkt = (1-AFoodvsMarket_estuary) * Crab_Harvest
compartment: CrabPool Unconditional
dCrabPool/dt = 0
Initial Value = 45284
compartment: Crabs_Money Unconditional
dCrabs_Money/dt = +(BPPB_Crab*Crabs_toMoney)-Crabs_toBayCash
Initial Value = 1091
flow: Crabs_toBayCash Unconditional
Flow from Crabs_Money to BAYCash_Market
Crabs_toBayCash = Crabs_Money
flow: Crabs_toBayProd Unconditional
Flow from Crab_Calories2 to BAYFood_CaloriesProduced
Crabs_toBayProd = Crab_Calories2
flow: Crabs_toCalories Unconditional
Flow from Crab_Food to Crab_Calories2
Crabs_toCalories = Crab_Food
flow: Crabs_toMoney Unconditional

Flow from Crab_Market to Crabs_Money
Crabs_toMoney = Crab_Market
compartment: Expenses_Fishing Unconditional
dExpenses_Fishing/dt = +FishingExpenses-TotalExpensesFishermenNegative
Initial Value = 19630
FishingCosts
compartment: AnnualCosts Unconditional
1Year
dAnnualCosts/dt = +AnnualOysterPlantingCosts+AnnualOysterGearOutfitCosts-Annualized1YrCosts
Initial Value = 16056
flow: AnnualFishHouseCosts Unconditional
Flow from FishHousesCosts to CapitalCosts
AnnualFishHouseCosts = (1/30) * FishHousesCosts
flow: AnnualFishingVesselCosts Unconditional
Flow from FishingVesselsCosts to CapitalCosts
AnnualFishingVesselCosts = (1/30) * FishingVesselsCosts
flow: AnnualFykesCosts Unconditional
Flow from FykesCosts to ShortCosts
AnnualFykesCosts = (1/3) * FykesCosts
flow: AnnualGillNetCosts Unconditional
Flow from GillNetCosts to ShortCosts
AnnualGillNetCosts = (1/3) * GillNetCosts
flow: Annualized1YrCosts Unconditional
Flow from AnnualCosts to TotalAnnualFishingCosts
Annualized1YrCosts = AnnualCosts
flow: Annualized30YrCosts Unconditional
Flow from CapitalCosts to TotalAnnualFishingCosts
Annualized30YrCosts = CapitalCosts
flow: Annualized3YrCosts Unconditional
Flow from ShortCosts to TotalAnnualFishingCosts
Annualized3YrCosts = ShortCosts
flow: AnnualOysterBuildingCosts Unconditional
Flow from OysterBuildingsCosts to CapitalCosts
AnnualOysterBuildingCosts = (1/30) * OysterBuildingsCosts
flow: AnnualOysterCanneriesCosts Unconditional
Flow from OysterCanneriesCosts to CapitalCosts
AnnualOysterCanneriesCosts = (1/30) * OysterCanneriesCosts
flow: AnnualOysterGearOutfitCosts Unconditional
Flow from OysterGearOutfitCosts to AnnualCosts
AnnualOysterGearOutfitCosts = OysterGearOutfitCosts
flow: AnnualOysterPlantingCosts Unconditional
Flow from OysterPlantingCosts to AnnualCosts
AnnualOysterPlantingCosts = OysterPlantingCosts
flow: AnnualOysterVesselCosts Unconditional
Flow from OysterVesselsCosts to CapitalCosts
AnnualOysterVesselCosts = (1/30) * OysterVesselsCosts
flow: AnnualPoundNetCosts Unconditional
Flow from PoundNetCosts to ShortCosts
AnnualPoundNetCosts = (1/3) * PoundNetCosts
flow: AnnualSeinesCosts Unconditional
Flow from SeinesCosts to ShortCosts
AnnualSeinesCosts = (1/3) * SeinesCosts
compartment: CapitalCosts Unconditional
30Years
dCapitalCosts/dt =
+AnnualFishingVesselCosts+AnnualFishHouseCosts+AnnualOysterVesselCosts+AnnualOysterCanneriesCosts+
AnnualOysterBuildingCosts-Annualized30YrCosts
Initial Value = 1792
compartment: FishHousesCosts Unconditional
1

dFishHousesCosts/dt = 0
Initial Value = 684
compartment: FishingVesselsCosts Unconditional
87
dFishingVesselsCosts/dt = 0
Initial Value = 4830
compartment: FykesCosts Unconditional
1
dFykesCosts/dt = 0
Initial Value = 57
compartment: GillNetCosts Unconditional
5
dGillNetCosts/dt = 0
Initial Value = 110
compartment: OysterBuildingsCosts Unconditional
1
dOysterBuildingsCosts/dt = 0
Initial Value = 7091
compartment: OysterCanneriesCosts Unconditional
1
dOysterCanneriesCosts/dt = 0
Initial Value = 12144
compartment: OysterGearOutfitCosts Unconditional
1
dOysterGearOutfitCosts/dt = 0
Initial Value = 13940
compartment: OysterPlantingCosts Unconditional
1
dOysterPlantingCosts/dt = 0
Initial Value = 2117
compartment: OysterVesselsCosts Unconditional
248
dOysterVesselsCosts/dt = 0
Initial Value = 29001
compartment: PoundNetCosts Unconditional
4
dPoundNetCosts/dt = 0
Initial Value = 4278
compartment: SeinesCosts Unconditional
3
dSeinesCosts/dt = 0
Initial Value = 900
compartment: ShortCosts Unconditional
3Years
dShortCosts/dt = +AnnualFykesCosts+AnnualSeinesCosts+AnnualGillNetCosts+AnnualPoundNetCosts-Annualized3YrCosts
Initial Value = 1782
compartment: TotalAnnualFishingCosts Unconditional
dTotalAnnualFishingCosts/dt = +Annualized30YrCosts+Annualized1YrCosts+Annualized3YrCosts-TotalAnnualFishingCoststoBay
Initial Value = 19630
flow: TotalAnnualFishingCoststoBay Unconditional
Flow from TotalAnnualFishingCosts to TotalAnnualFishingCostsfromSu
TotalAnnualFishingCoststoBay = TotalAnnualFishingCosts
flow: FishingExpenses Unconditional
Flow from TotalAnnualFishingCostsfromSu to Expenses
FishingExpenses = 1 * TotalAnnualFishingCostsfromSu
compartment: GreyTrout_Harvest Unconditional
dGreyTrout_Harvest/dt = (BayHealthFactor*GreyTroutPool)+(RandomNumber1sd3_Fish*GreyTroutPool)-GrTrout_toFood-GrTrout_toMkt

Initial Value = 216752
compartment: GreyTroutPool Unconditional
dGreyTroutPool/dt = 0
Initial Value = 216752
flow: GrossMoneytoPeople_Bay Unconditional
Flow from BAYCash_Market to MoneyProduced_Bay
GrossMoneytoPeople_Bay = BAYCash_Market
compartment: GrTrout_Calories2 Unconditional
dGrTrout_Calories2/dt = +(GreyTrout_Calories*GrTrout_toCalories)-GrTrout_toBayProd
Initial Value = 28733490
compartment: GrTrout_Food Unconditional
dGrTrout_Food/dt = +GrTrout_toFood-GrTrout_toCalories
Initial Value = 42758
compartment: GrTrout_Market Unconditional
dGrTrout_Market/dt = +GrTrout_toMkt-GrTrout_toMoney
Initial Value = 173994
compartment: GrTrout_Money Unconditional
dGrTrout_Money/dt = +(BPPB_GreyTrout*GrTrout_toMoney)-GrTrout_toBayCash
Initial Value = 3480
flow: GrTrout_toBayCash Unconditional
Flow from GrTrout_Money to BAYCash_Market
GrTrout_toBayCash = GrTrout_Money
flow: GrTrout_toBayProd Unconditional
Flow from GrTrout_Calories2 to BAYFood_CaloriesProduced
GrTrout_toBayProd = GrTrout_Calories2
flow: GrTrout_toCalories Unconditional
Flow from GrTrout_Food to GrTrout_Calories2
GrTrout_toCalories = GrTrout_Food
flow: GrTrout_toFood Unconditional
Flow from GreyTrout_Harvest to GrTrout_Food
GrTrout_toFood = AFoodvsMarket_estuary * GreyTrout_Harvest
flow: GrTrout_toMkt Unconditional
Flow from GreyTrout_Harvest to GrTrout_Market
GrTrout_toMkt = (1-AFoodvsMarket_estuary) * GreyTrout_Harvest
flow: GrTrout_toMoney Unconditional
Flow from GrTrout_Market to GrTrout_Money
GrTrout_toMoney = GrTrout_Market
compartment: Menhaden_Harvest Unconditional
dMenhaden_Harvest/dt = (BayHealthFactor*MenhadenPool)+(RandomNumber1sd3_Fish*MenhadenPool)-
Menhaden_toMarket
Initial Value = 427800
compartment: Menhaden_Market Unconditional
dMenhaden_Market/dt = +Menhaden_toMarket-Menhaden_toMoney
Initial Value = 427800
compartment: Menhaden_Money Unconditional
dMenhaden_Money/dt = +(BPPB_Menhaden*Menhaden_toMoney)-Menhaden_toBayCash
Initial Value = 343
flow: Menhaden_toBayCash Unconditional
Flow from Menhaden_Money to BAYCash_Market
Menhaden_toBayCash = Menhaden_Money
flow: Menhaden_toMarket Unconditional
Flow from Menhaden_Harvest to Menhaden_Market
Menhaden_toMarket = Menhaden_Harvest
flow: Menhaden_toMoney Unconditional
Flow from Menhaden_Market to Menhaden_Money
Menhaden_toMoney = Menhaden_Market
compartment: MenhadenPool Unconditional
dMenhadenPool/dt = 0
Initial Value = 427800
compartment: MoneyProduced_Bay Unconditional

dMoneyProduced_Bay/dt = +GrossMoneytoPeople_Bay-TotalRevenuesFishermen
Initial Value = 104298
flow: NetCaloriestoPeople Unconditional
Flow from BAYFood_CaloriesProduced to TotalCaloriesFromFishing
NetCaloriestoPeople = BAYFood_CaloriesProduced
flow: NetMoneytoPeopleFishing Unconditional
Flow from NetProfittoFishermen to NetMoneyFromFishing
NetMoneytoPeopleFishing = NetProfittoFishermen
compartment: NetProfittoFishermen Unconditional
dNetProfittoFishermen/dt = +TotalRevenuesFishermen-TotalExpensesFishermenNegative-NetMoneytoPeopleFishing
Initial Value = 84668
flow: Other_toCalories Unconditional
Flow from OtherFish_Food to OtherFish_Calories2
Other_toCalories = OtherFish_Food
compartment: OtherFish_Calories2 Unconditional
dOtherFish_Calories2/dt = +(OtherFish_Calories*Other_toCalories)-OtherFish_toBayProd
Initial Value = 36183497
compartment: OtherFish_Food Unconditional
dOtherFish_Food/dt = +OtherFish_toFood-Other_toCalories
Initial Value = 56726
compartment: OtherFish_Harvest Unconditional
dOtherFish_Harvest/dt = (BayHealthFactor*OtherFishPool)+(RandomNumber1sd3_Fish*OtherFishPool)-OtherFish_toFood-OtherFish_toMkt
Initial Value = 287557
compartment: OtherFish_Market Unconditional
dOtherFish_Market/dt = +OtherFish_toMkt-OtherFish_toMoney
Initial Value = 230832
compartment: OtherFish_Money Unconditional
dOtherFish_Money/dt = +(BPPB_OtherFish*OtherFish_toMoney)-OtherFish_toBayCash
Initial Value = 4617
flow: OtherFish_toBayCash Unconditional
Flow from OtherFish_Money to BAYCash_Market
OtherFish_toBayCash = OtherFish_Money
flow: OtherFish_toBayProd Unconditional
Flow from OtherFish_Calories2 to BAYFood_CaloriesProduced
OtherFish_toBayProd = OtherFish_Calories2
flow: OtherFish_toFood Unconditional
Flow from OtherFish_Harvest to OtherFish_Food
OtherFish_toFood = AFoodvsMarket_estuary * OtherFish_Harvest
flow: OtherFish_toMkt Unconditional
Flow from OtherFish_Harvest to OtherFish_Market
OtherFish_toMkt = (1-AFoodvsMarket_estuary) * OtherFish_Harvest
flow: OtherFish_toMoney Unconditional
Flow from OtherFish_Market to OtherFish_Money
OtherFish_toMoney = OtherFish_Market
compartment: OtherFishPool Unconditional
dOtherFishPool/dt = 0
Initial Value = 287557
compartment: Oyster_Food Unconditional
dOyster_Food/dt = +Oyster_toFood-Oysters_toCalories
Initial Value = 68798
compartment: Oyster_Harvest Unconditional
Bushels
dOyster_Harvest/dt = (BayHealthFactor*OysterPool)+(RandomNumber1sd3_Fish*OysterPool)-Oyster_toFood-Oyster_toMkt
Initial Value = 348755
compartment: Oyster_Market Unconditional
dOyster_Market/dt = +Oyster_toMkt-Oyster_toMoney
Initial Value = 279957

compartment: Oyster_Money Unconditional
dOyster_Money/dt = +(BPPP_Oyster * Oyster_toMoney)-Oysters_toBayCash
Initial Value = 78388
flow: Oyster_toFood Unconditional
Flow from Oyster_Harvest to Oyster_Food
Oyster_toFood = AFoodvsMarket_estuary * Oyster_Harvest
flow: Oyster_toMkt Unconditional
Flow from Oyster_Harvest to Oyster_Market
Oyster_toMkt = (1-AFoodvsMarket_estuary) * Oyster_Harvest
flow: Oyster_toMoney Unconditional
Flow from Oyster_Market to Oyster_Money
Oyster_toMoney = Oyster_Market
compartment: OysterPool Unconditional
dOysterPool/dt = 0
Initial Value = 348755
flow: Oysters_toBayCash Unconditional
Flow from Oyster_Money to BAYCash_Market
Oysters_toBayCash = Oyster_Money
flow: Oysters_toBayProd Unconditional
Flow from Oystes_Calories to BAYFood_CaloriesProduced
Oysters_toBayProd = Oystes_Calories
flow: Oysters_toCalories Unconditional
Flow from Oyster_Food to Oystes_Calories
Oysters_toCalories = Oyster_Food
compartment: Oystes_Calories Unconditional
dOystes_Calories/dt = +(Oyster_Calories*Oysters_toCalories)-Oysters_toBayProd
Initial Value = 146402423
compartment: Shad_Calories2 Unconditional
dShad_Calories2/dt = +(Shad_Calories*Shad_toCalories)-Shad_toBayProd
Initial Value = 1212982
compartment: Shad_Food Unconditional
dShad_Food/dt = +Shad_toFood-Shad_toCalories
Initial Value = 1378
compartment: Shad_Harvest Unconditional
dShad_Harvest/dt = (BayHealthFactor*ShadPool)+(RandomNumber1sd3_Fish*ShadPool)-Shad_toFood-Shad_toMkt
Initial Value = 6978
compartment: Shad_Market Unconditional
dShad_Market/dt = +Shad_toMkt-Shad_toMoney
Initial Value = 5609
compartment: Shad_Money Unconditional
dShad_Money/dt = +(BPPB_Shad*Shad_toMoney)-Shad_toBayCash
Initial Value = 337
flow: Shad_toBayCash Unconditional
Flow from Shad_Money to BAYCash_Market
Shad_toBayCash = Shad_Money
flow: Shad_toBayProd Unconditional
Flow from Shad_Calories2 to BAYFood_CaloriesProduced
Shad_toBayProd = Shad_Calories2
flow: Shad_toCalories Unconditional
Flow from Shad_Food to Shad_Calories2
Shad_toCalories = Shad_Food
flow: Shad_toFood Unconditional
Flow from Shad_Harvest to Shad_Food
Shad_toFood = AFoodvsMarket_estuary * Shad_Harvest
flow: Shad_toMkt Unconditional
Flow from Shad_Harvest to Shad_Market
Shad_toMkt = (1-AFoodvsMarket_estuary) * Shad_Harvest
flow: Shad_toMoney Unconditional
Flow from Shad_Market to Shad_Money

Shad_toMoney = Shad_Market
compartment: ShadPool Unconditional
dShadPool/dt = 0
Initial Value = 6987
compartment: Sheepshead_calories2 Unconditional
dSheepshead_calories2/dt = +(Sheepshead_Calories*Sheepshead_toCalories)-Sheepshead_toBayProd
Initial Value = 5968140
compartment: Sheepshead_Food Unconditional
dSheepshead_Food/dt = +Sheepshead_toFood-Sheepshead_toCalories
Initial Value = 13165
compartment: Sheepshead_Harvest Unconditional
dSheepshead_Harvest/dt = (BayHealthFactor*SheepsheadPool)+(RandomNumber1sd3_Fish*SheepsheadPool)-Sheepshead_toFood-Sheepshead_toMkt
Initial Value = 66737
compartment: Sheepshead_Market Unconditional
dSheepshead_Market/dt = +Sheepshead_toMkt-Sheepshead_toMoney
Initial Value = 53572
compartment: Sheepshead_Money Unconditional
dSheepshead_Money/dt = +(BPPB_Sheepshead*Sheepshead_toMoney)-Sheepshead_toBayCash
Initial Value = 3214
flow: Sheepshead_toBayCash Unconditional
Flow from Sheepshead_Money to BAYCash_Market
Sheepshead_toBayCash = Sheepshead_Money
flow: Sheepshead_toBayProd Unconditional
Flow from Sheepshead_calories2 to BAYFood_CaloriesProduced
Sheepshead_toBayProd = Sheepshead_calories2
flow: Sheepshead_toCalories Unconditional
Flow from Sheepshead_Food to Sheepshead_calories2
Sheepshead_toCalories = Sheepshead_Food
flow: Sheepshead_toFood Unconditional
Flow from Sheepshead_Harvest to Sheepshead_Food
Sheepshead_toFood = AFoodvsMarket_estuary * Sheepshead_Harvest
flow: Sheepshead_toMkt Unconditional
Flow from Sheepshead_Harvest to Sheepshead_Market
Sheepshead_toMkt = (1-AFoodvsMarket_estuary) * Sheepshead_Harvest
flow: Sheepshead_toMoney Unconditional
Flow from Sheepshead_Market to Sheepshead_Money
Sheepshead_toMoney = Sheepshead_Market
compartment: SheepsheadPool Unconditional
dSheepsheadPool/dt = 0
Initial Value = 66737
compartment: SpanishMackerel_Harvest Unconditional
dSpanishMackerel_Harvest/dt =
(BayHealthFactor*SpMackeralPool)+(RandomNumber1sd3_Fish*SpMackeralPool)-SpMack_toFood-SpMack_toMkt
Initial Value = 152012
flow: SpMack_toFood Unconditional
Flow from SpanishMackerel_Harvest to SPMackeral_Food
SpMack_toFood = AFoodvsMarket_estuary * SpanishMackerel_Harvest
flow: SpMack_toMkt Unconditional
Flow from SpanishMackerel_Harvest to SpMackerel_Market
SpMack_toMkt = (1-AFoodvsMarket_estuary) * SpanishMackerel_Harvest
compartment: SpMackeral_Calories2 Unconditional
dSpMackeral_Calories2/dt = +(SpanMack_Calories*SpMackeral_toCalories)-SpMackeral_toBayProd
Initial Value = 18711875
compartment: SPMackeral_Food Unconditional
dSPMackeral_Food/dt = +SpMack_toFood-SpMackeral_toCalories
Initial Value = 29987
compartment: SpMackeral_Money Unconditional
dSpMackeral_Money/dt = +(BPPB_SpanMack*SpMackeral_toMoney)-SpMackeral_toBayCash

Initial Value = 8542
flow: SpMackeral_toBayCash Unconditional
Flow from SpMackeral_Money to BAYCash_Market
SpMackeral_toBayCash = SpMackeral_Money
flow: SpMackeral_toBayProd Unconditional
Flow from SPMackeral_Calories2 to BAYFood_CaloriesProduced
SpMackeral_toBayProd = SpMackeral_Calories2
flow: SpMackeral_toCalories Unconditional
Flow from SPMackeral_Food to SPMackeral_Calories2
SpMackeral_toCalories = SPMackeral_Food
flow: SpMackeral_toMoney Unconditional
Flow from SpMackerel_Market to SpMackeral_Money
SpMackeral_toMoney = SpMackerel_Market
compartment: SpMackeralPool Unconditional
dSpMackeralPool/dt = 0
Initial Value = 152012
compartment: SpMackerel_Market Unconditional
dSpMackerel_Market/dt = +SpMack_toMkt-SpMackeral_toMoney
Initial Value = 122025
compartment: Terp_Food Unconditional
dTerp_Food/dt = +Terp_toFood-Terps_toCalories
Initial Value = 1383
compartment: Terp_Harvest Unconditional
dTerp_Harvest/dt = (BayHealthFactor*TerrapinPool)+(RandomNumber1sd3_Fish*TerrapinPool)-Terp_toFood-Terp_toMkt
Initial Value = 7011
compartment: Terp_Market Unconditional
dTerp_Market/dt = +Terp_toMkt-Terps_toMoney
Initial Value = 5628
compartment: Terp_Money Unconditional
dTerp_Money/dt = +(BPPB_Terp*Terps_toMoney)-Terps_toBayCash
Initial Value = 619
flow: Terp_toFood Unconditional
Flow from Terp_Harvest to Terp_Food
Terp_toFood = AFoodvsMarket_estuary * Terp_Harvest
flow: Terp_toMkt Unconditional
Flow from Terp_Harvest to Terp_Market
Terp_toMkt = (1-AFoodvsMarket_estuary) * Terp_Harvest
compartment: Terps_Calories2 Unconditional
dTerps_Calories2/dt = +(Terp_Calories*Terps_toCalories)-Terps_toBayProd
Initial Value = 973671
flow: Terps_toBayCash Unconditional
Flow from Terp_Money to BAYCash_Market
Terps_toBayCash = Terp_Money
flow: Terps_toBayProd Unconditional
Flow from Terps_Calories2 to BAYFood_CaloriesProduced
Terps_toBayProd = Terps_Calories2
flow: Terps_toCalories Unconditional
Flow from Terp_Food to Terps_Calories2
Terps_toCalories = Terp_Food
flow: Terps_toMoney Unconditional
Flow from Terp_Market to Terp_Money
Terps_toMoney = Terp_Market
compartment: TerrapinPool Unconditional
dTerrapinPool/dt = 0
Initial Value = 7011
flow: TotalExpensesFishermenNegative Unconditional
Flow from Expenses_Fishing to NetProfittoFishermen
TotalExpensesFishermenNegative = Expenses_Fishing
flow: TotalRevenuesFishermen Unconditional

Flow from MoneyProduced_Bay to NetProfittoFishermen
TotalRevenuesFishermen = MoneyProduced_Bay
compartment: CropEnhancementDump Unconditional
dCropEnhancementDump/dt = +F21
Initial Value = 0.0
compartment: CropEnhancementFactor Conditional Global
dCropEnhancementFactor/dt =
 +3-F21 for FertilizerUse_Annual>=3
 +2-F21 for FertilizerUse_Annual>=2
 +1-F21 for FertilizerUse_Annual>=1
 0-F21 by default
Initial Value = 0
define value: D1 Unconditional
If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D1 = 0
define value: D2 Unconditional
If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D2 = 0
define value: D3 Unconditional
If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D3 = 0
define value: D4 Unconditional
If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D4 = 0
flow: F1 Conditional
Flow from MB_Under_1 to MB_Under_1_Deaths
F1 =
 MortalityRate_MB_U1*ABMortalityRateStress4*MB_Under_1 for RatioCalDemandtoAvail>=1.25
 MortalityRate_MB_U1*ABMortalityRateStress3*MB_Under_1 for RatioCalDemandtoAvail>=1.2
 MortalityRate_MB_U1*ABMortalityRateStress2*MB_Under_1 for RatioCalDemandtoAvail>=1.1
 MortalityRate_MB_U1*ABMortalityRateStress1*MB_Under_1 for RatioCalDemandtoAvail>=1.0
 MortalityRate_MB_U1*ABMortalityRateStress0*MB_Under_1 for RatioCalDemandtoAvail>=.95
 MortalityRate_MB_U1*MB_Under_1 by default
flow: F10 Unconditional
Flow from MW_Under_1_deaths to MW_Deaths
F10 = MW_Under_1_deaths
flow: F11 Conditional
Flow from FW1_4 to FW_1_4_Deaths
F11 =
 MortalityRate_FB01_4*ABMortalityRateStress4*FW1_4 for RatioCalDemandtoAvail>=1.25
 MortalityRate_FB01_4*ABMortalityRateStress3*FW1_4 for RatioCalDemandtoAvail>=1.2
 MortalityRate_FB01_4*ABMortalityRateStress2*FW1_4 for RatioCalDemandtoAvail>=1.1
 MortalityRate_FB01_4*ABMortalityRateStress1*FW1_4 for RatioCalDemandtoAvail>=1.0
 MortalityRate_FB01_4*ABMortalityRateStress0*FW1_4 for RatioCalDemandtoAvail>=.95
 MortalityRate_FB01_4*FW1_4 by default
flow: F12 Unconditional
Flow from C1 to FW_Deaths
F12 = FW_1_4_Deaths
flow: F13 Conditional
Flow from FW5_14 to FW_Deaths
F13 =
 MortalityRate_FB05_14 * ABirthRateStress4*FW5_14 for RatioCalDemandtoAvail>=1.25
 MortalityRate_FB05_14 * ABirthRateStress3*FW5_14 for RatioCalDemandtoAvail>=1.2
 MortalityRate_FB05_14 * ABirthRateStress2*FW5_14 for RatioCalDemandtoAvail>=1.1
 MortalityRate_FB05_14 * ABirthRateStress1*FW5_14 for RatioCalDemandtoAvail>=1.0
 MortalityRate_FB05_14 * ABirthRateStress0*FW5_14 for RatioCalDemandtoAvail>=.95
 MortalityRate_FB05_14 * FW5_14 by default
flow: F14 Unconditional
Flow from FertilizerUse_Annual to FertilizerUse_Aggregate
F14 = 1 * FertilizerUse_Annual

flow: F15 Conditional
Flow from FW65_Above to FW_Deaths
F15 =
MortalityRate_FW65_Above * ABMortalityRateStress4*FW65_Above for RatioCalDemandtoAvail>=1.25
MortalityRate_FW65_Above * ABMortalityRateStress3*FW65_Above for RatioCalDemandtoAvail>=1.2
MortalityRate_FW65_Above * ABMortalityRateStress2*FW65_Above for RatioCalDemandtoAvail>=1.1
MortalityRate_FW65_Above * ABMortalityRateStress1*FW65_Above for RatioCalDemandtoAvail>=1.0
MortalityRate_FW65_Above * ABMortalityRateStress0*FW65_Above for RatioCalDemandtoAvail>=.95
MortalityRate_FW65_Above * FW65_Above by default
flow: F16 Unconditional
Flow from BayHealthFactor to BayHEalthDump
F16 = 1 * BayHealthFactor
flow: F17 Conditional
Flow from MB1_4 to MB_1_4_Deaths
F17 =
MortalityRate_MB01_4 * ABMortalityRateStress4*MB1_4 for RatioCalDemandtoAvail>=1.25
MortalityRate_MB01_4 * ABMortalityRateStress3*MB1_4 for RatioCalDemandtoAvail>=1.2
MortalityRate_MB01_4 * ABMortalityRateStress2*MB1_4 for RatioCalDemandtoAvail>=1.1
MortalityRate_MB01_4 * ABMortalityRateStress1*MB1_4 for RatioCalDemandtoAvail>=1.0
MortalityRate_MB01_4 * ABMortalityRateStress0*MB1_4 for RatioCalDemandtoAvail>=.95
MortalityRate_MB01_4 * MB1_4 by default
flow: F18 Unconditional
Flow from MB_1_4_Deaths to MB_Deaths
F18 = MB_1_4_Deaths
flow: F19 Conditional
Flow from MW1_4 to MW_1_4_deaths
F19 =
MortalityRate_MW01_4*ABMortalityRateStress4* MW1_4 for RatioCalDemandtoAvail>=1.25
MortalityRate_MW01_4*ABMortalityRateStress3* MW1_4 for RatioCalDemandtoAvail>=1.2
MortalityRate_MW01_4*ABMortalityRateStress2* MW1_4 for RatioCalDemandtoAvail>=1.1
MortalityRate_MW01_4*ABMortalityRateStress1* MW1_4 for RatioCalDemandtoAvail>=1.0
MortalityRate_MW01_4*ABMortalityRateStress0* MW1_4 for RatioCalDemandtoAvail>=.95
MortalityRate_MW01_4* MW1_4 by default
flow: F2 Unconditional
Flow from MB_Under_1_Deaths to MB_Deaths
F2 = MB_Under_1_Deaths
flow: F20 Unconditional
Flow from MW_1_4_deaths to MW_Deaths
F20 = MW_1_4_deaths
flow: F21 Unconditional
Flow from CropEnhancementFactor to CropEnhancementDump
F21 = 1 * CropEnhancementFactor
flow: F22 Unconditional
Flow from FemaleTotal to PopDump
F22 = FemaleTotal
flow: F23 Unconditional
Flow from MaleTotal to PopDump
F23 = MaleTotal
flow: F24 Unconditional
Flow from BlackTotal to PopDump
F24 = BlackTotal
flow: F25 Unconditional
Flow from WhiteTotal to PopDump
F25 = WhiteTotal
flow: F26 Unconditional
Flow from C1 to PopDump
F26 = TotalPopulation
flow: F3 Conditional
Flow from FB_Under_1 to FB_Under_1_Deaths
F3 =

MortalityRate_FB_U1*ABMortalityRateStress4*FB_Under_1 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB_U1*ABMortalityRateStress3*FB_Under_1 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB_U1*ABMortalityRateStress2*FB_Under_1 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB_U1*ABMortalityRateStress1*FB_Under_1 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB_U1*ABMortalityRateStress0*FB_Under_1 for RatioCalDemandtoAvail>=.95
MortalityRate_FB_U1*FB_Under_1 by default
flow: F4 Unconditional
Flow from FB_Under_1_Deaths to FB_Deaths
F4 = FB_Under_1_Deaths
flow: F5 Conditional
Flow from FB1_4 to FB_1_4_Deaths
F5 =
MortalityRate_FB01_4 *ABMortalityRateStress4* FB1_4 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB01_4 *ABMortalityRateStress3* FB1_4 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB01_4 *ABMortalityRateStress2* FB1_4 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB01_4 *ABMortalityRateStress1* FB1_4 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB01_4 *ABMortalityRateStress0* FB1_4 for RatioCalDemandtoAvail>=.95
MortalityRate_FB01_4 * FB1_4 by default
flow: F6 Unconditional
Flow from FB_1_4_Deaths to FB_Deaths
F6 = FB_1_4_Deaths
flow: F7 Conditional
Flow from FW_Under_1 to FW_Under_1_Deaths
F7 =
MortalityRate_FW_U1 * ABMortalityRateStress4*FW_Under_1 for RatioCalDemandtoAvail>=1.25
MortalityRate_FW_U1 * ABMortalityRateStress3*FW_Under_1 for RatioCalDemandtoAvail>=1.2
MortalityRate_FW_U1 * ABMortalityRateStress2*FW_Under_1 for RatioCalDemandtoAvail>=1.1
MortalityRate_FW_U1 * ABMortalityRateStress1*FW_Under_1 for RatioCalDemandtoAvail>=1.0
MortalityRate_FW_U1 * ABMortalityRateStress0*FW_Under_1 for RatioCalDemandtoAvail>=.95
MortalityRate_FW_U1 * FW_Under_1 by default
flow: F8 Unconditional
Flow from FW_Under_1_Deaths to FW_Deaths
F8 = FW_Under_1_Deaths
flow: F9 Conditional
Flow from MW_Under_1 to MW_Under_1_deaths
F9 =
MortalityRate_MW_U1 * ABMortalityRateStress4*MW_Under_1 for RatioCalDemandtoAvail>=1.25
MortalityRate_MW_U1 * ABMortalityRateStress3*MW_Under_1 for RatioCalDemandtoAvail>=1.2
MortalityRate_MW_U1 * ABMortalityRateStress2*MW_Under_1 for RatioCalDemandtoAvail>=1.1
MortalityRate_MW_U1 * ABMortalityRateStress1*MW_Under_1 for RatioCalDemandtoAvail>=1.0
MortalityRate_MW_U1 * ABMortalityRateStress0*MW_Under_1 for RatioCalDemandtoAvail>=.95
MortalityRate_MW_U1 * MW_Under_1 by default
compartment: FB_1_4_Deaths Unconditional
dFB_1_4_Deaths/dt = +F5-F6
Initial Value = 0.0
compartment: FB_Deaths Unconditional
dFB_Deaths/dt = +FB_Die5_14+FB_Die15_49+FB_Die50_64+FB_Die65+F4+F6
Initial Value = 0.0
flow: FB_Die15_49 Conditional
Flow from FB15_49 to FB_Deaths
FB_Die15_49 =
MortalityRate_FB15_49 * ABMortalityRateStress4*FB15_49 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB15_49 * ABMortalityRateStress3*FB15_49 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB15_49 * ABMortalityRateStress2*FB15_49 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB15_49 * ABMortalityRateStress1*FB15_49 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB15_49 * ABMortalityRateStress0*FB15_49 for RatioCalDemandtoAvail>=.95
MortalityRate_FB15_49 * FB15_49 by default
flow: FB_Die5_14 Conditional
Flow from FB5_14 to FB_Deaths
FB_Die5_14 =

MortalityRate_FB05_14 * ABMortalityRateStress4*FB5_14 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB05_14 * ABMortalityRateStress3*FB5_14 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB05_14 * ABMortalityRateStress2*FB5_14 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB05_14 * ABMortalityRateStress1*FB5_14 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB05_14 * ABMortalityRateStress0*FB5_14 for RatioCalDemandtoAvail>=.95
MortalityRate_FB05_14 * FB5_14 by default
flow: FB_Die50_64 Conditional
Flow from FB50_64 to FB_Deaths
FB_Die50_64 =
MortalityRate_FB50_64 * ABMortalityRateStress4*FB50_64 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB50_64 * ABMortalityRateStress3*FB50_64 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB50_64 * ABMortalityRateStress2*FB50_64 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB50_64 * ABMortalityRateStress1*FB50_64 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB50_64 * ABMortalityRateStress0*FB50_64 for RatioCalDemandtoAvail>=.95
MortalityRate_FB50_64 * FB50_64 by default
flow: FB_Die65 Conditional
Flow from FB65_Above to FB_Deaths
FB_Die65 =
MortalityRate_FB65_Above * ABMortalityRateStress4*FB65_Above for RatioCalDemandtoAvail>=1.25
MortalityRate_FB65_Above * ABMortalityRateStress3*FB65_Above for RatioCalDemandtoAvail>=1.2
MortalityRate_FB65_Above * ABMortalityRateStress2*FB65_Above for RatioCalDemandtoAvail>=1.1
MortalityRate_FB65_Above * ABMortalityRateStress1*FB65_Above for RatioCalDemandtoAvail>=1.0
MortalityRate_FB65_Above * ABMortalityRateStress0*FB65_Above for RatioCalDemandtoAvail>=.95
MortalityRate_FB65_Above * FB65_Above by default
flow: FB_Live1 Unconditional
Flow from FB_Under_1 to FB1_4
FB_Live1 = (1-MortalityRate_FB_U1) * FB_Under_1
flow: FB_Live15 Unconditional
Flow from FB5_14 to FB15_49
FB_Live15 = (1/10)*(1-MortalityRate_FB05_14) * FB5_14
flow: FB_Live5 Unconditional
Flow from FB1_4 to FB5_14
FB_Live5 = (1/4)*(1-MortalityRate_FB01_4) * FB1_4
flow: FB_Live50 Unconditional
Flow from FB15_49 to FB50_64
FB_Live50 = (1/35)*(1-MortalityRate_FB15_49) * FB15_49
flow: FB_Live65 Unconditional
Flow from FB50_64 to FB65_Above
FB_Live65 = (1/15)*(1-MortalityRate_FB50_64)* FB50_64
flow: FB_Liveto1 Unconditional
Flow from New_Births_Black to FB_Under_1
FB_Liveto1 = ABirthGenderRateF_FB * New_Births_Black
compartment: FB_Under_1 Unconditional
dFB_Under_1/dt = -FB_Live1+FB_Liveto1-F3
Initial Value = 20
compartment: FB_Under_1_Deaths Unconditional
dFB_Under_1_Deaths/dt = +F3-F4
Initial Value = 0.0
compartment: FB1_4 Unconditional
dFB1_4/dt = +FB_Live1-FB_Live5-F5
Initial Value = 99
compartment: FB15_49 Unconditional
dFB15_49/dt = +FB_Live15-FB_Live50-FB_Die15_49
Initial Value = 301
compartment: FB5_14 Unconditional
dFB5_14/dt = +FB_Live5-FB_Live15-FB_Die5_14
Initial Value = 203
compartment: FB50_64 Unconditional
dFB50_64/dt = +FB_Live50-FB_Live65-FB_Die50_64
Initial Value = 58

compartment: FB65_Above Unconditional
dFB65_Above/dt = +FB_Live65-FB_Die65
Initial Value = 29
flow: FemaleCaloricDemand Unconditional
Flow from FemaleCalorieDemand_Total to HumanCaloricDemmand
FemaleCaloricDemand = FemaleCalorieDemand_Total
compartment: FemaleCalorieDemand_Total Unconditional
dFemaleCalorieDemand_Total/dt =
(Calories_F01_4*FB1_4)+(Calories_F05_14*FB5_14)+(Calories_F15_49*FB15_49)+(Calories_F50_64*FB50_64)+(Calories_F65*FB65_Above)+(Calories_F01_4*FW1_4)+(Calories_F05_14*FW5_14)+(Calories_F15_49*FW15_49)+(Calories_F50_64*FW50_64)+(Calories_F65*FW65_Above)-FemaleCaloricDemand
Initial Value = 869649001
compartment: FemaleTotal Unconditional
dFemaleTotal/dt = TotalPop_FB+TotalPop_FW-F22
Initial Value = 1284
compartment: FertilizerUse_Aggregate Unconditional Global
dFertilizerUse_Aggregate/dt = +F14
Initial Value = 0
compartment: FertilizerUse_Annual Conditional Global
dFertilizerUse_Annual/dt =
 +(4*FertilzerToggle)-F14 for t>75
 +(3*FertilzerToggle)-F14 for t>50
 +(2*FertilzerToggle)-F14 for t>25
 +(0*FertilzerToggle)-F14 by default
Initial Value = 0
define value: FertilzerToggle Unconditional
Off if 0, fx = 0; On if 1, fx = 1
FertilzerToggle = 1
compartment: FW_1_4_Deaths Unconditional
dFW_1_4_Deaths/dt = +(F11)-F12
Initial Value = 0.0
compartment: FW_Deaths Conditional
dFW_Deaths/dt =
 +FW_Die15_49+FW_Die50_64+F8+F12+F15+F13 by default
Initial Value = 0.0
flow: FW_Die15_49 Conditional
Flow from FW15_49 to FW_Deaths
FW_Die15_49 =
 MortalityRate_FW15_49 * ABirthRateStress4*FW15_49 for RatioCalDemandtoAvail>=1.25
 MortalityRate_FW15_49 * ABirthRateStress3*FW15_49 for RatioCalDemandtoAvail>=1.2
 MortalityRate_FW15_49 * ABirthRateStress2*FW15_49 for RatioCalDemandtoAvail>=1.1
 MortalityRate_FW15_49 * ABirthRateStress1*FW15_49 for RatioCalDemandtoAvail>=1.0
 MortalityRate_FW15_49 * ABirthRateStress0*FW15_49 for RatioCalDemandtoAvail>=.95
 MortalityRate_FW15_49 * FW15_49 by default
flow: FW_Die50_64 Conditional
Flow from FW50_64 to FW_Deaths
FW_Die50_64 =
 MortalityRate_FW50_64 * ABMortalityRateStress4*FW50_64 for RatioCalDemandtoAvail>=1.25
 MortalityRate_FW50_64 * ABMortalityRateStress3*FW50_64 for RatioCalDemandtoAvail>=1.2
 MortalityRate_FW50_64 * ABMortalityRateStress2*FW50_64 for RatioCalDemandtoAvail>=1.1
 MortalityRate_FW50_64 * ABMortalityRateStress1*FW50_64 for RatioCalDemandtoAvail>=1.0
 MortalityRate_FW50_64 * ABMortalityRateStress0*FW50_64 for RatioCalDemandtoAvail>=.95
 MortalityRate_FW50_64 * FW50_64 by default
flow: FW_Live1 Unconditional
Flow from FW_Under_1 to FW1_4
FW_Live1 = (1-MortalityRate_FW_U1) * FW_Under_1
flow: FW_Live15 Unconditional
Flow from FW5_14 to FW15_49
FW_Live15 = (1/10)*(1-MortalityRate_FW05_14) * FW5_14
flow: FW_Live5 Unconditional

Flow from FW1_4 to FW5_14
FW_Live5 = (1/4)*(1-MortalityRate_FW01_4) * FW1_4
flow: FW_Live50 Unconditional
Flow from FW15_49 to FW50_64
FW_Live50 = (1/35)*(1-MortalityRate_FW15_49) * FW15_49
flow: FW_Live65 Unconditional
Flow from FW50_64 to FW65_Above
FW_Live65 = (1/15)*(1-MortalityRate_FW50_64)* FW50_64
flow: FW_Liveto1 Unconditional
Flow from New_Births_White to FW_Under_1
FW_Liveto1 = ABirthGenderRateF_FW * New_Births_White
compartment: FW_Under_1 Unconditional
dFW_Under_1/dt = -FW_Live1+FW_Liveto1-F7
Initial Value = 21
compartment: FW_Under_1_Deaths Unconditional
dFW_Under_1_Deaths/dt = +F7-F8
Initial Value = 1
compartment: FW1_4 Unconditional
dFW1_4/dt = +FW_Live1-FW_Live5-F11
Initial Value = 62
compartment: FW15_49 Unconditional
dFW15_49/dt = +FW_Live15-FW_Live50-FW_Die15_49
Initial Value = 275
compartment: FW5_14 Unconditional
dFW5_14/dt = +FW_Live5-FW_Live15-F13
Initial Value = 141
compartment: FW50_64 Unconditional
dFW50_64/dt = +FW_Live50-FW_Live65-FW_Die50_64
Initial Value = 55
compartment: FW65_Above Unconditional
dFW65_Above/dt = +FW_Live65-F15
Initial Value = 20
compartment: HumanCalDump Unconditional
dHumanCalDump/dt = +toHumanCalDump
Initial Value = 0.0
compartment: HumanCaloricDemand Unconditional
dHumanCaloricDemand/dt = +FemaleCaloricDemand+MaleCaloricDemand-toHumanCalDump
Initial Value = 1751817500
flow: MaleCaloricDemand Unconditional
Flow from MaleCalorieDemand_Total to HumanCaloricDemmand
MaleCaloricDemand = MaleCalorieDemand_Total
compartment: MaleCalorieDemand_Total Unconditional
dMaleCalorieDemand_Total/dt =
(Calories_M01_4*MB1_4)+(Calories_M05_14*MB5_14)+(Calories_M15_49*MB15_49)+(Calories_M50_64*MB50_64)+(Calories_M65*MB65_Above)+(Calories_M01_4*MW1_4)+(Calories_M05_14*MW5_14)+(Calories_M15_49*MW15_49)+(Calories_M50_64*MW50_64)+(Calories_M65*MW65_Above)-MaleCaloricDemand
Initial Value = 882168500
compartment: MaleTotal Unconditional
dMaleTotal/dt = TotalPop_MB+TotalPop_MW-F23
Initial Value = 1326
compartment: MB_1_4_Deaths Unconditional
dMB_1_4_Deaths/dt = F17-F18
Initial Value = 0.0
compartment: MB_Deaths Unconditional
dMB_Deaths/dt = +MB_Die65+MB_Die5_14+MB_Die15_49+MB_Die50_64+F2+F18
Initial Value = 0.0
flow: MB_Die15_49 Conditional
Flow from MB15_49 to MB_Deaths
MB_Die15_49 =
MortalityRate_MB15_49 * ABirthRateStress4*MB15_49 for RatioCalDemandtoAvail>=1.25

MortalityRate_MB15_49 * ABirthRateStress3*MB15_49 for RatioCalDemandtoAvail>=1.2
MortalityRate_MB15_49 * ABirthRateStress2*MB15_49 for RatioCalDemandtoAvail>=1.1
MortalityRate_MB15_49 * ABirthRateStress1*MB15_49 for RatioCalDemandtoAvail>=1.0
MortalityRate_MB15_49 * ABirthRateStress0*MB15_49 for RatioCalDemandtoAvail>=.95
MortalityRate_MB15_49 * MB15_49 by default
flow: MB_Die5_14 Conditional
Flow from MB5_14 to MB_Deaths
MB_Die5_14 =
MortalityRate_MB05_14 * ABirthRateStress4*MB5_14 for RatioCalDemandtoAvail>=1.25
MortalityRate_MB05_14 * ABirthRateStress3*MB5_14 for RatioCalDemandtoAvail>=1.2
MortalityRate_MB05_14 * ABirthRateStress2*MB5_14 for RatioCalDemandtoAvail>=1.1
MortalityRate_MB05_14 * ABirthRateStress1*MB5_14 for RatioCalDemandtoAvail>=1.0
MortalityRate_MB05_14 * ABirthRateStress0*MB5_14 for RatioCalDemandtoAvail>=.95
MortalityRate_MB05_14 * MB5_14 by default
flow: MB_Die50_64 Conditional
Flow from MB50_64 to MB_Deaths
MB_Die50_64 =
MortalityRate_MB50_64 * ABMortalityRateStress4*MB50_64 for RatioCalDemandtoAvail>=1.25
MortalityRate_MB50_64 * ABMortalityRateStress3*MB50_64 for RatioCalDemandtoAvail>=1.2
MortalityRate_MB50_64 * ABMortalityRateStress2*MB50_64 for RatioCalDemandtoAvail>=1.1
MortalityRate_MB50_64 * ABMortalityRateStress1*MB50_64 for RatioCalDemandtoAvail>=1.0
MortalityRate_MB50_64 * ABMortalityRateStress0*MB50_64 for RatioCalDemandtoAvail>=.95
MortalityRate_MB50_64 * MB50_64 by default
flow: MB_Die65 Conditional
Flow from MB65_Above to MB_Deaths
MB_Die65 =
MortalityRate_MB65_Above *ABMortalityRateStress4* MB65_Above for RatioCalDemandtoAvail>=1.25
MortalityRate_MB65_Above *ABMortalityRateStress3* MB65_Above for RatioCalDemandtoAvail>=1.2
MortalityRate_MB65_Above *ABMortalityRateStress2* MB65_Above for RatioCalDemandtoAvail>=1.1
MortalityRate_MB65_Above *ABMortalityRateStress1* MB65_Above for RatioCalDemandtoAvail>=1.0
MortalityRate_MB65_Above *ABMortalityRateStress0* MB65_Above for RatioCalDemandtoAvail>=.95
MortalityRate_MB65_Above * MB65_Above by default
flow: MB_Live1 Unconditional
Flow from MB_Under_1 to MB1_4
MB_Live1 = (1-MortalityRate_MB_U1) * MB_Under_1
flow: MB_Live15 Unconditional
Flow from MB5_14 to MB15_49
MB_Live15 = (1/10)*(1-MortalityRate_MB05_14)* MB5_14
flow: MB_Live5 Unconditional
Flow from MB1_4 to MB5_14
MB_Live5 = (1/4)*(1-MortalityRate_MB01_4) * MB1_4
flow: MB_Live50 Unconditional
Flow from MB15_49 to MB50_64
MB_Live50 = (1/35)*(1-MortalityRate_MB15_49) * MB15_49
flow: MB_Live65 Unconditional
Flow from MB50_64 to MB65_Above
MB_Live65 = (1/15)*(1-MortalityRate_MB50_64) * MB50_64
flow: MB_Liveto1 Unconditional
Flow from New_Births_Black to MB_Under_1
MB_Liveto1 = (1-ABirthGenderRateF_FB) * New_Births_Black
compartment: MB_Under_1 Unconditional
dMB_Under_1/dt = -MB_Live1+MB_Liveto1-F1
Initial Value = 15
compartment: MB_Under_1_Deaths Unconditional
dMB_Under_1_Deaths/dt = +F1-F2
Initial Value = 0.0
compartment: MB1_4 Unconditional
dMB1_4/dt = +MB_Live1-MB_Live5-F17
Initial Value = 104
compartment: MB15_49 Unconditional

dMB15_49/dt = +MB_Live15-MB_Live50-MB_Die15_49
Initial Value = 340
compartment: MB5_14 Unconditional
dMB5_14/dt = +MB_Live5-MB_Live15-MB_Die5_14
Initial Value = 181
compartment: MB50_64 Unconditional
dMB50_64/dt = +MB_Live50-MB_Live65-MB_Die50_64
Initial Value = 48
compartment: MB65_Above Unconditional
dMB65_Above/dt = +MB_Live65-MB_Die65
Initial Value = 23
compartment: Money_from_Ag_and_ChesBay Unconditional
dMoney_from_Ag_and_ChesBay/dt = +MoneyfromFishing+MoneyfromAgric-toMoneyDump
Initial Value = 63808.57
compartment: MoneyDump Unconditional
dMoneyDump/dt = +toMoneyDump
Initial Value = 0.0
flow: MoneyfromAgric Unconditional
Flow from Out1 to Money_from_Ag_and_ChesBay
MoneyfromAgric = 1 * NetMoneyfromAgric
flow: MoneyfromFishing Unconditional
Flow from Out2 to Money_from_Ag_and_ChesBay
MoneyfromFishing = 1 * NetMoneyFromFishing
compartment: MW_1_4_deaths Unconditional
dMW_1_4_deaths/dt = +F19-F20
Initial Value = 0.0
compartment: MW_Deaths Unconditional
dMW_Deaths/dt = +MW_Die65+MW_Die5_14+MW_Die15_49+MW_Die50_64+F10+F20
Initial Value = 0.0
flow: MW_Die15_49 Conditional
Flow from MW15_49 to MW_Deaths
MW_Die15_49 =
  MortalityRate_MW15_49 * ABirthRateStress4*MW15_49 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MW15_49 * ABirthRateStress3*MW15_49 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MW15_49 * ABirthRateStress2*MW15_49 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MW15_49 * ABirthRateStress1*MW15_49 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MW15_49 * ABirthRateStress0*MW15_49 for RatioCalDemandtoAvail>=.95
  MortalityRate_MW15_49 * MW15_49 by default
flow: MW_Die5_14 Conditional
Flow from MW5_14 to MW_Deaths
MW_Die5_14 =
  MortalityRate_MW05_14 * ABirthRateStress4*MW5_14 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MW05_14 * ABirthRateStress3*MW5_14 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MW05_14 * ABirthRateStress2*MW5_14 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MW05_14 * ABirthRateStress1*MW5_14 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MW05_14 * ABirthRateStress0*MW5_14 for RatioCalDemandtoAvail>=.95
  MortalityRate_MW05_14 * MW5_14 by default
flow: MW_Die50_64 Conditional
Flow from MW50_64 to MW_Deaths
MW_Die50_64 =
  MortalityRate_MW50_64 * ABirthRateStress4*MW50_64 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MW50_64 * ABirthRateStress3*MW50_64 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MW50_64 * ABirthRateStress2*MW50_64 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MW50_64 * ABirthRateStress1*MW50_64 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MW50_64 * ABirthRateStress0*MW50_64 for RatioCalDemandtoAvail>=.95
  MortalityRate_MW50_64 * MW50_64 by default
flow: MW_Die65 Conditional
Flow from MW65_Above to MW_Deaths
MW_Die65 =
  MortalityRate_MW65_Above * ABMortalityRateStress4*MW65_Above for RatioCalDemandtoAvail>=1.25

MortalityRate_MW65_Above * ABMortalityRateStress3*MW65_Above for RatioCalDemandtoAvail>=1.2
MortalityRate_MW65_Above * ABMortalityRateStress2*MW65_Above for RatioCalDemandtoAvail>=1.1
MortalityRate_MW65_Above * ABMortalityRateStress1*MW65_Above for RatioCalDemandtoAvail>=1.0
MortalityRate_MW65_Above * ABMortalityRateStress0*MW65_Above for RatioCalDemandtoAvail>=.95
MortalityRate_MW65_Above * MW65_Above by default
flow: MW_Live1 Unconditional
Flow from MW_Under_1 to MW1_4
MW_Live1 = (1-MortalityRate_MW_U1) * MW_Under_1
flow: MW_Live15 Unconditional
Flow from MW5_14 to MW15_49
MW_Live15 = (1/10)*(1-MortalityRate_MW05_14)* MW5_14
flow: MW_Live5 Unconditional
Flow from MW1_4 to MW5_14
MW_Live5 = (1/4)*(1-MortalityRate_MW01_4) * MW1_4
flow: MW_Live50 Unconditional
Flow from MW15_49 to MW50_64
MW_Live50 = (1/35)*(1-MortalityRate_MW15_49) * MW15_49
flow: MW_Live65 Unconditional
Flow from MW50_64 to MW65_Above
MW_Live65 = (1/15)*(1-MortalityRate_MW50_64) * MW50_64
flow: MW_Liveto1 Unconditional
Flow from New_Births_White to MW_Under_1
MW_Liveto1 = (1-ABirthGenderRateF_FW) * New_Births_White
compartment: MW_Under_1 Unconditional
dMW_Under_1/dt = -MW_Live1+MW_Liveto1-F9
Initial Value = 13
compartment: MW_Under_1_deaths Unconditional
dMW_Under_1_deaths/dt = +F9-F10
Initial Value = 0.0
compartment: MW1_4 Unconditional
dMW1_4/dt = +MW_Live1-MW_Live5-F19
Initial Value = 64
compartment: MW15_49 Unconditional
dMW15_49/dt = +MW_Live15-MW_Live50-MW_Die15_49
Initial Value = 311
compartment: MW5_14 Unconditional
dMW5_14/dt = +MW_Live5-MW_Live15-MW_Die5_14
Initial Value = 144
compartment: MW50_64 Unconditional
dMW50_64/dt = +MW_Live50-MW_Live65-MW_Die50_64
Initial Value = 49
compartment: MW65_Above Unconditional
dMW65_Above/dt = +MW_Live65-MW_Die65
Initial Value = 34
compartment: New_Births_Black Conditional
dNew_Births_Black/dt =
(ABirthRate1B*ABirthRateStress4*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=1.1
(ABirthRate1B*ABirthRateStress3*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=1.05
(ABirthRate1B*ABirthRateStress2*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=1
(ABirthRate1B*ABirthRateStress1*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=.95
(ABirthRate1B*ABirthRateStress0*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=.9
(ABirthRate1B*FB15_49)-FB_Liveto1-MB_Liveto1 by default
Initial Value = 44
compartment: New_Births_White Conditional
dNew_Births_White/dt =
+(ABirthRate1W*ABirthRateStress4*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=1.1
+(ABirthRate1W*ABirthRateStress3*FW15_49)-FW_Liveto1-MW_Liveto1 for
RatioCalDemandtoAvail>=1.05
+(ABirthRate1W*ABirthRateStress2*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=1.0
+(ABirthRate1W*ABirthRateStress1*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=.95

+(ABirthRate1W*ABirthRateStress0*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=.9
+(ABirthRate1W*FW15_49)-FW_Liveto1-MW_Liveto1 by default
Initial Value = 41
compartment: PopDump Unconditional
dPopDump/dt =
+toPopDumpFW+toPopDump_MW+toPopDump_BM+toPopDump_FB+F22+F23+F24+F25+F26
Initial Value = 0.0
variable: RandomNumber1sd_Crops Conditional Universal
RandomNumber1sd_Crops =
randn(1,.1) for D1=1
randn(1,.25) for D1=2
1 by default
variable: RandomNumber1sd2_Animals Conditional Universal
RandomNumber1sd2_Animals =
randn(1,.1) for D2=1
randn(1,.25) for D2=2
1 by default
variable: RandomNumber1sd3_Fish Conditional Universal
RandomNumber1sd3_Fish =
randn(1,.1) for D3=1
randn(1,.25) for D3=2
1 by default
variable: RandomNumber1sd4_Markets Conditional Universal
RandomNumber1sd4_Markets =
randn(1,.1) for D4=1
randn(1,.25) for D4=2
1 by default
compartment: RatioCalDemandtoAvail Unconditional Global
dRatioCalDemandtoAvail/dt = HumanCaloricDemand/Calories_from_Ag_and_ChesBay-toRatioDump
Initial Value = 0.898433014
compartment: RatioDump Unconditional
dRatioDump/dt = +toRatioDump
Initial Value = 0.0
flow: toCalDump Unconditional
Flow from Calories_from_Ag_and_ChesBay to CalDump
toCalDump = Calories_from_Ag_and_ChesBay
flow: toHumanCalDump Unconditional
Flow from HumanCaloricDemmand to HumanCalDump
toHumanCalDump = HumanCaloricDemand
flow: toMoneyDump Unconditional
Flow from Money_from_Ag_and_ChesBay to MoneyDump
toMoneyDump = Money_from_Ag_and_ChesBay
flow: toPopDump_BM Unconditional
Flow from TotalPop_MB to PopDump
toPopDump_BM = TotalPop_MB
flow: toPopDump_FB Unconditional
Flow from TotalPop_FB to PopDump
toPopDump_FB = TotalPop_FB
flow: toPopDump_MW Unconditional
Flow from TotalPop_MW to PopDump
toPopDump_MW = TotalPop_MW
flow: toPopDumpFW Unconditional
Flow from TotalPop_FW to PopDump
toPopDumpFW = TotalPop_FW
flow: toRatioDump Unconditional
Flow from RatioCalDemandtoAvail to RatioDump
toRatioDump = RatioCalDemandtoAvail
flow: TotalCaloriesfromAgric Unconditional
Flow from TotalCaloriesfromAgriculture to Calories_from_Ag_and_ChesBay
TotalCaloriesfromAgric = TotalCaloriesfromAgriculture

compartment: TotalPop_FB Unconditional
dTotalPop_FB/dt = FB_Under_1+FB1_4+FB15_49+FB5_14+FB50_64+FB65_Above-toPopDump_FB
Initial Value = 710
compartment: TotalPop_FW Unconditional
dTotalPop_FW/dt = FW_Under_1+FW1_4+FW15_49+FW5_14+FW50_64+FW65_Above-toPopDumpFW
Initial Value = 574
compartment: TotalPop_MB Unconditional
dTotalPop_MB/dt = MB_Under_1+MB1_4+MB15_49+MB5_14+MB50_64+MB65_Above-toPopDump_BM
Initial Value = 711
compartment: TotalPop_MW Unconditional
dTotalPop_MW/dt = MW_Under_1+MW1_4+MW15_49+MW5_14+MW50_64+MW65_Above-toPopDump_MW
Initial Value = 615
compartment: TotalPopulation Unconditional
dTotalPopulation/dt = FemaleTotal+MaleTotal-F26
Initial Value = 2610
compartment: WhiteTotal Unconditional
dWhiteTotal/dt = TotalPop_FW+TotalPop_MW-F25
Initial Value = 1189

Appendix D. Parameters and Source Code for NHS-ESVA:1920

Source Code from ModelMaker4.0 File:

Main
Agriculture
compartment: Ag_CaloriesProduced Unconditional
dAg_CaloriesProduced/dt = -
NetCaloriestoPeople_Agric+Peach_toAgCaloriesProduced+Apples_toAgCaloriesProduced+Corn_toAgCalories+
Oats_toAgCaloriesProduced+Wheat_toAgCalProd+Pot_toAgCalProd+SwPot_toAgCalProd+OtherCow_toAgCal
Prod+MilkCows_toAgCalProd+Sheep_toAgCalProd+Hogs_toAgCalProd+Poultry_toAgCalProd+Eggs_toAgCalP
rod+Milk_toCalories+Butter_toCalories+PlumPrune_toAgCaloriesProduced+Cherry_toAgCalorieProduced+Grap
es_toAgCaloriesProduced+Strawberry_toAgCaloriesProduced+Rye_toAgCalProd+SoyBean_toAgCalProduced+
DryPeas_toAgCalProd
Initial Value = 3898163990
compartment: Ag_CashMarket Unconditional
dAg_CashMarket/dt =
Tob_toCash+SwPot_toCash+Pot_toCash+Wheat_toCash+Oats_toCash+Corn_toCash+Apples_toCash+Peach_to
Cash+OtherCows_toCash+MilkCow_toCash+Sheep_toCash+Milk_toMoney-GrossAgMoneytoPeople-
(MilkCow_PricetoPurchase*MilkCow_Purchased)-(OtherCows_PricetoPurchase*OtherCow_Purchased)-
(Sheep_PricetoPurchase*Sheep_Purchased)+Poultry_toCash+Pear_toCash+PlumPrune_toCash+Cherry_toCash+
Grapes_toCash+Strawberry_toCash+Rye_toCsh+SoyBean_toCash+DryPeas_toCash
Initial Value = 2253007*a1cpi1920to1880
compartment: Ag_MoneyProduced Unconditional
dAg_MoneyProduced/dt = +GrossAgMoneytoPeople-GrossAgMoneyPeople2
Initial Value = 2253007*a1cpi1920to1880
compartment: Ag_MoneyTotal UnconditionaldAg_MoneyTotal/dt = -
TotalRevenuesFarmers+(RandomNumber1sd4_Markets*GrossAgMoneyPeople2)
Initial Value = 2253007*a1cpi1920to1880
AgEconomics
compartment: AnnualCosts_Ag Unconditional
1Year
dAnnualCosts_Ag/dt = +WageCostsAnnual+FertilizerCostsAnnual-Annualized1YrCosts+FeedCost_Annual
Initial Value = 807782*a1cpi1920to1880
flow: Annualized10YrCosts Unconditional
Flow from ShortCosts_Ag to TotalFarmingCosts
Annualized10YrCosts = ShortCosts_Ag
flow: Annualized1YrCosts Unconditional
Flow from AnnualCosts_Ag to TotalFarmingCosts
Annualized1YrCosts = AnnualCosts_Ag
flow: Annualized30YrCosts Unconditional
Flow from CapitalCosts_Ag to TotalFarmingCosts
Annualized30YrCosts = CapitalCosts_Ag
compartment: CapitalCosts_Ag Unconditional
30Years
dCapitalCosts_Ag/dt = +FarmCosts30Yr-Annualized30YrCosts
Initial Value = 155981*a1cpi1920to1880
flow: FarmCosts30Yr Unconditional
Flow from FarmLand_Cost to CapitalCosts_Ag
FarmCosts30Yr = (1/30) * FarmLand_Cost
compartment: FarmLand_Cost Unconditional
dFarmLand_Cost/dt = 0
Initial Value = 4679442*a1cpi1920to1880
compartment: Feed_Cost Unconditional
dFeed_Cost/dt = 0
Initial Value = 41022*a1cpi1920to1880

flow: FeedCost_Annual Unconditional
Flow from Feed_Cost to AnnualCosts_Ag
FeedCost_Annual = Feed_Cost
compartment: Fence_Cost Unconditional
dFence_Cost/dt = 0
Initial Value = 89347*a1cpi1920to1880
flow: FenceCosts10Yr Unconditional
Flow from Fence_Cost to ShortCosts_Ag
FenceCosts10Yr = (1/10) * Fence_Cost
compartment: Fertilier_Cost Unconditional
dFertilier_Cost/dt = (a1cpi1920to1880*477421)+(119355*a1cpi1920to1880*FertilizerUse_Annual)-FertilizerCostsAnnual
Initial Value = 477421*a1cpi1920to1880
flow: FertilizerCostsAnnual Unconditional
Flow from Fertilier_Cost to AnnualCosts_Ag
FertilizerCostsAnnual = Fertilier_Cost
compartment: Machine_Cost Unconditional
dMachine_Cost/dt = 0
Initial Value = 246429*a1cpi1920to1880
flow: MachineCosts10Yr Unconditional
Flow from Machine_Cost to ShortCosts_Ag
MachineCosts10Yr = (1/10) * Machine_Cost
compartment: ShortCosts_Ag Unconditional
10Years
dShortCosts_Ag/dt = +MachineCosts10Yr-Annualized10YrCosts+FenceCosts10Yr
Initial Value = 33578*a1cpi1920to1880
flow: TotalAnnualCostsFarming Unconditional
Flow from TotalFarmingCosts to TotalAnnualFarmingCostsfromSu
TotalAnnualCostsFarming = TotalFarmingCosts
compartment: TotalFarmingCosts Unconditional
dTotalFarmingCosts/dt = +Annualized1YrCosts+Annualized10YrCosts+Annualized30YrCosts-TotalAnnualCostsFarming
Initial Value = 997341*a1cpi1920to1880
compartment: Wage_Costs Unconditional
dWage_Costs/dt = 0
Initial Value = 289339*a1cpi1920to1880
flow: WageCostsAnnual Unconditional
Flow from Wage_Costs to AnnualCosts_Ag
WageCostsAnnual = Wage_Costs
compartment: Apple_Calories2 Unconditional
dApple_Calories2/dt = +(Apple_weightperbush*Calories_Apples*Apples_toCalories)-Apples_toAgCaloriesProduced
Initial Value = 663732
flow: Apple_Sold Unconditional
Flow from Apples_bushels to Apples_Market
Apple_Sold = APercent_AgFood_toMarket * Apples_bushels
compartment: Apples_Animals Unconditional
dApples_Animals/dt = +Apples_toAnimals
Initial Value = 202
compartment: Apples_bushels Unconditional
dApples_bushels/dt = (BperTree_apples * CropEnhancementFactor* Apples_trees)+(BperTree_apples * RandomNumber1sd_Crops* Apples_trees)-Apple_Sold-Apples_toAnimals-Apples_toPeople
Initial Value = 1303
compartment: Apples_Food Unconditional
dApples_Food/dt = +Apples_toPeople-Apples_toCalories
Initial Value = 59
compartment: Apples_Market Unconditional
dApples_Market/dt = +Apple_Sold-Apples_toMoney
Initial Value = 1042
compartment: Apples_Money Unconditional

dApples_Money/dt = +(APPB_Apples*a1cpi1920to1880*Apples_toMoney)-Apples_toCash
Initial Value = 1668*a1cpi1920to1880
flow: Apples_toAgCaloriesProduced Unconditional
Flow from C1 to Ag_CaloriesProduced
Apples_toAgCaloriesProduced = Apple_Calories2
flow: Apples_toAnimals Unconditional
Flow from Apples_bushels to Apples_Animals
Apples_toAnimals = APercent_AgFood_toAnimals * Apples_bushels
flow: Apples_toCalories Unconditional
Flow from Apples_Food to C1
Apples_toCalories = Apples_Food
flow: Apples_toCash Unconditional
Flow from Apples_Money to Ag_CashMarket
Apples_toCash = Apples_Money
flow: Apples_toMoney Unconditional
Flow from Apples_Market to Apples_Money
Apples_toMoney = Apples_Market
flow: Apples_toPeople Unconditional
Flow from Apples_bushels to Apples_Food
Apples_toPeople = APercent_AgFood_toPeople * Apples_bushels
compartment: Apples_trees Unconditional
dApples_trees/dt = 0
Initial Value = 897
flow: Butter_toCalories Unconditional
Flow from ButtertoCalories to Ag_CaloriesProduced
Butter_toCalories = ButtertoCalories
compartment: ButtertoCalories Unconditional
dButtertoCalories/dt = +(Butter_Calories*ButterTranstoCal/3)-Butter_toCalories
Initial Value = 65560789
flow: ButterTranstoCal Unconditional
Flow from MilkforButter to ButtertoCalories
ButterTranstoCal = MilkforButter
compartment: Cherry_Animals Unconditional
dCherry_Animals/dt = +Cherry_toAnimals
Initial Value = 8
compartment: Cherry_bushels Unconditional
dCherry_bushels/dt = (CropEnhancementFactor*BperTree_cherries * Cherry_trees)+(RandomNumber1sd_Crops*BperTree_cherries * Cherry_trees)-Cherry_toAnimals-Cherry_Sold-Cherry_toPeople
Initial Value = 52
compartment: Cherry_Calories2 Unconditional
dCherry_Calories2/dt = +(Cherry_weightperbushel*Cherry_calories*Cherry_toCalories)-Cherry_toAgCalorieProduced
Initial Value = 19679
compartment: Cherry_Food Unconditional
dCherry_Food/dt = +Cherry_toPeople-Cherry_toCalories
Initial Value = 2
compartment: Cherry_Market Unconditional
dCherry_Market/dt = +Cherry_Sold-Cherry_toMoney
Initial Value = 42
compartment: Cherry_Money Unconditional
dCherry_Money/dt = +(APPB_Cherries*a1cpi1920to1880*Cherry_toMoney)-Cherry_toCash
Initial Value = 104*a1cpi1920to1880
flow: Cherry_Sold Unconditional
Flow from Cherry_bushels to Cherry_Market
Cherry_Sold = APercent_AgFood_toMarket * Cherry_bushels
flow: Cherry_toAgCalorieProduced Unconditional
Flow from Cherry_Calories2 to Ag_CaloriesProduced
Cherry_toAgCalorieProduced = Cherry_Calories2
flow: Cherry_toAnimals Unconditional

Flow from Cherry_bushels to Cherry_Animals
Cherry_toAnimals = APercent_AgFood_toAnimals * Cherry_bushels
flow: Cherry_toCalories Unconditional
Flow from Cherry_Food to Cherry_Calories2
Cherry_toCalories = Cherry_Food
flow: Cherry_toCash Unconditional
Flow from Cherry_Money to Ag_CashMarket
Cherry_toCash = Cherry_Money
flow: Cherry_toMoney Unconditional
Flow from Cherry_Market to Cherry_Money
Cherry_toMoney = Cherry_Market
flow: Cherry_toPeople Unconditional
Flow from Cherry_bushels to Cherry_Food
Cherry_toPeople = APercent_AgFood_toPeople * Cherry_bushels
compartment: Cherry_trees Unconditional
dCherry_trees/dt = 0
Initial Value = 102
compartment: Corn_acres Unconditional
dCorn_acres/dt = 0
Initial Value = 6589
compartment: Corn_Animals Unconditional
dCorn_Animals/dt = +Corn_toAnimals
Initial Value = 29705
compartment: Corn_bushels Unconditional
dCorn_bushels/dt = (BperAcre_corn * CropEnhancementFactor* Corn_acres)+(BperAcre_corn * RandomNumber1sd_Crops* Corn_acres)-Corn_toPeople-Corn_Sold-Corn_toAnimals
Initial Value = 191645
compartment: Corn_Calories2 Unconditional
dCorn_Calories2/dt = +(Corn_weightperbush*Corn_calories*Corn_toCalories)-Corn_toAgCalories
Initial Value = 999291786
compartment: Corn_Food Unconditional
dCorn_Food/dt = +Corn_toPeople-Corn_toCalories
Initial Value = 8624
compartment: Corn_Market Unconditional
dCorn_Market/dt = +Corn_Sold-Corn_toMoney
Initial Value = 153316
compartment: Corn_Money Unconditional
dCorn_Money/dt = +(APPB_Corn*a1cpi1920to1880*Corn_toMoney)-Corn_toCash
Initial Value = 283635*a1cpi1920to1880
flow: Corn_Sold Unconditional
Flow from Corn_bushels to Corn_Market
Corn_Sold = APercent_AgFood_toMarket * Corn_bushels
flow: Corn_toAgCalories Unconditional
Flow from Corn_Calories2 to Ag_CaloriesProduced
Corn_toAgCalories = Corn_Calories2
flow: Corn_toAnimals Unconditional
Flow from Corn_bushels to Corn_Animals
Corn_toAnimals = APercent_AgFood_toAnimals * Corn_bushels
flow: Corn_toCalories Unconditional
Flow from Corn_Food to Corn_Calories2
Corn_toCalories = Corn_Food
flow: Corn_toCash Unconditional
Flow from Corn_Money to Ag_CashMarket
Corn_toCash = Corn_Money
flow: Corn_toMoney Unconditional
Flow from Corn_Market to Corn_Money
Corn_toMoney = Corn_Market
flow: Corn_toPeople Unconditional
Flow from Corn_bushels to Corn_Food
Corn_toPeople = APercent_AgFood_toPeople * Corn_bushels

flow: CostsofFarming Unconditional
Flow from ExpensesFarmingtoNegative to NetProfittoFarmers
CostsofFarming = ExpensesFarmingtoNegative
compartment: DeadAnimals Unconditional
dDeadAnimals/dt = +MilkCows_toDead+OtherCows_toDead+Sheep_toDead
Initial Value = 0.0
compartment: DryPeas_acres Unconditional
dDryPeas_acres/dt = 0
Initial Value = 9
compartment: DryPeas_Animals Unconditional
dDryPeas_Animals/dt = +DryPeas_toAnimals
Initial Value = 10
compartment: DryPeas_bushels Unconditional
dDryPeas_bushels/dt =
(BperAcre_DryPeas*CropEnhancementFactor*DryPeas_acres)+(BperAcre_DryPeas*RandomNumber1sd_Crops*DryPeas_acres)-DryPeas_toPeople-DryPeas_Sold-DryPeas_toAnimals
Initial Value = 67
compartment: DryPeas_Calories2 Unconditional
dDryPeas_Calories2/dt = +(DryPeas_weightperbush*DryPeas_calories*DryPeas_toCalories)-DryPeas_toAgCalProd
Initial Value = 101666
compartment: DryPeas_Food Unconditional
dDryPeas_Food/dt = +DryPeas_toPeople-DryPeas_toCalories
Initial Value = 3
compartment: DryPeas_Market Unconditional
dDryPeas_Market/dt = +DryPeas_Sold-DryPeas_toMoney
Initial Value = 54
compartment: DryPeas_Money Unconditional
dDryPeas_Money/dt = +(APPB_DryPeas*a1cpi1920to1880*DryPeas_toMoney)-DryPeas_toCash
Initial Value = 228*a1cpi1920to1880
flow: DryPeas_Sold Unconditional
Flow from DryPeas_bushels to SwPot_Market1
DryPeas_Sold = APercent_AgFood_toMarket * DryPeas_bushels
flow: DryPeas_toAgCalProd Unconditional
Flow from SwPot_Calories3 to Ag_CaloriesProduced
DryPeas_toAgCalProd = DryPeas_Calories2
flow: DryPeas_toAnimals Unconditional
Flow from DryPeas_bushels to SwPotatoes_Animals1
DryPeas_toAnimals = APercent_AgFood_toAnimals * DryPeas_bushels
flow: DryPeas_toCalories Unconditional
Flow from DryPeas_Food to SwPot_Calories3
DryPeas_toCalories = DryPeas_Food
flow: DryPeas_toCash Unconditional
Flow from SwPotatoe_Money1 to Ag_CashMarket
DryPeas_toCash = DryPeas_Money
flow: DryPeas_toMoney Unconditional
Flow from DryPeas_Market to SwPotatoe_Money1
DryPeas_toMoney = DryPeas_Market
flow: DryPeas_toPeople Unconditional
Flow from DryPeas_bushels to SwPot_Food1
DryPeas_toPeople = APercent_AgFood_toPeople * DryPeas_bushels
compartment: Egg_Calories2 Unconditional
dEgg_Calories2/dt = +(Egg_Calories*Eggs_toCalories)-Eggs_toAgCalProd
Initial Value = 41459340
compartment: Eggs Unconditional
dEggs/dt = +(Poultry*15)-Eggs_toCalories-Eggs_toSold
Initial Value = 637836
flow: Eggs_toAgCalProd Unconditional
Flow from Egg_Calories2 to Ag_CaloriesProduced
Eggs_toAgCalProd = Egg_Calories2

flow: Eggs_toCalories Unconditional
Flow from Eggs to Egg_Calories2
Eggs_toCalories = Eggs
flow: Eggs_toSold Unconditional
Flow from Eggs to EggsSold
Eggs_toSold = .502 * Eggs
compartment: EggsSold Unconditional
dEggsSold/dt = +(.21*Eggs_toSold)
Initial Value = 5601
compartment: ExpensesFarming Unconditional
dExpensesFarming/dt = +FarmingExpenses-tonegative
Initial Value = 997341*a1cpi1920to1880
compartment: ExpensesFarmingtoNegative Unconditional
dExpensesFarmingtoNegative/dt = +(-1*tonegative)-CostsofFarming
Initial Value = -997341*a1cpi1920to1880
flow: FarmingExpenses Unconditional
Flow from TotalAnnualFarmingCostsfromSu to ExpensesFarming
FarmingExpenses = TotalAnnualFarmingCostsfromSu
compartment: Grape_Vines Unconditional
dGrape_Vines/dt = 0
Initial Value = 56
compartment: Grapes_Animals Unconditional
dGrapes_Animals/dt = +Grapes_toAnimals
Initial Value = 4
compartment: Grapes_bushels Unconditional
dGrapes_bushels/dt = (CropEnhancementFactor*BperVine_Grapes*
Grape_Vines)+(RandomNumber1sd_Crops*BperVine_Grapes * Grape_Vines)-Grapes_toAnimals-Grapes_Sold-
Grapes_toPeople
Initial Value = 24
compartment: Grapes_Calories2 Unconditional
dGrapes_Calories2/dt = +(Grape_weightperbush*Grape_calories*Grapes_toCalories)-
Grapes_toAgCaloriesProduced
Initial Value = 91200
compartment: Grapes_Food Unconditional
dGrapes_Food/dt = +Grapes_toPeople-Grapes_toCalories
Initial Value = 1
compartment: Grapes_Market Unconditional
dGrapes_Market/dt = +Grapes_Sold-Grapes_toMoney
Initial Value = 19
compartment: Grapes_Money Unconditional
dGrapes_Money/dt = +(APPB_Grapes*a1cpi1920to1880*Grapes_toMoney)-Grapes_toCash
Initial Value = 35*a1cpi1920to1880
flow: Grapes_Sold Unconditional
Flow from Grapes_bushels to Grapes_Market
Grapes_Sold = APercent_AgFood_toMarket * Grapes_bushels
flow: Grapes_toAgCaloriesProduced Unconditional
Flow from Grapes_Calories2 to Ag_CaloriesProduced
Grapes_toAgCaloriesProduced = Grapes_Calories2
flow: Grapes_toAnimals Unconditional
Flow from Grapes_bushels to Grapes_Animals
Grapes_toAnimals = APercent_AgFood_toAnimals * Grapes_bushels
flow: Grapes_toCalories Unconditional
Flow from Grapes_Food to PlumPrune_Calories4
Grapes_toCalories = Grapes_Food
flow: Grapes_toCash Unconditional
Flow from Grapes_Money to Ag_CashMarket
Grapes_toCash = Grapes_Money
flow: Grapes_toMoney Unconditional
Flow from Grapes_Market to PlumPrune_Money2
Grapes_toMoney = Grapes_Market

flow: Grapes_toPeople Unconditional
Flow from Grapes_bushels to Grapes_Food
Grapes_toPeople = APercent_AgFood_toPeople * Grapes_bushels
flow: GrossAgMoneyPeople2 Unconditional
Flow from Ag_MoneyProduced to Ag_MoneyTotal
GrossAgMoneyPeople2 = Ag_MoneyProduced
flow: GrossAgMoneytoPeople Unconditional
Flow from Ag_CashMarket to Ag_MoneyProduced
GrossAgMoneytoPeople = Ag_CashMarket
compartment: Hog_Pop Unconditional
dHog_Pop/dt = -Hogs_toHogs
Initial Value = 1000000
compartment: Hogs Unconditional
dHogs/dt = +Hogs_toHogs-Hogs_toCalories
Initial Value = 2553
compartment: Hogs_Calories Unconditional
dHogs_Calories/dt = +(Hog_Calories*Hogs_toCalories)-Hogs_toAgCalProd
Initial Value = 87567900
flow: Hogs_toAgCalProd Unconditional
Flow from Hogs_Calories to Ag_CaloriesProduced
Hogs_toAgCalProd = Hogs_Calories
flow: Hogs_toCalories Unconditional
Flow from Hogs to Hogs_Calories
Hogs_toCalories = .25*Hogs
flow: Hogs_toHogs Unconditional
Flow from Hog_Pop to Hogs
Hogs_toHogs = .25*Hogs
compartment: Milk Unconditional
Gallons
dMilk/dt = (MilkCow_GallonsPerCow*MilkCows)-MilktoPeople-MilktoButter-MilkforSale
Initial Value = 132179
flow: Milk_toCalories Unconditional
Flow from MilkCalories to Ag_CaloriesProduced
Milk_toCalories = MilkCalories
flow: Milk_toMoney Unconditional
Flow from MilkSold to Ag_CashMarket
Milk_toMoney = MilkSold
compartment: MilkCalories Unconditional
dMilkCalories/dt = +(Milk_Calories*MilktoPeople)-Milk_toCalories
Initial Value = 154146816
compartment: MilkCow_Dropped Unconditional
dMilkCow_Dropped/dt = +MilkCow_toDrop-MilkCowDropped_toMilkCow
Initial Value = 144
compartment: MilkCow_Money Unconditional
dMilkCow_Money/dt = +(MilkCows_PricePerSale*a1cpi1920to1880*MilkCow_toMoney)-MilkCow_toCash
Initial Value = 3485*a1cpi1920to1880
compartment: MilkCow_Pop Unconditional
dMilkCow_Pop/dt = -MilkCow_toDrop-MilkCow_toPurchase
Initial Value = 100000000
compartment: MilkCow_Purchased Unconditional
dMilkCow_Purchased/dt = +MilkCow_toPurchase-MilkCowPurchased_toMilkCow
Initial Value = 22
flow: MilkCow_toCash Unconditional
Flow from MilkCow_Money to Ag_CashMarket
MilkCow_toCash = MilkCow_Money
flow: MilkCow_toDrop Unconditional
Flow from MilkCow_Pop to MilkCow_Dropped
MilkCow_toDrop = MilkCow_Dropped
flow: MilkCow_toMoney Unconditional
Flow from MilkCows_sold to MilkCow_Money

MilkCow_toMoney = MilkCows_sold
flow: MilkCow_toPurchase Unconditional
Flow from MilkCow_Pop to MilkCow_Purchased
MilkCow_toPurchase = MilkCow_Purchased
flow: MilkCowDropped_toMilkCow Unconditional
Flow from MilkCow_Dropped to MilkCows
MilkCowDropped_toMilkCow = MilkCow_Dropped
flow: MilkCowPurchased_toMilkCow Unconditional
Flow from MilkCow_Purchased to MilkCows
MilkCowPurchased_toMilkCow = MilkCow_Purchased
compartment: MilkCows Conditional
dMilkCows/dt =
 0 for MilkCows>894
 -MilkCows_toSold-MilkCows_toDied-
MilkCows_toSlaughtered+MilkCowDropped_toMilkCow+MilkCowPurchased_toMilkCow by default
Initial Value = 522
compartment: MilkCows_Calories2 Unconditional
dMilkCows_Calories2/dt = +(MilkCow_Calories*MilkCows_toCalories)-MilkCows_toAgCalProd
Initial Value = 15105877
compartment: MilkCows_died Unconditional
dMilkCows_died/dt = +MilkCows_toDied-MilkCows_toDead
Initial Value = 27
compartment: MilkCows_slaughtered Unconditional
dMilkCows_slaughtered/dt = +MilkCows_toSlaughtered-MilkCows_toCalories
Initial Value = 38
compartment: MilkCows_sold Unconditional
dMilkCows_sold/dt = +MilkCows_toSold-MilkCow_toMoney
Initial Value = 56
flow: MilkCows_toAgCalProd Unconditional
Flow from MilkCows_Calories2 to Ag_CaloriesProduced
MilkCows_toAgCalProd = MilkCows_Calories2
flow: MilkCows_toCalories Unconditional
Flow from MilkCows_slaughtered to MilkCows_Calories2
MilkCows_toCalories = MilkCows_slaughtered
flow: MilkCows_toDead Unconditional
Flow from MilkCows_died to DeadAnimals
MilkCows_toDead = MilkCows_died
flow: MilkCows_toDied Unconditional
Flow from MilkCows to MilkCows_died
MilkCows_toDied = MilkCows_died
flow: MilkCows_toSlaughtered Unconditional
Flow from MilkCows to MilkCows_slaughtered
MilkCows_toSlaughtered = MilkCows_slaughtered
flow: MilkCows_toSold Unconditional
Flow from MilkCows to MilkCows_sold
MilkCows_toSold = MilkCows_sold
compartment: MilkforButter Unconditional
lbs
dMilkforButter/dt = +MilktoButter-ButterTranstoCal
Initial Value = 60486
flow: MilkforSale Unconditional
Flow from Milk to MilkSold
MilkforSale = MilkSold_Perct * Milk
compartment: MilkSold Unconditional
dMilkSold/dt = +(APPG_Milk*a1cpi1920to1880*MilkforSale)-Milk_toMoney
Initial Value = 862*a1cpi1920to1880
flow: MilktoButter Unconditional
Flow from Milk to MilkforButter
MilktoButter = MilkButter_Perct * Milk
flow: MilktoPeople Unconditional

Flow from Milk to MilkCalories
MilktoPeople = MilkConsumed_Perct * Milk
flow: NetCaloriestoPeople_Agric Unconditional
Flow from Ag_CaloriesProduced to TotalCaloriesfromAgriculture
NetCaloriestoPeople_Agric = Ag_CaloriesProduced
flow: NetMoneytoPeopleAgric Unconditional
Flow from NetProfittoFarmers to NetMoneyfromAgric
NetMoneytoPeopleAgric = NetProfittoFarmers
compartment: NetProfittoFarmers Unconditional
dNetProfittoFarmers/dt = +TotalRevenuesFarmers+CostsofFarming-NetMoneytoPeopleAgric
Initial Value = 1255666*a1cpi1920to1880
flow: Oat_toCalories Unconditional
Flow from Oats_Food to C1
Oat_toCalories = Oats_Food
compartment: Oats_acres Unconditional
dOats_acres/dt = 0
Initial Value = 17
compartment: Oats_Animals Unconditional
dOats_Animals/dt = +Oats_toAnimals
Initial Value = 82
compartment: Oats_bushels Unconditional
dOats_bushels/dt = (BperAcre_oats * CropEnhancementFactor*Oats_acres)+(BperAcre_oats * RandomNumber1sd_Crops*Oats_acres)-Oats_toPeople-Oats_Sold-Oats_toAnimals
Initial Value = 529
compartment: Oats_Food Unconditional
dOats_Food/dt = +Oats_toPeople-Oat_toCalories
Initial Value = 24
compartment: Oats_Market Unconditional
dOats_Market/dt = +Oats_Sold-Oats_toMoney
Initial Value = 423
compartment: Oats_Money Unconditional
dOats_Money/dt = +(APPB_Oats*a1cpi1920to1880*Oats_toMoney)-Oats_toCash
Initial Value = 466*a1cpi1920to1880
flow: Oats_Sold Unconditional
Flow from Oats_bushels to Oats_Market
Oats_Sold = APercent_AgFood_toMarket * Oats_bushels
flow: Oats_toAgCaloriesProduced Unconditional
Flow from C1 to Ag_CaloriesProduced
Oats_toAgCaloriesProduced = Oats_toCalories2
flow: Oats_toAnimals Unconditional
Flow from Oats_bushels to Oats_Animals
Oats_toAnimals = APercent_AgFood_toAnimals * Oats_bushels
compartment: Oats_toCalories2 Unconditional
dOats_toCalories2/dt = +(Oat_weightperbush*Oat_calories*Oat_toCalories)-Oats_toAgCaloriesProduced
Initial Value = 1343876
flow: Oats_toCash Unconditional
Flow from Oats_Money to Ag_CashMarket
Oats_toCash = Oats_Money
flow: Oats_toMoney Unconditional
Flow from Oats_Market to Oats_Money
Oats_toMoney = Oats_Market
flow: Oats_toPeople Unconditional
Flow from Oats_bushels to Oats_Food
Oats_toPeople = APercent_AgFood_toPeople * Oats_bushels
compartment: OtherCattle Conditional
dOtherCattle/dt =
0 for OtherCattle>56
-OtherCattleSold-OtherCattleDied-OtherCattleSlaughtered+OtherCowDropped_toOtherCow+OtherCowPurchased_toOtherCow by default
Initial Value = 33

compartment: OtherCattle_sold Unconditional
dOtherCattle_sold/dt = +OtherCattleSold-OtherCows_toMoney
Initial Value = 4
flow: OtherCattleDied Unconditional
Flow from OtherCattle to OtherCows_died
OtherCattleDied = OtherCows_died
flow: OtherCattleSlaughtered Unconditional
Flow from OtherCattle to OtherCows_slaughtered
OtherCattleSlaughtered = OtherCows_slaughtered
flow: OtherCattleSold Unconditional
Flow from OtherCattle to OtherCattle_sold
OtherCattleSold = OtherCattle_sold
compartment: OtherCow_Calories2 Unconditional
dOtherCow_Calories2/dt = +(OtherCows_Calories*OtherCow_toCalories)-OtherCow_toAgCalProd
Initial Value = 954969
compartment: OtherCow_Dropped Unconditional
dOtherCow_Dropped/dt = +OtherCow_toDrop-OtherCowDropped_toOtherCow
Initial Value = 4
compartment: OtherCow_Pop Unconditional
dOtherCow_Pop/dt = -OtherCow_toDrop-OtherCow_toPurchase
Initial Value = 100000000
compartment: OtherCow_Purchased Unconditional
dOtherCow_Purchased/dt = +OtherCow_toPurchase-OtherCowPurchased_toOtherCow
Initial Value = 1
flow: OtherCow_toAgCalProd Unconditional
Flow from OtherCow_Calories2 to Ag_CaloriesProduced
OtherCow_toAgCalProd = OtherCow_Calories2
flow: OtherCow_toCalories Unconditional
Flow from OtherCows_slaughtered to OtherCow_Calories2
OtherCow_toCalories = OtherCows_slaughtered
flow: OtherCow_toDrop Unconditional
Flow from OtherCow_Pop to OtherCow_Dropped
OtherCow_toDrop = OtherCow_Dropped
flow: OtherCow_toPurchase Unconditional
Flow from OtherCow_Pop to OtherCow_Purchased
OtherCow_toPurchase = OtherCow_Purchased
flow: OtherCowDropped_toOtherCow Unconditional
Flow from OtherCow_Dropped to OtherCattle
OtherCowDropped_toOtherCow = OtherCow_Dropped
flow: OtherCowPurchased_toOtherCow Unconditional
Flow from OtherCow_Purchased to OtherCattle
OtherCowPurchased_toOtherCow = OtherCow_Purchased
compartment: OtherCows_died Unconditional
dOtherCows_died/dt = +OtherCattleDied-OtherCows_toDead
Initial Value = 2
compartment: OtherCows_Money Unconditional
dOtherCows_Money/dt = +(OtherCows_PricePerSale*a1cpi1920to1880*OtherCows_toMoney)-
OtherCows_toCash
Initial Value = 220*a1cpi1920to1880
compartment: OtherCows_slaughtered Unconditional
dOtherCows_slaughtered/dt = +OtherCattleSlaughtered-OtherCow_toCalories
Initial Value = 2
flow: OtherCows_toCash Unconditional
Flow from OtherCows_Money to Ag_CashMarket
OtherCows_toCash = OtherCows_Money
flow: OtherCows_toDead Unconditional
Flow from OtherCows_died to DeadAnimals
OtherCows_toDead = OtherCows_died
flow: OtherCows_toMoney Unconditional
Flow from OtherCattle_sold to OtherCows_Money

OtherCows_toMoney = OtherCattle_sold
compartment: Peach_Animals Unconditional
dPeach_Animals/dt = +Peach_toAnimals
Initial Value = 47
compartment: Peach_bushels Unconditional
dPeach_bushels/dt = (CropEnhancementFactor*Bpertree_peach * Peach_trees)+(RandomNumber1sd_Crops*Bpertree_peach * Peach_trees)-Peach_Sold-Peach_toPeople-Peach_toAnimals
Initial Value = 300
compartment: Peach_Calories2 Unconditional
dPeach_Calories2/dt = +(Peach_weightperbush*Peach_calories*Peach_toCalories)-Peach_toAgCaloriesProduced
Initial Value = 119388
compartment: Peach_Food Unconditional
dPeach_Food/dt = +Peach_toPeople-Peach_toCalories
Initial Value = 14
compartment: Peach_Market Unconditional
dPeach_Market/dt = +Peach_Sold-Peach_toMoney
Initial Value = 240
compartment: Peach_Money Unconditional
dPeach_Money/dt = +(APPB_Peach*a1cpi1920to1880*Peach_toMoney)-Peach_toCash
Initial Value = 480*a1cpi1920to1880
flow: Peach_Sold Unconditional
Flow from Peach_bushels to Peach_Market
Peach_Sold = APercent_AgFood_toMarket * Peach_bushels
flow: Peach_toAgCaloriesProduced Unconditional
Flow from Peach_Calories2 to Ag_CaloriesProduced
Peach_toAgCaloriesProduced = Peach_Calories2
flow: Peach_toAnimals Unconditional
Flow from Peach_bushels to Peach_Animals
Peach_toAnimals = APercent_AgFood_toAnimals * Peach_bushels
flow: Peach_toCalories Unconditional
Flow from Peach_Food to Peach_Calories2
Peach_toCalories = Peach_Food
flow: Peach_toCash Unconditional
Flow from Peach_Money to Ag_CashMarket
Peach_toCash = Peach_Money
flow: Peach_toMoney Unconditional
Flow from Peach_Market to Peach_Money
Peach_toMoney = Peach_Market
flow: Peach_toPeople Unconditional
Flow from Peach_bushels to Peach_Food
Peach_toPeople = APercent_AgFood_toPeople * Peach_bushels
compartment: Peach_trees Unconditional
dPeach_trees/dt = 0
Initial Value = 507
compartment: Pear_Animals Unconditional
dPear_Animals/dt = +Pear_toAnimals
Initial Value = 169
compartment: Pear_bushels Unconditional
dPear_bushels/dt = (Bpertree_pears * CropEnhancementFactor* Pear_trees)+(Bpertree_pears * RandomNumber1sd_Crops* Pear_trees)-Pear_Sold-Pear_toAnimals-Pear_toPeople
Initial Value = 1090
compartment: Pear_Calories2 Unconditional
dPear_Calories2/dt = +(Pear_calories*Pear_weightperbush*Pear_toCalories)-Pear_toAgCaloriesProduced
Initial Value = 748209
compartment: Pear_Food Unconditional
dPear_Food/dt = +Pear_toPeople-Pear_toCalories
Initial Value = 49
compartment: Pear_Market Unconditional
dPear_Market/dt = +Pear_Sold-Pear_toMoney

Initial Value = 872
compartment: Pear_Money Unconditional
dPear_Money/dt = +(APPB_Pears*a1cpi1920to1880*Pear_toMoney)-Pear_toCash
Initial Value = 1395*a1cpi1920to1880
flow: Pear_Sold Unconditional
Flow from Pear_bushels to Pear_Market
Pear_Sold = APercent_AgFood_toMarket * Pear_bushels
flow: Pear_toAgCaloriesProduced Unconditional
Flow from Pear_Calories to Ag_CaloriesProduced
Pear_toAgCaloriesProduced = Pear_Calories2
flow: Pear_toAnimals Unconditional
Flow from Pear_bushels to Pear_Animals
Pear_toAnimals = APercent_AgFood_toAnimals * Pear_bushels
flow: Pear_toCalories Unconditional
Flow from Pear_Food to Pear_Calories
Pear_toCalories = Pear_Food
flow: Pear_toCash Unconditional
Flow from Pear_Money to Ag_CashMarket
Pear_toCash = Pear_Money
flow: Pear_toMoney Unconditional
Flow from Pear_Market to Pear_Money
Pear_toMoney = Pear_Market
flow: Pear_toPeople Unconditional
Flow from Pear_bushels to Pear_Food
Pear_toPeople = APercent_AgFood_toPeople * Pear_bushels
compartment: Pear_trees Unconditional
dPear_trees/dt = 0
Initial Value = 384
compartment: PlumPrune_Animals Unconditional
dPlumPrune_Animals/dt = +PlumPrune_toAnimals
Initial Value = 8
compartment: PlumPrune_bushels Unconditional
dPlumPrune_bushels/dt = (CropEnhancementFactor*Bpertree_plumprune * PlumPrune_trees)+(RandomNumber1sd_Crops*Bpertree_plumprune * PlumPrune_trees)-PlumPrune_toAnimals-PlumPrune_Sold-PlumPrune_toPeople
Initial Value = 52
compartment: PlumPrune_Calories2 Unconditional
dPlumPrune_Calories2/dt = +(PlumPrune_weightperbushel*PlumPrune_calories*PlumPrune_toCalories)-PlumPrune_toAgCaloriesProduced
Initial Value = 22389
compartment: PlumPrune_Food Unconditional
dPlumPrune_Food/dt = +PlumPrune_toPeople-PlumPrune_toCalories
Initial Value = 2
compartment: PlumPrune_Market Unconditional
dPlumPrune_Market/dt = +PlumPrune_Sold-PlumPrune_toMoney
Initial Value = 42
compartment: PlumPrune_Money Unconditional
dPlumPrune_Money/dt = +(APPB_PlumPrune*a1cpi1920to1880*PlumPrune_toMoney)-PlumPrune_toCash
Initial Value = 79*a1cpi1920to1880
flow: PlumPrune_Sold Unconditional
Flow from PlumPrune_bushels to Peach_Market1
PlumPrune_Sold = APercent_AgFood_toMarket * PlumPrune_bushels
flow: PlumPrune_toAgCaloriesProduced Unconditional
Flow from PlumPrune_Calories2 to Ag_CaloriesProduced
PlumPrune_toAgCaloriesProduced = PlumPrune_Calories2
flow: PlumPrune_toAnimals Unconditional
Flow from Plum_bushels to PlumPrune_Animals
PlumPrune_toAnimals = APercent_AgFood_toAnimals * PlumPrune_bushels
flow: PlumPrune_toCalories Unconditional
Flow from PlumPrune_Food to PlumPrune_Calories2

PlumPrune_toCalories = PlumPrune_Food
flow: PlumPrune_toCash Unconditional
Flow from PlumPrune_Money to Ag_CashMarket
PlumPrune_toCash = PlumPrune_Money
flow: PlumPrune_toMoney Unconditional
Flow from PlumPrune_Market to PlumPrune_Money
PlumPrune_toMoney = PlumPrune_Market
flow: PlumPrune_toPeople Unconditional
Flow from PlumPrune_bushels to Peach_Food1
PlumPrune_toPeople = APercent_AgFood_toPeople * PlumPrune_bushels
compartment: PlumPrune_trees Unconditional
dPlumPrune_trees/dt = 0
Initial Value = 68
compartment: Pot_Calories2 Unconditional
dPot_Calories2/dt = +(Potato_irish_weightperbush*Potato_irish_calories*Pot_toCalories)-Pot_toAgCalProd
Initial Value = 2253713584
compartment: Pot_Food Unconditional
dPot_Food/dt = +Potato_toPeople-Pot_toCalories
Initial Value = 41830
compartment: Pot_Market Unconditional
dPot_Market/dt = +Potato_Sold-Pot_toMoney
Initial Value = 743650
flow: Pot_toAgCalProd Unconditional
Flow from C1 to Ag_CaloriesProduced
Pot_toAgCalProd = Pot_Calories2
flow: Pot_toCalories Unconditional
Flow from Pot_Food to C1
Pot_toCalories = Pot_Food
flow: Pot_toCash Unconditional
Flow from Potatoe_Money to Ag_CashMarket
Pot_toCash = Potatoe_Money
flow: Pot_toMoney Unconditional
Flow from Pot_Market to Potatoe_Money
Pot_toMoney = Pot_Market
flow: Potato_Sold Unconditional
Flow from Potatoes_bushels to Pot_Market
Potato_Sold = APercent_AgFood_toMarket * Potatoes_bushels
flow: Potato_toPeople Unconditional
Flow from Potatoes_bushels to Pot_Food
Potato_toPeople = APercent_AgFood_toPeople * Potatoes_bushels
compartment: Potatoe_Money Unconditional
dPotatoe_Money/dt = +(APPB_Potato_irish*a1cpi1920to1880*Pot_toMoney)-Pot_toCash
Initial Value = 1636029*a1cpi1920to1880
compartment: Potatoes_acres Unconditional
dPotatoes_acres/dt = 0
Initial Value = 6484
compartment: Potatoes_Animals Unconditional
dPotatoes_Animals/dt = +Potatoes_toAnimals
Initial Value = 144082
compartment: Potatoes_bushels Unconditional
dPotatoes_bushels/dt =
(BperAcre_potato_irish*CropEnhancementFactor*Potatoes_acres)+(BperAcre_potato_irish*RandomNumber1sd_
Crops*Potatoes_acres)-Potato_toPeople-Potato_Sold-Potatoes_toAnimals
Initial Value = 929562
flow: Potatoes_toAnimals Unconditional
Flow from Potatoes_bushels to Potatoes_Animals
Potatoes_toAnimals = APercent_AgFood_toAnimals * Potatoes_bushels
flow: Poulltry_toCalories Unconditional
Flow from Poultry to Poultry_Calories2
Poulltry_toCalories = .5 * Poultry

compartment: Poultry Unconditional
dPoultry/dt = +Poultry_toPoultry-Poulltry_toCalories-Poultry_toSold
Initial Value = 44088
compartment: Poultry_Calories2 Unconditional
dPoultry_Calories2/dt = +(Poultry_Calories*Poulltry_toCalories)-Poultry_toAgCalProd
Initial Value = 23493605
compartment: Poultry_Pop Unconditional
dPoultry_Pop/dt = -Poultry_toPoultry
Initial Value = 1000000000
compartment: Poultry_sold Unconditional
dPoultry_sold/dt = +(Poultry_Price*a1cpi1920to1880*Poultry_toSold)-Poultry_toCash
Initial Value = 7358*a1cpi1920to1880
flow: Poultry_toAgCalProd Unconditional
Flow from Poultry_Calories2 to Ag_CaloriesProduced
Poultry_toAgCalProd = Poultry_Calories2
flow: Poultry_toCash Unconditional
Flow from Poultry_sold to Ag_CashMarket
Poultry_toCash = Poultry_sold
flow: Poultry_toPoultry Unconditional
Flow from Poultry_Pop to Poultry
Poultry_toPoultry = .67 * Poultry
flow: Poultry_toSold Unconditional
Flow from Poultry to Poultry_sold
Poultry_toSold = .17*Poultry
compartment: Rye_acres Unconditional
dRye_acres/dt = 0
Initial Value = 25
compartment: Rye_Animals Unconditional
dRye_Animals/dt = +Rye_toAnimals
Initial Value = 12
compartment: Rye_bushels Unconditional
dRye_bushels/dt =
(BperAcre_Rye*CropEnhancementFactor*Rye_acres)+(BperAcre_Rye*RandomNumber1sd_Crops*Rye_acres)-
Rye_toPeople-Rye_Sold-Rye_toAnimals
Initial Value = 80
compartment: Rye_Calories2 Unconditional
dRye_Calories2/dt = +(Rye_weightperbushel*Rye_Calories*Rye_toCalories)-Rye_toAgCalProd
Initial Value = 335020
compartment: Rye_Food Unconditional
dRye_Food/dt = +Rye_toPeople-Rye_toCalories
Initial Value = 4
compartment: Rye_Market Unconditional
dRye_Market/dt = +Rye_Sold-Rye_toMoney
Initial Value = 64
compartment: Rye_Money Unconditional
dRye_Money/dt = +(APPB_Rye*a1cpi1920to1880*Rye_toMoney)-Rye_toCsh
Initial Value = 99*a1cpi1920to1880
flow: Rye_Sold Unconditional
Flow from Rye_bushels to Rye_Market
Rye_Sold = APercent_AgFood_toMarket * Rye_bushels
flow: Rye_toAgCalProd Unconditional
Flow from Rye_Calories2 to Ag_CaloriesProduced
Rye_toAgCalProd = Rye_Calories2
flow: Rye_toAnimals Unconditional
Flow from Rye_bushels to Rye_Animals
Rye_toAnimals = APercent_AgFood_toAnimals * Rye_bushels
flow: Rye_toCalories Unconditional
Flow from Rye_Food to Pot_Calories3
Rye_toCalories = Rye_Food
flow: Rye_toCsh Unconditional

Flow from Rye_Money to Ag_CashMarket
Rye_toCsh = Rye_Money
flow: Rye_toMoney Unconditional
Flow from Rye_Market to Potatoe_Money1
Rye_toMoney = Rye_Market
flow: Rye_toPeople Unconditional
Flow from Rye_bushels to Rye_Food
Rye_toPeople = APercent_AgFood_toPeople * Rye_bushels
compartment: Sheep Conditional
dSheep/dt =
 0 for Sheep>1038
 -SheepDied-SheepSlaughtered-SheepSold+SheepDropped_toSheep+SheepPurchased_toSheep by default
Initial Value = 613
compartment: Sheep_Calories2 Unconditional
dSheep_Calories2/dt = +(Sheep_Calories*Sheep_toCalories)-Sheep_toAgCalProd
Initial Value = 1062640
compartment: Sheep_died Unconditional
dSheep_died/dt = +SheepDied-Sheep_toDead
Initial Value = 146
compartment: Sheep_Dropped Unconditional
dSheep_Dropped/dt = +Sheep_toDrop-SheepDropped_toSheep
Initial Value = 62
compartment: Sheep_Money Unconditional
dSheep_Money/dt = +(Sheep_PricePerSale*a1cpi1920to1880*Sheep_toMoney)-Sheep_toCash
Initial Value = 172*a1cpi1920to1880
compartment: Sheep_Pop Unconditional
dSheep_Pop/dt = -Sheep_toDrop-Sheep_toPurchase
Initial Value = 100000000
compartment: Sheep_Purchased Unconditional
dSheep_Purchased/dt = +Sheep_toPurchase-SheepPurchased_toSheep
Initial Value = 31
compartment: Sheep_slaughtered Unconditional
dSheep_slaughtered/dt = +SheepSlaughtered-Sheep_toCalories
Initial Value = 17
compartment: Sheep_sold Unconditional
dSheep_sold/dt = +SheepSold-Sheep_toMoney
Initial Value = 16
flow: Sheep_toAgCalProd Unconditional
Flow from Sheep_Calories2 to Ag_CaloriesProduced
Sheep_toAgCalProd = Sheep_Calories2
flow: Sheep_toCalories Unconditional
Flow from Sheep_slaughtered to Sheep_Calories2
Sheep_toCalories = Sheep_slaughtered
flow: Sheep_toCash Unconditional
Flow from Sheep_Money to Ag_CashMarket
Sheep_toCash = Sheep_Money
flow: Sheep_toDead Unconditional
Flow from Sheep_died to DeadAnimals
Sheep_toDead = Sheep_died
flow: Sheep_toDrop Unconditional
Flow from Sheep_Pop to Sheep_Dropped
Sheep_toDrop = Sheep_Dropped
flow: Sheep_toMoney Unconditional
Flow from Sheep_sold to Sheep_Money
Sheep_toMoney = Sheep_sold
flow: Sheep_toPurchase Unconditional
Flow from Sheep_Pop to Sheep_Purchased
Sheep_toPurchase = Sheep_Purchased
flow: SheepDied Unconditional
Flow from Sheep to Sheep_died

SheepDied = Sheep_died
flow: SheepDropped_toSheep Unconditional
Flow from Sheep_Dropped to Sheep
SheepDropped_toSheep = Sheep_Dropped
flow: SheepPurchased_toSheep Unconditional
Flow from Sheep_Purchased to Sheep
SheepPurchased_toSheep = Sheep_Purchased
flow: SheepSlaughtered Unconditional
Flow from Sheep to Sheep_slaughtered
SheepSlaughtered = Sheep_slaughtered
flow: SheepSold Unconditional
Flow from Sheep to Sheep_sold
SheepSold = Sheep_sold
compartment: SoyBean_acres Unconditional
dSoyBean_acres/dt = 0
Initial Value = 11
compartment: SoyBean_Animals Unconditional
dSoyBean_Animals/dt = +SoyBean_toAnimals
Initial Value = 9
compartment: SoyBean_bushels Unconditional
dSoyBean_bushels/dt =
(BperAcre_SoyBeans*CropEnhancementFactor*SoyBean_acres)+(BperAcre_SoyBeans*RandomNumber1sd_Crops*SoyBean_acres)-SoyBean_toPeople-SoyBean_Sold-SoyBean_toAnimals
Initial Value = 60
compartment: SoyBean_Calories2 Unconditional
dSoyBean_Calories2/dt = +(SoyBean_weightperbushel*SoyBean_Calories*SoyBean_toCalories)-SoyBean_toAgCalProduced
Initial Value = 107892
compartment: SoyBean_Food Unconditional
dSoyBean_Food/dt = +SoyBean_toPeople-SoyBean_toCalories
Initial Value = 3
compartment: SoyBean_Market Unconditional
dSoyBean_Market/dt = +SoyBean_Sold-SoyBean_toMoney
Initial Value = 48
compartment: SoyBean_Money Unconditional
dSoyBean_Money/dt = +(APPB_SoyBeans*a1cpi1920to1880*SoyBean_toMoney)-SoyBean_toCash
Initial Value = 223*a1cpi1920to1880
flow: SoyBean_Sold Unconditional
Flow from SoyBean_bushels to Pot_Market1
SoyBean_Sold = APercent_AgFood_toMarket * SoyBean_bushels
flow: SoyBean_toAgCalProduced Unconditional
Flow from SoyBean_Calories2 to Ag_CaloriesProduced
SoyBean_toAgCalProduced = SoyBean_Calories2
flow: SoyBean_toAnimals Unconditional
Flow from SoyBean_bushels to Potatoes_Animals1
SoyBean_toAnimals = APercent_AgFood_toAnimals * SoyBean_bushels
flow: SoyBean_toCalories Unconditional
Flow from SoyBean_Food to Pot_Calories3
SoyBean_toCalories = SoyBean_Food
flow: SoyBean_toCash Unconditional
Flow from SoyBean_Money to Ag_CashMarket
SoyBean_toCash = SoyBean_Money
flow: SoyBean_toMoney Unconditional
Flow from SoyBean_Market to Potatoe_Money1
SoyBean_toMoney = SoyBean_Market
flow: SoyBean_toPeople Unconditional
Flow from SoyBean_bushels to Pot_Food1
SoyBean_toPeople = APercent_AgFood_toPeople * SoyBean_bushels
compartment: Strawberry_acres Unconditional
dStrawberry_acres/dt = 0

Initial Value = 6
compartment: Strawberry_Animals Unconditional
dStrawberry_Animals/dt = +Strawberry_toAnimals
Initial Value = 969
compartment: Strawberry_Calories2 Unconditional
dStrawberry_Calories2/dt = +(Strawberry_weightperquart*Strawberry_calories*Strawberry_toCalories)-Strawberry_toAgCaloriesProduced
Initial Value = 176175
compartment: Strawberry_Food Unconditional
dStrawberry_Food/dt = +Strawberry_toPeople-Strawberry_toCalories
Initial Value = 281
compartment: Strawberry_Market Unconditional
dStrawberry_Market/dt = +Strawberry_Sold-Strawberry_toMoney
Initial Value = 5003
compartment: Strawberry_Money Unconditional
dStrawberry_Money/dt = +(APPQuart_Strawberries*a1cpi1920to1880*Strawberry_toMoney)-Strawberry_toCash
Initial Value = 1001*a1cpi1920to1880
compartment: Strawberry_Quarts Unconditional
dStrawberry_Quarts/dt = (CropEnhancementFactor*BQuartsperAcre_Strawberry * Strawberry_acres)+(RandomNumber1sd_Crops*BQuartsperAcre_Strawberry * Strawberry_acres)-Strawberry_toAnimals-Strawberry_Sold-Strawberry_toPeople
Initial Value = 6254
flow: Strawberry_Sold Unconditional
Flow from Strawberry_Quarts to Strawberry_Market
Strawberry_Sold = APercent_AgFood_toMarket * Strawberry_Quarts
flow: Strawberry_toAgCaloriesProduced Unconditional
Flow from Strawberry_Calories2 to Ag_CaloriesProduced
Strawberry_toAgCaloriesProduced = Strawberry_Calories2
flow: Strawberry_toAnimals Unconditional
Flow from Strawberry_Quarts to Strawberry_Animals
Strawberry_toAnimals = APercent_AgFood_toAnimals * Strawberry_Quarts
flow: Strawberry_toCalories Unconditional
Flow from Strawberry_Food to Strawberry_Calories2
Strawberry_toCalories = Strawberry_Food
flow: Strawberry_toCash Unconditional
Flow from Strawberry_Money to Ag_CashMarket
Strawberry_toCash = Strawberry_Money
flow: Strawberry_toMoney Unconditional
Flow from Strawberry_Market to Strawberry_Money
Strawberry_toMoney = Strawberry_Market
flow: Strawberry_toPeople Unconditional
Flow from PlumPrune_bushels3 to PlumPrune_Food3
Strawberry_toPeople = APercent_AgFood_toPeople * Strawberry_Quarts
compartment: Sw_Potatoes_acres Unconditional
dSw_Potatoes_acres/dt = 0
Initial Value = 1387
compartment: Sw_Potatoes_bushels Unconditional
dSw_Potatoes_bushels/dt = (BperAcre_potatos_sw*CropEnhancementFactor*Sw_Potatoes_acres)+(BperAcre_potatos_sw*RandomNumber1sd_Crops*Sw_Potatoes_acres)-SwPotato_toPeople-SwPotato_Sold-SwPotatoes_toAnimals
Initial Value = 242309
compartment: SwPot_Calories2 Unconditional
dSwPot_Calories2/dt = +(Potato_sweet_weightperbushel*Potato_sweet_calories*SwPot_toCalories)-SwPot_toAgCalProd
Initial Value = 244781541
compartment: SwPot_Food Unconditional
dSwPot_Food/dt = +SwPotato_toPeople-SwPot_toCalories
Initial Value = 10904
compartment: SwPot_Market Unconditional
dSwPot_Market/dt = +SwPotato_Sold-SwPot_toMoney

Initial Value = 193847
flow: SwPot_toAgCalProd Unconditional
Flow from C1 to Ag_CaloriesProduced
SwPot_toAgCalProd = SwPot_Calories2
flow: SwPot_toCalories Unconditional
Flow from SwPot_Food to SwPot_Calories2
SwPot_toCalories = SwPot_Food
flow: SwPot_toCash Unconditional
Flow from SwPotatoe_Money to Ag_CashMarket
SwPot_toCash = SwPotatoe_Money
flow: SwPot_toMoney Unconditional
Flow from SwPot_Market to SwPotatoe_Money
SwPot_toMoney = SwPot_Market
flow: SwPotato_Sold Unconditional
Flow from Sw_Potatoes_bushels to SwPot_Market
SwPotato_Sold = APercent_AgFood_toMarket * Sw_Potatoes_bushels
flow: SwPotato_toPeople Unconditional
Flow from Sw_Potatoes_bushels to SwPot_Food
SwPotato_toPeople = APercent_AgFood_toPeople * Sw_Potatoes_bushels
compartment: SwPotatoe_Money Unconditional
dSwPotatoe_Money/dt = +(APPB_Potato_sweet*a1cpi1920to1880*SwPot_toMoney)-SwPot_toCash
Initial Value = 310156*a1cpi1920to1880
compartment: SwPotatoes_Animals Unconditional
dSwPotatoes_Animals/dt = +SwPotatoes_toAnimals
Initial Value = 37558
flow: SwPotatoes_toAnimals Unconditional
Flow from Sw_Potatoes_bushels to SwPotatoes_Animals
SwPotatoes_toAnimals = APercent_AgFood_toAnimals * Sw_Potatoes_bushels
compartment: Tob_Market Unconditional
dTob_Market/dt = +Tobacco_Sold-Tob_toMoney
Initial Value = 0
flow: Tob_toCash Unconditional
Flow from Tobacco_Money to Ag_CashMarket
Tob_toCash = Tobacco_Money
flow: Tob_toMoney Unconditional
Flow from Tob_Market to Tobacco_Money
Tob_toMoney = Tob_Market
compartment: Tobacco_acres Unconditional
dTobacco_acres/dt = 0
Initial Value = 0
compartment: Tobacco_Money Unconditional
dTobacco_Money/dt = +(APPP_Tobacco*a1cpi1920to1880*Tob_toMoney)-Tob_toCash
Initial Value = 0*a1cpi1920to1880
compartment: Tobacco_pounds Unconditional
dTobacco_pounds/dt = (PoundsperAcre_tobacco *
CropEnhancementFactor*Tobacco_acres)+(PoundsperAcre_tobacco *
RandomNumber1sd_Crops*Tobacco_acres)-Tobacco_Sold
Initial Value = 0
flow: Tobacco_Sold Unconditional
Flow from Tobacco_pounds to Tob_Market
Tobacco_Sold = Tobacco_pounds
flow: tonegative Unconditional
Flow from ExpensesFarming to ExpensesFarmingtoNegative
tonegative = ExpensesFarming
flow: TotalRevenuesFarmers Unconditional
Flow from Ag_MoneyTotal to NetProfittoFarmers
TotalRevenuesFarmers = Ag_MoneyTotal
compartment: Wheat_acres Unconditional
dWheat_acres/dt = 0
Initial Value = 110

compartment: Wheat_Animals Unconditional
dWheat_Animals/dt = +Wheat_toAnimals
Initial Value = 273
compartment: Wheat_bushels Unconditional
dWheat_bushels/dt = (BperAcre_wheat * CropEnhancementFactor*Wheat_acres)+(BperAcre_wheat * RandomNumber1sd_Crops*Wheat_acres)-Wheat_toPeople-Wheat_Sold-Wheat_toAnimals
Initial Value = 1763
compartment: Wheat_Calories2 Unconditional
dWheat_Calories2/dt = +(Wheat_weightperbush*Wheat_calories*Wheat_toCalories)-Wheat_toAgCalProd
Initial Value = 7383012
compartment: Wheat_Food Unconditional
dWheat_Food/dt = +Wheat_toPeople-Wheat_toCalories
Initial Value = 79
compartment: Wheat_Market Unconditional
dWheat_Market/dt = +Wheat_Sold-Wheat_toMoney
Initial Value = 1410
compartment: Wheat_Money Unconditional
dWheat_Money/dt = +(APPB_Wheat*a1cpi1920to1880*Wheat_toMoney)-Wheat_toCash
Initial Value = 3300*a1cpi1920to1880
flow: Wheat_Sold Unconditional
Flow from Wheat_bushels to Wheat_Market
Wheat_Sold = APercent_AgFood_toMarket * Wheat_bushels
flow: Wheat_toAgCalProd Unconditional
Flow from C1 to Ag_CaloriesProduced
Wheat_toAgCalProd = Wheat_Calories2
flow: Wheat_toAnimals Unconditional
Flow from Wheat_bushels to Wheat_Animals
Wheat_toAnimals = APercent_AgFood_toAnimals* Wheat_bushels
flow: Wheat_toCalories Unconditional
Flow from Wheat_Food to C1
Wheat_toCalories = Wheat_Food
flow: Wheat_toCash Unconditional
Flow from Wheat_Money to Ag_CashMarket
Wheat_toCash = Wheat_Money
flow: Wheat_toMoney Unconditional
Flow from Wheat_Market to Wheat_Money
Wheat_toMoney = Wheat_Market
flow: Wheat_toPeople Unconditional
Flow from Wheat_bushels to Wheat_Food
Wheat_toPeople = APercent_AgFood_toPeople * Wheat_bushels
compartment: Wool Unconditional
4.89 lbs wool per sheep
dWool/dt = (APPP_Wool*a1cpi1920to1880*4.89*Sheep)
Initial Value = 2998*a1cpi1920to1880
flow: Wool_toMarket Unconditional
Flow from Wool to Ag_CashMarket
Wool_toMarket = Wool
compartment: BayHealthDump Unconditional
dBayHealthDump/dt = +F16
Initial Value = 0.0
compartment: BayHealthFactor Conditional Global
dBayHealthFactor/dt =
  -.50-F16 for FertilizerUse_Aggregate>=450
  -.45-F16 for FertilizerUse_Aggregate>=400
  -.40-F16 for FertilizerUse_Aggregate>=350
  -.35-F16 for FertilizerUse_Aggregate>=300
  -.30-F16 for FertilizerUse_Aggregate>=250
  -.25-F16 for FertilizerUse_Aggregate>=200
  -.20-F16 for FertilizerUse_Aggregate>=150
  -.15-F16 for FertilizerUse_Aggregate>=100

-.10-F16 for FertilizerUse_Aggregate>=50
-.05-F16 for FertilizerUse_Aggregate>=25
0-F16 by default
Initial Value = 0
compartment: BlackTotal Unconditional
dBlackTotal/dt = TotalPop_FB+TotalPop_MB-F24
Initial Value = 2759
compartment: CalDump Unconditional
dCalDump/dt = +toCalDump
Initial Value = 0.0
compartment: Calories_from_Ag_and_ChesBay Unconditional
dCalories_from_Ag_and_ChesBay/dt = +CaloriesfromFishing+TotalCaloriesfromAgric-toCalDump
Initial Value = 4291772959
flow: CaloriesfromFishing Unconditional
Flow from TotalCaloriesFromFishing to Calories_from_Ag_and_ChesBay
CaloriesfromFishing = TotalCaloriesFromFishing
Chesapeake
compartment: BAYCash_Market Unconditional
dBAYCash_Market/dt = -
GrossMoneytoPeople_Bay+Oysters_toBayCash+Clams_toBayCash+Crabs_toBayCash+Crabs_toBayCash+Terps_toBayCash+Shad_toBayCash+SpMackeral_toBayCash+Bluefish_toBayCash+GrTrout_toBayCash+Sheepshead_toBayCash+OtherFish_toBayCash+Menhaden_toBayCash+CrabsSoft_toBayCash
Initial Value = 108196*a1cpi1920to1880
compartment: BAYFood_CaloriesProduced Unconditional
dBAYFood_CaloriesProduced/dt = -
NetCaloriestoPeople+Oysters_toBayProd+CrabSoft_toBayProd+Crabs_toBayProd+Clams_toBayProd+Terps_toBayProd+Shad_toBayProd+SpMackeral_toBayProd+Bluefish_toBayProd+GrTrout_toBayProd+Sheepshead_toBayProd+OtherFish_toBayProd+CrabSoft_toBayProd
Initial Value = 393608969
compartment: Bluefish_Calories2 Unconditional
dBluefish_Calories2/dt = +(Calories_Bluefish*Bluefish_toCalories)-Bluefish_toBayProd
Initial Value = 3210123
compartment: Bluefish_Food Unconditional
dBluefish_Food/dt = +Bluefish_toFood-Bluefish_toCalories
Initial Value = 5732
compartment: BlueFish_Harvest Unconditional
dBlueFish_Harvest/dt = (BayHealthFactor*BluefishPool)+(RandomNumber1sd3_Fish*BluefishPool)-
Bluefish_toFood-Bluefish_toMkt
Initial Value = 29059
compartment: Bluefish_Market Unconditional
dBluefish_Market/dt = +Bluefish_toMkt-Bluefish_toMoney
Initial Value = 23326
compartment: Bluefish_Money Unconditional
dBluefish_Money/dt = +(BPPP_Bluefish*a1cpi1920to1880*Bluefish_toMoney)-Bluefish_toBayCash
Initial Value = 3266*a1cpi1920to1880
flow: Bluefish_toBayCash Unconditional
Flow from Bluefish_Money to BAYCash_Market
Bluefish_toBayCash = Bluefish_Money
flow: Bluefish_toBayProd Unconditional
Flow from Bluefish_Calories2 to BAYFood_CaloriesProduced
Bluefish_toBayProd = Bluefish_Calories2
flow: Bluefish_toCalories Unconditional
Flow from Bluefish_Food to Bluefish_Calories2
Bluefish_toCalories = Bluefish_Food
flow: Bluefish_toFood Unconditional
Flow from BlueFish_Harvest to Bluefish_Food
Bluefish_toFood = AFoodvsMarket_estuary * BlueFish_Harvest
flow: Bluefish_toMkt Unconditional
Flow from BlueFish_Harvest to Bluefish_Market
Bluefish_toMkt = (1-AFoodvsMarket_estuary) * BlueFish_Harvest

flow: Bluefish_toMoney Unconditional
Flow from Bluefish_Market to Bluefish_Money
Bluefish_toMoney = Bluefish_Market
compartment: BluefishPool Unconditional
dBluefishPool/dt = 0
Initial Value = 29059
compartment: Clam_Calories2 Unconditional
dClam_Calories2/dt = +(Clam_Calories*Clams_toCalories)-Clams_toBayProd
Initial Value = 1374721
compartment: Clam_Food Unconditional
dClam_Food/dt = +Clam_toFood-Clams_toCalories
Initial Value = 4091
compartment: Clam_Harvest Unconditional
dClam_Harvest/dt = (BayHealthFactor*ClamPool)+(RandomNumber1sd3_Fish*ClamPool)-Clam_toFood-Clam_toMkt
Initial Value = 20741
compartment: Clam_Market Unconditional
dClam_Market/dt = +Clam_toMkt-Clams_toMoney
Initial Value = 16649
flow: Clam_toFood Unconditional
Flow from Clam_Harvest to Clam_Food
Clam_toFood = AFoodvsMarket_estuary * Clam_Harvest
flow: Clam_toMkt Unconditional
Flow from Clam_Harvest to Clam_Market
Clam_toMkt = (1-AFoodvsMarket_estuary) * Clam_Harvest
compartment: ClamPool Unconditional
dClamPool/dt = 0
Initial Value = 20741
compartment: Clams_Money Unconditional
dClams_Money/dt = +(BPPP_Clam*a1cpi1920to1880*Clams_toMoney)-Clams_toBayCash
Initial Value = 499*a1cpi1920to1880
flow: Clams_toBayCash Unconditional
Flow from Clams_Money to BAYCash_Market
Clams_toBayCash = Clams_Money
flow: Clams_toBayProd Unconditional
Flow from Clam_Calories2 to BAYFood_CaloriesProduced
Clams_toBayProd = Clam_Calories2
flow: Clams_toCalories Unconditional
Flow from Clam_Food to Clam_Calories2
Clams_toCalories = Clam_Food
flow: Clams_toMoney Unconditional
Flow from Clam_Market to Clams_Money
Clams_toMoney = Clam_Market
compartment: Crab_Calories2 Unconditional
dCrab_Calories2/dt = +(Crab_Calories*Crabs_toCalories)-Crabs_toBayProd
Initial Value = 12598276
compartment: Crab_CaloriesSoft Unconditional
dCrab_CaloriesSoft/dt = +(Crab_Calories*CrabsSoft_toCalories)-CrabSoft_toBayProd
Initial Value = 1560872
compartment: Crab_Food Unconditional
dCrab_Food/dt = +Crab_toFood-Crabs_toCalories
Initial Value = 37495
compartment: Crab_FoodSoft Unconditional
dCrab_FoodSoft/dt = +Crab_toFoodSoft-CrabsSoft_toCalories
Initial Value = 1121
compartment: Crab_Harvest Unconditional
dCrab_Harvest/dt = (BayHealthFactor*CrabPool)+(RandomNumber1sd3_Fish*CrabPool)-Crab_toFood-Crab_toMkt
Initial Value = 190071
compartment: Crab_HarvestSoft Unconditional

dCrab_HarvestSoft/dt = (BayHealthFactor*CrabPoolSoft)+(RandomNumber1sd3_Fish*CrabPoolSoft)-Crab_toFoodSoft-CrabSoft_toMarket
Initial Value = 5684
compartment: Crab_Market Unconditional
dCrab_Market/dt = +Crab_toMkt-Crabs_toMoney
Initial Value = 152576
compartment: Crab_MarketSoft Unconditional
dCrab_MarketSoft/dt = +CrabSoft_toMarket-CrabSoft_toMoney
Initial Value = 4563
flow: Crab_toFood Unconditional
Flow from Crab_Harvest to Crab_Food
Crab_toFood = AFoodvsMarket_estuary * Crab_Harvest
flow: Crab_toFoodSoft Unconditional
Flow from Crab_HarvestSoft to Crab_FoodSoft
Crab_toFoodSoft = AFoodvsMarket_estuary * Crab_HarvestSoft
flow: Crab_toMkt Unconditional
Flow from Crab_Harvest to Crab_Market
Crab_toMkt = (1-AFoodvsMarket_estuary) * Crab_Harvest
compartment: CrabPool Unconditional
dCrabPool/dt = 0
Initial Value = 190071
compartment: CrabPoolSoft Unconditional
dCrabPoolSoft/dt = 0
Initial Value = 5684
compartment: Crabs_Money Unconditional
dCrabs_Money/dt = +(BPPB_CrabHard*a1cpi1920to1880*Crabs_toMoney)-Crabs_toBayCash
Initial Value = 4577*a1cpi1920to1880
compartment: Crabs_MoneySoft Unconditional
dCrabs_MoneySoft/dt = +(BPPB_CrabSoft*a1cpi1920to1880*CrabSoft_toMoney)-CrabsSoft_toBayCash
Initial Value = 730*a1cpi1920to1880
flow: Crabs_toBayCash Unconditional
Flow from Crabs_Money to BAYCash_Market
Crabs_toBayCash = Crabs_Money
flow: Crabs_toBayProd Unconditional
Flow from Crab_Calories2 to BAYFood_CaloriesProduced
Crabs_toBayProd = Crab_Calories2
flow: Crabs_toCalories Unconditional
Flow from Crab_Food to Crab_Calories2
Crabs_toCalories = Crab_Food
flow: Crabs_toMoney Unconditional
Flow from Crab_Market to Crabs_Money
Crabs_toMoney = Crab_Market
flow: CrabSoft_toBayProd Unconditional
Flow from Crab_CaloriesSoft to BAYFood_CaloriesProduced
CrabSoft_toBayProd = Crab_CaloriesSoft
flow: CrabSoft_toMarket Unconditional
Flow from Crab_HarvestSoft to Crab_MarketSoft
CrabSoft_toMarket = (1-AFoodvsMarket_estuary) * Crab_HarvestSoft
flow: CrabSoft_toMoney Unconditional
Flow from Crab_MarketSoft to Crabs_MoneySoft
CrabSoft_toMoney = Crab_MarketSoft
flow: CrabsSoft_toBayCash Unconditional
Flow from Crabs_MoneySoft to BAYCash_Market
CrabsSoft_toBayCash = Crabs_MoneySoft
flow: CrabsSoft_toCalories Unconditional
Flow from Crab_FoodSoft to Crab_CaloriesSoft
CrabsSoft_toCalories = Crab_FoodSoft
compartment: Expenses_Fishing Unconditional
dExpenses_Fishing/dt = +FishingExpenses-TotalExpensesFishermenNegative
Initial Value = 33480*a1cpi1920to1880

FishingCosts
compartment: AnnualCosts Unconditional
1Year
dAnnualCosts/dt = +AnnualHandLineCosts+AnnualGearOutfitCosts-Annualized1YrCosts
Initial Value = 8545*a1cpi1920to1880
flow: AnnualFishHouseCosts Unconditional
Flow from FishHouses_ShoreProperty_Costs to CapitalCosts
AnnualFishHouseCosts = (1/30) * FishHouses_ShoreProperty_Costs
flow: AnnualFishingVesselCosts Unconditional
Flow from FishingVesselsCosts to CapitalCosts
AnnualFishingVesselCosts = (1/30) * FishingVesselsCosts
flow: AnnualGearOutfitCosts Unconditional
Flow from GearOutfitCosts to AnnualCosts
AnnualGearOutfitCosts = GearOutfitCosts
flow: AnnualGillNetCosts Unconditional
Flow from GillNetCosts to ShortCosts
AnnualGillNetCosts = (1/3) * GillNetCosts
flow: AnnualHandLineCosts Unconditional
Flow from HandLines to AnnualCosts
AnnualHandLineCosts = HandLines
flow: Annualized1YrCosts Unconditional
Flow from AnnualCosts to TotalAnnualFishingCosts
Annualized1YrCosts = AnnualCosts
flow: Annualized30YrCosts Unconditional
Flow from CapitalCosts to TotalAnnualFishingCosts
Annualized30YrCosts = CapitalCosts
flow: Annualized3YrCosts Unconditional
Flow from ShortCosts to TotalAnnualFishingCosts
Annualized3YrCosts = ShortCosts
flow: AnnualOtherCosts Unconditional
Flow from OtherCosts to ShortCosts
AnnualOtherCosts = (1/3) * OtherCosts
flow: AnnualPoundNetCosts Unconditional
Flow from PoundNetCosts to ShortCosts
AnnualPoundNetCosts = (1/3) * PoundNetCosts
flow: AnnualSeinesCosts Unconditional
Flow from SeinesCosts to ShortCosts
AnnualSeinesCosts = (1/3) * SeinesCosts
compartment: CapitalCosts Unconditional
30Years
dCapitalCosts/dt = +AnnualFishingVesselCosts+AnnualFishHouseCosts+OtherCapitalCosts-
Annualized30YrCosts
Initial Value = 6864*a1cpi1920to1880
compartment: FishHouses_ShoreProperty_Costs Unconditional
1
dFishHouses_ShoreProperty_Costs/dt = 0
Initial Value = 85444*a1cpi1920to1880
compartment: FishingVesselsCosts Unconditional
152, inc fishing (steam, gas/power, sail) and transport (gas, sail)
dFishingVesselsCosts/dt = 0
Initial Value = 108788*a1cpi1920to1880
compartment: GearOutfitCosts Unconditional
vessel outfits
dGearOutfitCosts/dt = 0
Initial Value = 8253*a1cpi1920to1880
compartment: GillNetCosts Unconditional
6
dGillNetCosts/dt = 0
Initial Value = 333*a1cpi1920to1880
compartment: HandLines Unconditional

1
dHandLines/dt = 0
Initial Value = 292*a1cpi1920to1880
flow: OtherCapitalCosts Unconditional
Flow from OtherCashCapital to CapitalCosts
OtherCapitalCosts = (1/30) * OtherCashCapital
compartment: OtherCashCapital Unconditional
1
dOtherCashCapital/dt = 0
Initial Value = 11691*a1cpi1920to1880
compartment: OtherCosts Unconditional
84 tongues and 39 dredges
dOtherCosts/dt = 0
Initial Value = 563*a1cpi1920to1880
compartment: PoundNetCosts Unconditional
16
dPoundNetCosts/dt = 0
Initial Value = 54769*a1cpi1920to1880
compartment: SeinesCosts Unconditional
3 Haul and 1 Purse
dSeinesCosts/dt = 0
Initial Value = 3003*a1cpi1920to1880
compartment: ShortCosts Unconditional
3Years
dShortCosts/dt = +AnnualOtherCosts+AnnualSeinesCosts+AnnualGillNetCosts+AnnualPoundNetCosts-Annualized3YrCosts
Initial Value = 19556*a1cpi1920to1880
compartment: TotalAnnualFishingCosts Unconditional
dTotalAnnualFishingCosts/dt = +Annualized30YrCosts+Annualized1YrCosts+Annualized3YrCosts-TotalAnnualFishingCoststoBay
Initial Value = 34965*a1cpi1920to1880
flow: TotalAnnualFishingCoststoBay Unconditional
Flow from TotalAnnualFishingCosts to TotalAnnualFishingCostsfromSu
TotalAnnualFishingCoststoBay = TotalAnnualFishingCosts
flow: FishingExpenses Unconditional
Flow from TotalAnnualFishingCostsfromSu to Expenses
FishingExpenses = 1 * TotalAnnualFishingCostsfromSu
compartment: GreyTrout_Harvest Unconditional
dGreyTrout_Harvest/dt = (BayHealthFactor*GreyTroutPool)+(RandomNumber1sd3_Fish*GreyTroutPool)-GrTrout_toFood-GrTrout_toMkt
Initial Value = 518890
compartment: GreyTroutPool Unconditional
dGreyTroutPool/dt = 0
Initial Value = 518890
flow: GrossMoneytoPeople_Bay Unconditional
Flow from BAYCash_Market to MoneyProduced_Bay
GrossMoneytoPeople_Bay = BAYCash_Market
compartment: GrTrout_Calories2 Unconditional
dGrTrout_Calories2/dt = +(GreyTrout_Calories*GrTrout_toCalories)-GrTrout_toBayProd
Initial Value = 68786123
compartment: GrTrout_Food Unconditional
dGrTrout_Food/dt = +GrTrout_toFood-GrTrout_toCalories
Initial Value = 102360
compartment: GrTrout_Market Unconditional
dGrTrout_Market/dt = +GrTrout_toMkt-GrTrout_toMoney
Initial Value = 416530
compartment: GrTrout_Money Unconditional
dGrTrout_Money/dt = +(BPPB_GreyTrout*a1cpi1920to1880*GrTrout_toMoney)-GrTrout_toBayCash
Initial Value = 20827*a1cpi1920to1880
flow: GrTrout_toBayCash Unconditional

Flow from GrTrout_Money to BAYCash_Market
GrTrout_toBayCash = GrTrout_Money
flow: GrTrout_toBayProd Unconditional
Flow from GrTrout_Calories2 to BAYFood_CaloriesProduced
GrTrout_toBayProd = GrTrout_Calories2
flow: GrTrout_toCalories Unconditional
Flow from GrTrout_Food to GrTrout_Calories2
GrTrout_toCalories = GrTrout_Food
flow: GrTrout_toFood Unconditional
Flow from GreyTrout_Harvest to GrTrout_Food
GrTrout_toFood = AFoodvsMarket_estuary * GreyTrout_Harvest
flow: GrTrout_toMkt Unconditional
Flow from GreyTrout_Harvest to GrTrout_Market
GrTrout_toMkt = (1-AFoodvsMarket_estuary) * GreyTrout_Harvest
flow: GrTrout_toMoney Unconditional
Flow from GrTrout_Market to GrTrout_Money
GrTrout_toMoney = GrTrout_Market
compartment: Menhaden_Harvest Unconditional
dMenhaden_Harvest/dt = (BayHealthFactor*MenhadenPool)+(RandomNumber1sd3_Fish*MenhadenPool)-Menhaden_toMarket
Initial Value = 3441535
compartment: Menhaden_Market Unconditional
dMenhaden_Market/dt = +Menhaden_toMarket-Menhaden_toMoney
Initial Value = 3441535
compartment: Menhaden_Money Unconditional
6883
dMenhaden_Money/dt = +(BPPB_Menhaden*a1cpi1920to1880*Menhaden_toMoney)-Menhaden_toBayCash
Initial Value = 343*a1cpi1920to1880
flow: Menhaden_toBayCash Unconditional
Flow from Menhaden_Money to BAYCash_Market
Menhaden_toBayCash = Menhaden_Money
flow: Menhaden_toMarket Unconditional
Flow from Menhaden_Harvest to Menhaden_Market
Menhaden_toMarket = Menhaden_Harvest
flow: Menhaden_toMoney Unconditional
Flow from Menhaden_Market to Menhaden_Money
Menhaden_toMoney = Menhaden_Market
compartment: MenhadenPool Unconditional
dMenhadenPool/dt = 0
Initial Value = 3441535
compartment: MoneyProduced_Bay Unconditional
dMoneyProduced_Bay/dt = +GrossMoneytoPeople_Bay-TotalRevenuesFishermen
Initial Value = 108196*a1cpi1920to1880
flow: NetCaloriestoPeople Unconditional
Flow from BAYFood_CaloriesProduced to TotalCaloriesFromFishing
NetCaloriestoPeople = BAYFood_CaloriesProduced
flow: NetMoneytoPeopleFishing Unconditional
Flow from NetProfittoFishermen to NetMoneyFromFishing
NetMoneytoPeopleFishing = NetProfittoFishermen
compartment: NetProfittoFishermen Unconditional
dNetProfittoFishermen/dt = +TotalRevenuesFishermen-TotalExpensesFishermenNegative-NetMoneytoPeopleFishing
Initial Value = 73231*a1cpi1920to1880
flow: Other_toCalories Unconditional
Flow from OtherFish_Food to OtherFish_Calories2
Other_toCalories = OtherFish_Food
compartment: OtherFish_Calories2 Unconditional
dOtherFish_Calories2/dt = +(OtherFish_Calories*Other_toCalories)-OtherFish_toBayProd
Initial Value = 104446241
compartment: OtherFish_Food Unconditional

dOtherFish_Food/dt = +OtherFish_toFood-Other_toCalories
Initial Value = 163743
compartment: OtherFish_Harvest Unconditional
dOtherFish_Harvest/dt = (BayHealthFactor*OtherFishPool)+(RandomNumber1sd3_Fish*OtherFishPool)-OtherFish_toFood-OtherFish_toMkt
Initial Value = 830055
compartment: OtherFish_Market Unconditional
dOtherFish_Market/dt = +OtherFish_toMkt-OtherFish_toMoney
Initial Value = 666312
compartment: OtherFish_Money Unconditional
dOtherFish_Money/dt = +(BPPB_OtherFish*a1cpi1920to1880*OtherFish_toMoney)-OtherFish_toBayCash
Initial Value = 39979*a1cpi1920to1880
flow: OtherFish_toBayCash Unconditional
Flow from OtherFish_Money to BAYCash_Market
OtherFish_toBayCash = OtherFish_Money
flow: OtherFish_toBayProd Unconditional
Flow from OtherFish_Calories2 to BAYFood_CaloriesProduced
OtherFish_toBayProd = OtherFish_Calories2
flow: OtherFish_toFood Unconditional
Flow from OtherFish_Harvest to OtherFish_Food
OtherFish_toFood = AFoodvsMarket_estuary * OtherFish_Harvest
flow: OtherFish_toMkt Unconditional
Flow from OtherFish_Harvest to OtherFish_Market
OtherFish_toMkt = (1-AFoodvsMarket_estuary) * OtherFish_Harvest
flow: OtherFish_toMoney Unconditional
Flow from OtherFish_Market to OtherFish_Money
OtherFish_toMoney = OtherFish_Market
compartment: OtherFishPool Unconditional
dOtherFishPool/dt = 0
Initial Value = 830055
compartment: Oyster_Food Unconditional
dOyster_Food/dt = +Oyster_toFood-Oysters_toCalories
Initial Value = 94404
compartment: Oyster_Harvest Unconditional
Bushels
dOyster_Harvest/dt = (BayHealthFactor*OysterPool)+(RandomNumber1sd3_Fish*OysterPool)-Oyster_toFood-Oyster_toMkt
Initial Value = 478555
compartment: Oyster_Market Unconditional
dOyster_Market/dt = +Oyster_toMkt-Oyster_toMoney
Initial Value = 384152
compartment: Oyster_Money Unconditional
dOyster_Money/dt = +(BPPP_Oyster * a1cpi1920to1880*Oyster_toMoney)-Oysters_toBayCash
Initial Value = 30732*a1cpi1920to1880
flow: Oyster_toFood Unconditional
Flow from Oyster_Harvest to Oyster_Food
Oyster_toFood = AFoodvsMarket_estuary * Oyster_Harvest
flow: Oyster_toMkt Unconditional
Flow from Oyster_Harvest to Oyster_Market
Oyster_toMkt = (1-AFoodvsMarket_estuary) * Oyster_Harvest
flow: Oyster_toMoney Unconditional
Flow from Oyster_Market to Oyster_Money
Oyster_toMoney = Oyster_Market
compartment: OysterPool Unconditional
dOysterPool/dt = 0
Initial Value = 478555
flow: Oysters_toBayCash Unconditional
Flow from Oyster_Money to BAYCash_Market
Oysters_toBayCash = Oyster_Money
flow: Oysters_toBayProd Unconditional

Flow from Oystes_Calories to BAYFood_CaloriesProduced
Oysters_toBayProd = Oystes_Calories
flow: Oysters_toCalories Unconditional
Flow from Oyster_Food to Oystes_Calories
Oysters_toCalories = Oyster_Food
compartment: Oystes_Calories Unconditional
dOystes_Calories/dt = +(Oyster_Calories*Oysters_toCalories)-Oysters_toBayProd
Initial Value = 200890741
compartment: Shad_Calories2 Unconditional
dShad_Calories2/dt = +(Shad_Calories*Shad_toCalories)-Shad_toBayProd
Initial Value = 564522
compartment: Shad_Food Unconditional
dShad_Food/dt = +Shad_toFood-Shad_toCalories
Initial Value = 642
compartment: Shad_Harvest Unconditional
dShad_Harvest/dt = (BayHealthFactor*ShadPool)+(RandomNumber1sd3_Fish*ShadPool)-Shad_toFood-Shad_toMkt
Initial Value = 3252
compartment: Shad_Market Unconditional
dShad_Market/dt = +Shad_toMkt-Shad_toMoney
Initial Value = 2610
compartment: Shad_Money Unconditional
dShad_Money/dt = +(BPPB_Shad*a1cpi1920to1880*Shad_toMoney)-Shad_toBayCash
Initial Value = 522*a1cpi1920to1880
flow: Shad_toBayCash Unconditional
Flow from Shad_Money to BAYCash_Market
Shad_toBayCash = Shad_Money
flow: Shad_toBayProd Unconditional
Flow from Shad_Calories2 to BAYFood_CaloriesProduced
Shad_toBayProd = Shad_Calories2
flow: Shad_toCalories Unconditional
Flow from Shad_Food to Shad_Calories2
Shad_toCalories = Shad_Food
flow: Shad_toFood Unconditional
Flow from Shad_Harvest to Shad_Food
Shad_toFood = AFoodvsMarket_estuary * Shad_Harvest
flow: Shad_toMkt Unconditional
Flow from Shad_Harvest to Shad_Market
Shad_toMkt = (1-AFoodvsMarket_estuary) * Shad_Harvest
flow: Shad_toMoney Unconditional
Flow from Shad_Market to Shad_Money
Shad_toMoney = Shad_Market
compartment: ShadPool Unconditional
dShadPool/dt = 0
Initial Value = 3252
compartment: Sheepshead_calories2 Unconditional
dSheepshead_calories2/dt = +(Sheepshead_Calories*Sheepshead_toCalories)-Sheepshead_toBayProd
Initial Value = 21114
compartment: Sheepshead_Food Unconditional
dSheepshead_Food/dt = +Sheepshead_toFood-Sheepshead_toCalories
Initial Value = 47
compartment: Sheepshead_Harvest Unconditional
dSheepshead_Harvest/dt = (BayHealthFactor*SheepsheadPool)+(RandomNumber1sd3_Fish*SheepsheadPool)-Sheepshead_toFood-Sheepshead_toMkt
Initial Value = 236
compartment: Sheepshead_Market Unconditional
dSheepshead_Market/dt = +Sheepshead_toMkt-Sheepshead_toMoney
Initial Value = 190
compartment: Sheepshead_Money Unconditional

dSheepshead_Money/dt = +(BPPB_Sheepshead*a1cpi1920to1880*Sheepshead_toMoney)-Sheepshead_toBayCash
Initial Value = 28*a1cpi1920to1880
flow: Sheepshead_toBayCash Unconditional
Flow from Sheepshead_Money to BAYCash_Market
Sheepshead_toBayCash = Sheepshead_Money
flow: Sheepshead_toBayProd Unconditional
Flow from Sheepshead_calories2 to BAYFood_CaloriesProduced
Sheepshead_toBayProd = Sheepshead_calories2
flow: Sheepshead_toCalories Unconditional
Flow from Sheepshead_Food to Sheepshead_calories2
Sheepshead_toCalories = Sheepshead_Food
flow: Sheepshead_toFood Unconditional
Flow from Sheepshead_Harvest to Sheepshead_Food
Sheepshead_toFood = AFoodvsMarket_estuary * Sheepshead_Harvest
flow: Sheepshead_toMkt Unconditional
Flow from Sheepshead_Harvest to Sheepshead_Market
Sheepshead_toMkt = (1-AFoodvsMarket_estuary) * Sheepshead_Harvest
flow: Sheepshead_toMoney Unconditional
Flow from Sheepshead_Market to Sheepshead_Money
Sheepshead_toMoney = Sheepshead_Market
compartment: SheepsheadPool Unconditional
dSheepsheadPool/dt = 0
Initial Value = 236
compartment: SpanishMackerel_Harvest Unconditional
dSpanishMackerel_Harvest/dt =
(BayHealthFactor*SpMackeralPool)+(RandomNumber1sd3_Fish*SpMackeralPool)-SpMack_toFood-SpMack_toMkt
Initial Value = 1269
flow: SpMack_toFood Unconditional
Flow from SpanishMackerel_Harvest to SPMackeral_Food
SpMack_toFood = AFoodvsMarket_estuary * SpanishMackerel_Harvest
flow: SpMack_toMkt Unconditional
Flow from SpanishMackerel_Harvest to SpMackerel_Market
SpMack_toMkt = (1-AFoodvsMarket_estuary) * SpanishMackerel_Harvest
compartment: SpMackeral_Calories2 Unconditional
dSpMackeral_Calories2/dt = +(SpanMack_Calories*SpMackeral_toCalories)-SpMackeral_toBayProd
Initial Value = 156237
compartment: SPMackeral_Food Unconditional
dSPMackeral_Food/dt = +SpMack_toFood-SpMackeral_toCalories
Initial Value = 250
compartment: SpMackeral_Money Unconditional
dSpMackeral_Money/dt = +(BPPB_SpanMack*a1cpi1920to1880*SpMackeral_toMoney)-SpMackeral_toBayCash
Initial Value = 153*a1cpi1920to1880
flow: SpMackeral_toBayCash Unconditional
Flow from SpMackeral_Money to BAYCash_Market
SpMackeral_toBayCash = SpMackeral_Money
flow: SpMackeral_toBayProd Unconditional
Flow from SPMackeral_Calories2 to BAYFood_CaloriesProduced
SpMackeral_toBayProd = SpMackeral_Calories2
flow: SpMackeral_toCalories Unconditional
Flow from SPMackeral_Food to SPMackeral_Calories2
SpMackeral_toCalories = SPMackeral_Food
flow: SpMackeral_toMoney Unconditional
Flow from SpMackerel_Market to SpMackeral_Money
SpMackeral_toMoney = SpMackerel_Market
compartment: SpMackeralPool Unconditional
dSpMackeralPool/dt = 0
Initial Value = 1269

compartment: SpMackerel_Market Unconditional
dSpMackerel_Market/dt = +SpMack_toMkt-SpMackeral_toMoney
Initial Value = 1019
compartment: Terp_Food Unconditional
dTerp_Food/dt = +Terp_toFood-Terps_toCalories
Initial Value = 0
compartment: Terp_Harvest Unconditional
dTerp_Harvest/dt = (BayHealthFactor*TerrapinPool)+(RandomNumber1sd3_Fish*TerrapinPool)-Terp_toFood-Terp_toMkt
Initial Value = 0
compartment: Terp_Market Unconditional
dTerp_Market/dt = +Terp_toMkt-Terps_toMoney
Initial Value = 0
compartment: Terp_Money Unconditional
dTerp_Money/dt = +(BPPB_Terp*a1cpi1920to1880*Terps_toMoney)-Terps_toBayCash
Initial Value = 0*a1cpi1920to1880
flow: Terp_toFood Unconditional
Flow from Terp_Harvest to Terp_Food
Terp_toFood = AFoodvsMarket_estuary * Terp_Harvest
flow: Terp_toMkt Unconditional
Flow from Terp_Harvest to Terp_Market
Terp_toMkt = (1-AFoodvsMarket_estuary) * Terp_Harvest
compartment: Terps_Calories2 Unconditional
dTerps_Calories2/dt = +(Terp_Calories*Terps_toCalories)-Terps_toBayProd
Initial Value = 0
flow: Terps_toBayCash Unconditional
Flow from Terp_Money to BAYCash_Market
Terps_toBayCash = Terp_Money
flow: Terps_toBayProd Unconditional
Flow from Terps_Calories2 to BAYFood_CaloriesProduced
Terps_toBayProd = Terps_Calories2
flow: Terps_toCalories Unconditional
Flow from Terp_Food to Terps_Calories2
Terps_toCalories = Terp_Food
flow: Terps_toMoney Unconditional
Flow from Terp_Market to Terp_Money
Terps_toMoney = Terp_Market
compartment: TerrapinPool Unconditional
dTerrapinPool/dt = 0
Initial Value = 0
flow: TotalExpensesFishermenNegative Unconditional
Flow from Expenses_Fishing to NetProfittoFishermen
TotalExpensesFishermenNegative = Expenses_Fishing
flow: TotalRevenuesFishermen Unconditional
Flow from MoneyProduced_Bay to NetProfittoFishermen
TotalRevenuesFishermen = MoneyProduced_Bay
compartment: CropEnhancementDump Unconditional
dCropEnhancementDump/dt = +F21
Initial Value = 0.0
compartment: CropEnhancementFactor Conditional Global
dCropEnhancementFactor/dt =
  +3-F21 for FertilizerUse_Annual>=3
  +2-F21 for FertilizerUse_Annual>=2
  +1-F21 for FertilizerUse_Annual>=1
  0-F21 by default
Initial Value = 0
define value: D1 Unconditional
If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D1 = 0
define value: D2 Unconditional

If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D2 = 0
define value: D3 Unconditional
If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D3 = 0
define value: D4 Unconditional
If 0, RN = 1; If 1, RN = 1 +-.1; If 2, RN = 1+-.25
D4 = 0
flow: F1 Conditional
Flow from MB_Under_1 to MB_Under_1_Deaths
F1 =
MortalityRate_MB_U1*ABMortalityRateStress4*MB_Under_1 for RatioCalDemandtoAvail>=1.25
MortalityRate_MB_U1*ABMortalityRateStress3*MB_Under_1 for RatioCalDemandtoAvail>=1.2
MortalityRate_MB_U1*ABMortalityRateStress2*MB_Under_1 for RatioCalDemandtoAvail>=1.1
MortalityRate_MB_U1*ABMortalityRateStress1*MB_Under_1 for RatioCalDemandtoAvail>=1.0
MortalityRate_MB_U1*ABMortalityRateStress0*MB_Under_1 for RatioCalDemandtoAvail>=.95
MortalityRate_MB_U1*MB_Under_1 by default
flow: F10 Unconditional
Flow from MW_Under_1_deaths to MW_Deaths
F10 = MW_Under_1_deaths
flow: F11 Conditional
Flow from FW1_4 to FW_1_4_Deaths
F11 =
MortalityRate_FB01_4*ABMortalityRateStress4*FW1_4 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB01_4*ABMortalityRateStress3*FW1_4 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB01_4*ABMortalityRateStress2*FW1_4 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB01_4*ABMortalityRateStress1*FW1_4 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB01_4*ABMortalityRateStress0*FW1_4 for RatioCalDemandtoAvail>=.95
MortalityRate_FB01_4*FW1_4 by default
flow: F12 Unconditional
Flow from C1 to FW_Deaths
F12 = FW_1_4_Deaths
flow: F13 Conditional
Flow from FW5_14 to FW_Deaths
F13 =
MortalityRate_FB05_14 * ABirthRateStress4*FW5_14 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB05_14 * ABirthRateStress3*FW5_14 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB05_14 * ABirthRateStress2*FW5_14 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB05_14 * ABirthRateStress1*FW5_14 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB05_14 * ABirthRateStress0*FW5_14 for RatioCalDemandtoAvail>=.95
MortalityRate_FB05_14 * FW5_14 by default
flow: F14 Unconditional
Flow from FertilizerUse_Annual to FertilizerUse_Aggregate
F14 = 1 * FertilizerUse_Annual
flow: F15 Conditional
Flow from FW65_Above to FW_Deaths
F15 =
MortalityRate_FW65_Above * ABMortalityRateStress4*FW65_Above for RatioCalDemandtoAvail>=1.25
MortalityRate_FW65_Above * ABMortalityRateStress3*FW65_Above for RatioCalDemandtoAvail>=1.2
MortalityRate_FW65_Above * ABMortalityRateStress2*FW65_Above for RatioCalDemandtoAvail>=1.1
MortalityRate_FW65_Above * ABMortalityRateStress1*FW65_Above for RatioCalDemandtoAvail>=1.0
MortalityRate_FW65_Above * ABMortalityRateStress0*FW65_Above for RatioCalDemandtoAvail>=.95
MortalityRate_FW65_Above * FW65_Above by default
flow: F16 Unconditional
Flow from BayHealthFactor to BayHEalthDump
F16 = 1 * BayHealthFactor
flow: F17 Conditional
Flow from MB1_4 to MB_1_4_Deaths
F17 =
MortalityRate_MB01_4 * ABMortalityRateStress4*MB1_4 for RatioCalDemandtoAvail>=1.25

MortalityRate_MB01_4 * ABMortalityRateStress3*MB1_4 for RatioCalDemandtoAvail>=1.2
MortalityRate_MB01_4 * ABMortalityRateStress2*MB1_4 for RatioCalDemandtoAvail>=1.1
MortalityRate_MB01_4 * ABMortalityRateStress1*MB1_4 for RatioCalDemandtoAvail>=1.0
MortalityRate_MB01_4 * ABMortalityRateStress0*MB1_4 for RatioCalDemandtoAvail>=.95
MortalityRate_MB01_4 * MB1_4 by default
flow: F18 Unconditional
Flow from MB_1_4_Deaths to MB_Deaths
F18 = MB_1_4_Deaths
flow: F19 Conditional
Flow from MW1_4 to MW_1_4_deaths
F19 =
MortalityRate_MW01_4*ABMortalityRateStress4* MW1_4 for RatioCalDemandtoAvail>=1.25
MortalityRate_MW01_4*ABMortalityRateStress3* MW1_4 for RatioCalDemandtoAvail>=1.2
MortalityRate_MW01_4*ABMortalityRateStress2* MW1_4 for RatioCalDemandtoAvail>=1.1
MortalityRate_MW01_4*ABMortalityRateStress1* MW1_4 for RatioCalDemandtoAvail>=1.0
MortalityRate_MW01_4*ABMortalityRateStress0* MW1_4 for RatioCalDemandtoAvail>=.95
MortalityRate_MW01_4* MW1_4 by default
flow: F2 Unconditional
Flow from MB_Under_1_Deaths to MB_Deaths
F2 = MB_Under_1_Deaths
flow: F20 Unconditional
Flow from MW_1_4_deaths to MW_Deaths
F20 = MW_1_4_deaths
flow: F21 Unconditional
Flow from CropEnhancementFactor to CropEnhancementDump
F21 = 1 * CropEnhancementFactor
flow: F22 Unconditional
Flow from FemaleTotal to PopDump
F22 = FemaleTotal
flow: F23 Unconditional
Flow from MaleTotal to PopDump
F23 = MaleTotal
flow: F24 Unconditional
Flow from BlackTotal to PopDump
F24 = BlackTotal
flow: F25 Unconditional
Flow from WhiteTotal to PopDump
F25 = WhiteTotal
flow: F26 Unconditional
Flow from TotalPopulation to PopDump
F26 = TotalPopulation
flow: F3 Conditional
Flow from FB_Under_1 to FB_Under_1_Deaths
F3 =
MortalityRate_FB_U1*ABMortalityRateStress4*FB_Under_1 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB_U1*ABMortalityRateStress3*FB_Under_1 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB_U1*ABMortalityRateStress2*FB_Under_1 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB_U1*ABMortalityRateStress1*FB_Under_1 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB_U1*ABMortalityRateStress0*FB_Under_1 for RatioCalDemandtoAvail>=.95
MortalityRate_FB_U1*FB_Under_1 by default
flow: F4 Unconditional
Flow from FB_Under_1_Deaths to FB_Deaths
F4 = FB_Under_1_Deaths
flow: F5 Conditional
Flow from FB1_4 to FB_1_4_Deaths
F5 =
MortalityRate_FB01_4 *ABMortalityRateStress4* FB1_4 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB01_4 *ABMortalityRateStress3* FB1_4 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB01_4 *ABMortalityRateStress2* FB1_4 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB01_4 *ABMortalityRateStress1* FB1_4 for RatioCalDemandtoAvail>=1.0

MortalityRate_FB01_4 *ABMortalityRateStress0* FB1_4 for RatioCalDemandtoAvail>=.95
MortalityRate_FB01_4 * FB1_4 by default
flow: F6 Unconditional
Flow from FB_1_4_Deaths to FB_Deaths
F6 = FB_1_4_Deaths
flow: F7 Conditional
Flow from FW_Under_1 to FW_Under_1_Deaths
F7 =
MortalityRate_FW_U1 * ABMortalityRateStress4*FW_Under_1 for RatioCalDemandtoAvail>=1.25
MortalityRate_FW_U1 * ABMortalityRateStress3*FW_Under_1 for RatioCalDemandtoAvail>=1.2
MortalityRate_FW_U1 * ABMortalityRateStress2*FW_Under_1 for RatioCalDemandtoAvail>=1.1
MortalityRate_FW_U1 * ABMortalityRateStress1*FW_Under_1 for RatioCalDemandtoAvail>=1.0
MortalityRate_FW_U1 * ABMortalityRateStress0*FW_Under_1 for RatioCalDemandtoAvail>=.95
MortalityRate_FW_U1 * FW_Under_1 by default
flow: F8 Unconditional
Flow from FW_Under_1_Deaths to FW_Deaths
F8 = FW_Under_1_Deaths
flow: F9 Conditional
Flow from MW_Under_1 to MW_Under_1_deaths
F9 =
MortalityRate_MW_U1 * ABMortalityRateStress4*MW_Under_1 for RatioCalDemandtoAvail>=1.25
MortalityRate_MW_U1 * ABMortalityRateStress3*MW_Under_1 for RatioCalDemandtoAvail>=1.2
MortalityRate_MW_U1 * ABMortalityRateStress2*MW_Under_1 for RatioCalDemandtoAvail>=1.1
MortalityRate_MW_U1 * ABMortalityRateStress1*MW_Under_1 for RatioCalDemandtoAvail>=1.0
MortalityRate_MW_U1 * ABMortalityRateStress0*MW_Under_1 for RatioCalDemandtoAvail>=.95
MortalityRate_MW_U1 * MW_Under_1 by default
compartment: FB_1_4_Deaths Unconditional
dFB_1_4_Deaths/dt = +F5-F6
Initial Value = 0.0
compartment: FB_Deaths Unconditional
dFB_Deaths/dt = +FB_Die5_14+FB_Die15_49+FB_Die50_64+FB_Die65+F4+F6
Initial Value = 0.0
flow: FB_Die15_49 Conditional
Flow from FB15_49 to FB_Deaths
FB_Die15_49 =
MortalityRate_FB15_49 * ABMortalityRateStress4*FB15_49 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB15_49 * ABMortalityRateStress3*FB15_49 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB15_49 * ABMortalityRateStress2*FB15_49 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB15_49 * ABMortalityRateStress1*FB15_49 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB15_49 * ABMortalityRateStress0*FB15_49 for RatioCalDemandtoAvail>=.95
MortalityRate_FB15_49 * FB15_49 by default
flow: FB_Die5_14 Conditional
Flow from FB5_14 to FB_Deaths
FB_Die5_14 =
MortalityRate_FB05_14 * ABMortalityRateStress4*FB5_14 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB05_14 * ABMortalityRateStress3*FB5_14 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB05_14 * ABMortalityRateStress2*FB5_14 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB05_14 * ABMortalityRateStress1*FB5_14 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB05_14 * ABMortalityRateStress0*FB5_14 for RatioCalDemandtoAvail>=.95
MortalityRate_FB05_14 * FB5_14 by default
flow: FB_Die50_64 Conditional
Flow from FB50_64 to FB_Deaths
FB_Die50_64 =
MortalityRate_FB50_64 * ABMortalityRateStress4*FB50_64 for RatioCalDemandtoAvail>=1.25
MortalityRate_FB50_64 * ABMortalityRateStress3*FB50_64 for RatioCalDemandtoAvail>=1.2
MortalityRate_FB50_64 * ABMortalityRateStress2*FB50_64 for RatioCalDemandtoAvail>=1.1
MortalityRate_FB50_64 * ABMortalityRateStress1*FB50_64 for RatioCalDemandtoAvail>=1.0
MortalityRate_FB50_64 * ABMortalityRateStress0*FB50_64 for RatioCalDemandtoAvail>=.95
MortalityRate_FB50_64 * FB50_64 by default
flow: FB_Die65 Conditional

Flow from FB65_Above to FB_Deaths
FB_Die65 =
MortalityRate_FB65_Above * ABMortalityRateStress4*FB65_Above for RatioCalDemandtoAvail>=1.25
MortalityRate_FB65_Above * ABMortalityRateStress3*FB65_Above for RatioCalDemandtoAvail>=1.2
MortalityRate_FB65_Above * ABMortalityRateStress2*FB65_Above for RatioCalDemandtoAvail>=1.1
MortalityRate_FB65_Above * ABMortalityRateStress1*FB65_Above for RatioCalDemandtoAvail>=1.0
MortalityRate_FB65_Above * ABMortalityRateStress0*FB65_Above for RatioCalDemandtoAvail>=.95
MortalityRate_FB65_Above * FB65_Above by default
flow: FB_Live1 Unconditional
Flow from FB_Under_1 to FB1_4
FB_Live1 = (1-MortalityRate_FB_U1) * FB_Under_1
flow: FB_Live15 Unconditional
Flow from FB5_14 to FB15_49
FB_Live15 = (1/10)*(1-MortalityRate_FB05_14) * FB5_14
flow: FB_Live5 Unconditional
Flow from FB1_4 to FB5_14
FB_Live5 = (1/4)*(1-MortalityRate_FB01_4) * FB1_4
flow: FB_Live50 Unconditional
Flow from FB15_49 to FB50_64
FB_Live50 = (1/35)*(1-MortalityRate_FB15_49) * FB15_49
flow: FB_Live65 Unconditional
Flow from FB50_64 to FB65_Above
FB_Live65 = (1/15)*(1-MortalityRate_FB50_64)* FB50_64
flow: FB_Liveto1 Unconditional
Flow from New_Births_Black to FB_Under_1
FB_Liveto1 = ABirthGenderRateF_FB * New_Births_Black
compartment: FB_Under_1 Unconditional
dFB_Under_1/dt = -FB_Live1+FB_Liveto1-F3
Initial Value = 33
compartment: FB_Under_1_Deaths Unconditional
dFB_Under_1_Deaths/dt = +F3-F4
Initial Value = 0.0
compartment: FB1_4 Unconditional
dFB1_4/dt = +FB_Live1-FB_Live5-F5
Initial Value = 132
compartment: FB15_49 Unconditional
dFB15_49/dt = +FB_Live15-FB_Live50-FB_Die15_49
Initial Value = 717
compartment: FB5_14 Unconditional
dFB5_14/dt = +FB_Live5-FB_Live15-FB_Die5_14
Initial Value = 345
compartment: FB50_64 Unconditional
dFB50_64/dt = +FB_Live50-FB_Live65-FB_Die50_64
Initial Value = 106
compartment: FB65_Above Unconditional
dFB65_Above/dt = +FB_Live65-FB_Die65
Initial Value = 54
flow: FemaleCaloricDemand Unconditional
Flow from FemaleCalorieDemand_Total to HumanCaloricDemmand
FemaleCaloricDemand = FemaleCalorieDemand_Total
compartment: FemaleCalorieDemand_Total Unconditional
dFemaleCalorieDemand_Total/dt =
(Calories_F01_4*FB1_4)+(Calories_F05_14*FB5_14)+(Calories_F15_49*FB15_49)+(Calories_F50_64*FB50_64)+(Calories_F65*FB65_Above)+(Calories_F01_4*FW1_4)+(Calories_F05_14*FW5_14)+(Calories_F15_49*FW15_49)+(Calories_F50_64*FW50_64)+(Calories_F65*FW65_Above)-FemaleCaloricDemand
Initial Value = 1786273500
compartment: FemaleTotal Unconditional
dFemaleTotal/dt = TotalPop_FB+TotalPop_FW-F22
Initial Value = 2547
compartment: FertilizerUse_Aggregate Unconditional Global

dFertilizerUse_Aggregate/dt = +F14
Initial Value = 0
compartment: FertilizerUse_Annual Conditional Global
dFertilizerUse_Annual/dt =
 +(4*FertilzerToggle)-F14 for t>75
 +(3*FertilzerToggle)-F14 for t>50
 +(2*FertilzerToggle)-F14 for t>25
 +(0*FertilzerToggle)-F14 by default
Initial Value = 0
define value: FertilzerToggle Unconditional
Off if 0, fx = 0; On if 1, fx = 1
FertilzerToggle = 1
compartment: FW_1_4_Deaths Unconditional
dFW_1_4_Deaths/dt = +(F11)-F12
Initial Value = 0.0
compartment: FW_Deaths Conditional
dFW_Deaths/dt =
 +FW_Die15_49+FW_Die50_64+F8+F12+F15+F13 by default
Initial Value = 0.0
flow: FW_Die15_49 Conditional
Flow from FW15_49 to FW_Deaths
FW_Die15_49 =
 MortalityRate_FW15_49 * ABirthRateStress4*FW15_49 for RatioCalDemandtoAvail>=1.25
 MortalityRate_FW15_49 * ABirthRateStress3*FW15_49 for RatioCalDemandtoAvail>=1.2
 MortalityRate_FW15_49 * ABirthRateStress2*FW15_49 for RatioCalDemandtoAvail>=1.1
 MortalityRate_FW15_49 * ABirthRateStress1*FW15_49 for RatioCalDemandtoAvail>=1.0
 MortalityRate_FW15_49 * ABirthRateStress0*FW15_49 for RatioCalDemandtoAvail>=.95
 MortalityRate_FW15_49 * FW15_49 by default
flow: FW_Die50_64 Conditional
Flow from FW50_64 to FW_Deaths
FW_Die50_64 =
 MortalityRate_FW50_64 * ABMortalityRateStress4*FW50_64 for RatioCalDemandtoAvail>=1.25
 MortalityRate_FW50_64 * ABMortalityRateStress3*FW50_64 for RatioCalDemandtoAvail>=1.2
 MortalityRate_FW50_64 * ABMortalityRateStress2*FW50_64 for RatioCalDemandtoAvail>=1.1
 MortalityRate_FW50_64 * ABMortalityRateStress1*FW50_64 for RatioCalDemandtoAvail>=1.0
 MortalityRate_FW50_64 * ABMortalityRateStress0*FW50_64 for RatioCalDemandtoAvail>=.95
 MortalityRate_FW50_64 * FW50_64 by default
flow: FW_Live1 Unconditional
Flow from FW_Under_1 to FW1_4
FW_Live1 = (1-MortalityRate_FW_U1) * FW_Under_1
flow: FW_Live15 Unconditional
Flow from FW5_14 to FW15_49
FW_Live15 = (1/10)*(1-MortalityRate_FW05_14) * FW5_14
flow: FW_Live5 Unconditional
Flow from FW1_4 to FW5_14
FW_Live5 = (1/4)*(1-MortalityRate_FW01_4) * FW1_4
flow: FW_Live50 Unconditional
Flow from FW15_49 to FW50_64
FW_Live50 = (1/35)*(1-MortalityRate_FW15_49) * FW15_49
flow: FW_Live65 Unconditional
Flow from FW50_64 to FW65_Above
FW_Live65 = (1/15)*(1-MortalityRate_FW50_64)* FW50_64
flow: FW_Liveto1 Unconditional
Flow from New_Births_White to FW_Under_1
FW_Liveto1 = ABirthGenderRateF_FW * New_Births_White
compartment: FW_Under_1 Unconditional
dFW_Under_1/dt = -FW_Live1+FW_Liveto1-F7
Initial Value = 29
compartment: FW_Under_1_Deaths Unconditional
dFW_Under_1_Deaths/dt = +F7-F8

Initial Value = 1
compartment: FW1_4 Unconditional
dFW1_4/dt = +FW_Live1-FW_Live5-F11
Initial Value = 114
compartment: FW15_49 Unconditional
dFW15_49/dt = +FW_Live15-FW_Live50-FW_Die15_49
Initial Value = 580
compartment: FW5_14 Unconditional
dFW5_14/dt = +FW_Live5-FW_Live15-F13
Initial Value = 271
compartment: FW50_64 Unconditional
dFW50_64/dt = +FW_Live50-FW_Live65-FW_Die50_64
Initial Value = 110
compartment: FW65_Above Unconditional
dFW65_Above/dt = +FW_Live65-F15
Initial Value = 56
compartment: HumanCalDump Unconditional
dHumanCalDump/dt = +toHumanCalDump
Initial Value = 0.0
compartment: HumanCaloricDemand Unconditional
dHumanCaloricDemand/dt = +FemaleCaloricDemand+MaleCaloricDemand-toHumanCalDump
Initial Value = 3910610000
flow: MaleCaloricDemand Unconditional
Flow from MaleCalorieDemand_Total to HumanCaloricDemmand
MaleCaloricDemand = MaleCalorieDemand_Total
compartment: MaleCalorieDemand_Total Unconditional
dMaleCalorieDemand_Total/dt =
(Calories_M01_4*MB1_4)+(Calories_M05_14*MB5_14)+(Calories_M15_49*MB15_49)+(Calories_M50_64*MB50_64)+(Calories_M65*MB65_Above)+(Calories_M01_4*MW1_4)+(Calories_M05_14*MW5_14)+(Calories_M15_49*MW15_49)+(Calories_M50_64*MW50_64)+(Calories_M65*MW65_Above)-MaleCaloricDemand
Initial Value = 2124336500
compartment: MaleTotal Unconditional
dMaleTotal/dt = TotalPop_MB+TotalPop_MW-F23
Initial Value = 2562
compartment: MB_1_4_Deaths Unconditional
dMB_1_4_Deaths/dt = F17-F18
Initial Value = 0.0
compartment: MB_Deaths Unconditional
dMB_Deaths/dt = +MB_Die65+MB_Die5_14+MB_Die15_49+MB_Die50_64+F2+F18
Initial Value = 0.0
flow: MB_Die15_49 Conditional
Flow from MB15_49 to MB_Deaths
MB_Die15_49 =
  MortalityRate_MB15_49 * ABirthRateStress4*MB15_49 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MB15_49 * ABirthRateStress3*MB15_49 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MB15_49 * ABirthRateStress2*MB15_49 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MB15_49 * ABirthRateStress1*MB15_49 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MB15_49 * ABirthRateStress0*MB15_49 for RatioCalDemandtoAvail>=.95
  MortalityRate_MB15_49 * MB15_49 by default
flow: MB_Die5_14 Conditional
Flow from MB5_14 to MB_Deaths
MB_Die5_14 =
  MortalityRate_MB05_14 * ABirthRateStress4*MB5_14 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MB05_14 * ABirthRateStress3*MB5_14 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MB05_14 * ABirthRateStress2*MB5_14 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MB05_14 * ABirthRateStress1*MB5_14 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MB05_14 * ABirthRateStress0*MB5_14 for RatioCalDemandtoAvail>=.95
  MortalityRate_MB05_14 * MB5_14 by default
flow: MB_Die50_64 Conditional
Flow from MB50_64 to MB_Deaths

MB_Die50_64 =
MortalityRate_MB50_64 * ABMortalityRateStress4*MB50_64 for RatioCalDemandtoAvail>=1.25
MortalityRate_MB50_64 * ABMortalityRateStress3*MB50_64 for RatioCalDemandtoAvail>=1.2
MortalityRate_MB50_64 * ABMortalityRateStress2*MB50_64 for RatioCalDemandtoAvail>=1.1
MortalityRate_MB50_64 * ABMortalityRateStress1*MB50_64 for RatioCalDemandtoAvail>=1.0
MortalityRate_MB50_64 * ABMortalityRateStress0*MB50_64 for RatioCalDemandtoAvail>=.95
MortalityRate_MB50_64 * MB50_64 by default
flow: MB_Die65 Conditional
Flow from MB65_Above to MB_Deaths
MB_Die65 =
MortalityRate_MB65_Above *ABMortalityRateStress4* MB65_Above for RatioCalDemandtoAvail>=1.25
MortalityRate_MB65_Above *ABMortalityRateStress3* MB65_Above for RatioCalDemandtoAvail>=1.2
MortalityRate_MB65_Above *ABMortalityRateStress2* MB65_Above for RatioCalDemandtoAvail>=1.1
MortalityRate_MB65_Above *ABMortalityRateStress1* MB65_Above for RatioCalDemandtoAvail>=1.0
MortalityRate_MB65_Above *ABMortalityRateStress0* MB65_Above for RatioCalDemandtoAvail>=.95
MortalityRate_MB65_Above * MB65_Above by default
flow: MB_Live1 Unconditional
Flow from MB_Under_1 to MB1_4
MB_Live1 = (1-MortalityRate_MB_U1) * MB_Under_1
flow: MB_Live15 Unconditional
Flow from MB5_14 to MB15_49
MB_Live15 = (1/10)*(1-MortalityRate_MB05_14)* MB5_14
flow: MB_Live5 Unconditional
Flow from MB1_4 to MB5_14
MB_Live5 = (1/4)*(1-MortalityRate_MB01_4) * MB1_4
flow: MB_Live50 Unconditional
Flow from MB15_49 to MB50_64
MB_Live50 = (1/35)*(1-MortalityRate_MB15_49) * MB15_49
flow: MB_Live65 Unconditional
Flow from MB50_64 to MB65_Above
MB_Live65 = (1/15)*(1-MortalityRate_MB50_64) * MB50_64
flow: MB_Liveto1 Unconditional
Flow from New_Births_Black to MB_Under_1
MB_Liveto1 = (1-ABirthGenderRateF_FB) * New_Births_Black
compartment: MB_Under_1 Unconditional
dMB_Under_1/dt = -MB_Live1+MB_Liveto1-F1
Initial Value = 32
compartment: MB_Under_1_Deaths Unconditional
dMB_Under_1_Deaths/dt = +F1-F2
Initial Value = 0.0
compartment: MB1_4 Unconditional
dMB1_4/dt = +MB_Live1-MB_Live5-F17
Initial Value = 128
compartment: MB15_49 Unconditional
dMB15_49/dt = +MB_Live15-MB_Live50-MB_Die15_49
Initial Value = 691
compartment: MB5_14 Unconditional
dMB5_14/dt = +MB_Live5-MB_Live15-MB_Die5_14
Initial Value = 343
compartment: MB50_64 Unconditional
dMB50_64/dt = +MB_Live50-MB_Live65-MB_Die50_64
Initial Value = 123
compartment: MB65_Above Unconditional
dMB65_Above/dt = +MB_Live65-MB_Die65
Initial Value = 55
compartment: Money_from_Ag_and_ChesBay Unconditional
dMoney_from_Ag_and_ChesBay/dt = +MoneyfromFishing+MoneyfromAgric-toMoneyDump
Initial Value = 1330382*a1cpi1920to1880
compartment: MoneyDump Unconditional
dMoneyDump/dt = +toMoneyDump

Initial Value = 0.0
flow: MoneyfromAgric Unconditional
Flow from Out1 to Money_from_Ag_and_ChesBay
MoneyfromAgric = 1 * NetMoneyfromAgric
flow: MoneyfromFishing Unconditional
Flow from NetMoneyFromFishing to Money_from_Ag_and_ChesBay
MoneyfromFishing = 1 * NetMoneyFromFishing
compartment: MW_1_4_deaths Unconditional
dMW_1_4_deaths/dt = +F19-F20
Initial Value = 0.0
compartment: MW_Deaths Unconditional
dMW_Deaths/dt = +MW_Die65+MW_Die5_14+MW_Die15_49+MW_Die50_64+F10+F20
Initial Value = 0.0
flow: MW_Die15_49 Conditional
Flow from MW15_49 to MW_Deaths
MW_Die15_49 =
  MortalityRate_MW15_49 * ABirthRateStress4*MW15_49 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MW15_49 * ABirthRateStress3*MW15_49 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MW15_49 * ABirthRateStress2*MW15_49 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MW15_49 * ABirthRateStress1*MW15_49 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MW15_49 * ABirthRateStress0*MW15_49 for RatioCalDemandtoAvail>=.95
  MortalityRate_MW15_49 * MW15_49 by default
flow: MW_Die5_14 Conditional
Flow from MW5_14 to MW_Deaths
MW_Die5_14 =
  MortalityRate_MW05_14 * ABirthRateStress4*MW5_14 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MW05_14 * ABirthRateStress3*MW5_14 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MW05_14 * ABirthRateStress2*MW5_14 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MW05_14 * ABirthRateStress1*MW5_14 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MW05_14 * ABirthRateStress0*MW5_14 for RatioCalDemandtoAvail>=.95
  MortalityRate_MW05_14 * MW5_14 by default
flow: MW_Die50_64 Conditional
Flow from MW50_64 to MW_Deaths
MW_Die50_64 =
  MortalityRate_MW50_64 * ABirthRateStress4*MW50_64 for RatioCalDemandtoAvail>=1.25
  MortalityRate_MW50_64 * ABirthRateStress3*MW50_64 for RatioCalDemandtoAvail>=1.2
  MortalityRate_MW50_64 * ABirthRateStress2*MW50_64 for RatioCalDemandtoAvail>=1.1
  MortalityRate_MW50_64 * ABirthRateStress1*MW50_64 for RatioCalDemandtoAvail>=1.0
  MortalityRate_MW50_64 * ABirthRateStress0*MW50_64 for RatioCalDemandtoAvail>=.95
  MortalityRate_MW50_64 * MW50_64 by default
flow: MW_Die65 Conditional
Flow from MW65_Above to MW_Deaths
MW_Die65 =
  MortalityRate_MW65_Above * ABMortalityRateStress4*MW65_Above for RatioCalDemandtoAvail>=1.25
  MortalityRate_MW65_Above * ABMortalityRateStress3*MW65_Above for RatioCalDemandtoAvail>=1.2
  MortalityRate_MW65_Above * ABMortalityRateStress2*MW65_Above for RatioCalDemandtoAvail>=1.1
  MortalityRate_MW65_Above * ABMortalityRateStress1*MW65_Above for RatioCalDemandtoAvail>=1.0
  MortalityRate_MW65_Above * ABMortalityRateStress0*MW65_Above for RatioCalDemandtoAvail>=.95
  MortalityRate_MW65_Above * MW65_Above by default
flow: MW_Live1 Unconditional
Flow from MW_Under_1 to MW1_4
MW_Live1 = (1-MortalityRate_MW_U1) * MW_Under_1
flow: MW_Live15 Unconditional
Flow from MW5_14 to MW15_49
MW_Live15 = (1/10)*(1-MortalityRate_MW05_14)* MW5_14
flow: MW_Live5 Unconditional
Flow from MW1_4 to MW5_14
MW_Live5 = (1/4)*(1-MortalityRate_MW01_4) * MW1_4
flow: MW_Live50 Unconditional
Flow from MW15_49 to MW50_64

MW_Live50 = (1/35)*(1-MortalityRate_MW15_49) * MW15_49
flow: MW_Live65 Unconditional
Flow from MW50_64 to MW65_Above
MW_Live65 = (1/15)*(1-MortalityRate_MW50_64) * MW50_64
flow: MW_Liveto1 Unconditional
Flow from New_Births_White to MW_Under_1
MW_Liveto1 = (1-ABirthGenderRateF_FW) * New_Births_White
compartment: MW_Under_1 Unconditional
dMW_Under_1/dt = -MW_Live1+MW_Liveto1-F9
Initial Value = 30
compartment: MW_Under_1_deaths Unconditional
dMW_Under_1_deaths/dt = +F9-F10
Initial Value = 0.0
compartment: MW1_4 Unconditional
dMW1_4/dt = +MW_Live1-MW_Live5-F19
Initial Value = 116
compartment: MW15_49 Unconditional
dMW15_49/dt = +MW_Live15-MW_Live50-MW_Die15_49
Initial Value = 591
compartment: MW5_14 Unconditional
dMW5_14/dt = +MW_Live5-MW_Live15-MW_Die5_14
Initial Value = 280
compartment: MW50_64 Unconditional
dMW50_64/dt = +MW_Live50-MW_Live65-MW_Die50_64
Initial Value = 119
compartment: MW65_Above Unconditional
dMW65_Above/dt = +MW_Live65-MW_Die65
Initial Value = 54
compartment: New_Births_Black Conditional
dNew_Births_Black/dt =
 (ABirthRate1B*ABirthRateStress4*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=1.1
 (ABirthRate1B*ABirthRateStress3*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=1.05
 (ABirthRate1B*ABirthRateStress2*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=1.0
 (ABirthRate1B*ABirthRateStress1*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=.95
 (ABirthRate1B*ABirthRateStress0*FB15_49)-FB_Liveto1-MB_Liveto1 for RatioCalDemandtoAvail>=.9
 (ABirthRate1B*FB15_49)-FB_Liveto1-MB_Liveto1 by default
Initial Value = 89
compartment: New_Births_White Conditional
55
dNew_Births_White/dt =
 +(ABirthRate1W*ABirthRateStress4*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=1.1
 +(ABirthRate1W*ABirthRateStress3*FW15_49)-FW_Liveto1-MW_Liveto1 for
RatioCalDemandtoAvail>=1.05
 +(ABirthRate1W*ABirthRateStress2*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=1.0
 +(ABirthRate1W*ABirthRateStress1*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=.95
 +(ABirthRate1W*ABirthRateStress0*FW15_49)-FW_Liveto1-MW_Liveto1 for RatioCalDemandtoAvail>=.9
 +(ABirthRate1W*FW15_49)-FW_Liveto1-MW_Liveto1 by default
Initial Value = 55
compartment: PopDump Unconditional
dPopDump/dt =
+toPopDumpFW+toPopDump_MW+toPopDump_BM+toPopDump_FB+F22+F23+F24+F25+F26
Initial Value = 0.0
variable: RandomNumber1sd_Crops Conditional Universal
RandomNumber1sd_Crops =
 randn(1,.1) for D1=1
 randn(1,.25) for D1=2
 1 by default
variable: RandomNumber1sd2_Animals Conditional Universal
RandomNumber1sd2_Animals =
 randn(1,.1) for D2=1

randn(1,.25) for D2=2
1 by default
variable: RandomNumber1sd3_Fish Conditional Universal
RandomNumber1sd3_Fish =
randn(1,.1) for D3=1
randn(1,.25) for D3=2
1 by default
variable: RandomNumber1sd4_Markets Conditional Universal
RandomNumber1sd4_Markets =
randn(1,.1) for D4=1
randn(1,.25) for D4=2
1 by default
compartment: RatioCalDemandtoAvail Unconditional Global
dRatioCalDemandtoAvail/dt = HumanCaloricDemand/Calories_from_Ag_and_ChesBay-toRatioDump
Initial Value = 0.9106499
compartment: RatioDump Unconditional
dRatioDump/dt = +toRatioDump
Initial Value = 0.0
flow: toCalDump Unconditional
Flow from Calories_from_Ag_and_ChesBay to CalDump
toCalDump = Calories_from_Ag_and_ChesBay
flow: toHumanCalDump Unconditional
Flow from HumanCaloricDemmand to HumanCalDump
toHumanCalDump = HumanCaloricDemand
flow: toMoneyDump Unconditional
Flow from Money_from_Ag_and_ChesBay to MoneyDump
toMoneyDump = Money_from_Ag_and_ChesBay
flow: toPopDump_BM Unconditional
Flow from TotalPop_MB to PopDump
toPopDump_BM = TotalPop_MB
flow: toPopDump_FB Unconditional
Flow from TotalPop_FB to PopDump
toPopDump_FB = TotalPop_FB
flow: toPopDump_MW Unconditional
Flow from TotalPop_MW to PopDump
toPopDump_MW = TotalPop_MW
flow: toPopDumpFW Unconditional
Flow from TotalPop_FW to PopDump
toPopDumpFW = TotalPop_FW
flow: toRatioDump Unconditional
Flow from RatioCalDemandtoAvail to RatioDump
toRatioDump = RatioCalDemandtoAvail
flow: TotalCaloriesfromAgric Unconditional
Flow from TotalCaloriesfromAgriculture to Calories_from_Ag_and_ChesBay
TotalCaloriesfromAgric = TotalCaloriesfromAgriculture
compartment: TotalPop_FB Unconditional
dTotalPop_FB/dt = FB_Under_1+FB1_4+FB15_49+FB5_14+FB50_64+FB65_Above-toPopDump_FB
Initial Value = 1387
compartment: TotalPop_FW Unconditional
dTotalPop_FW/dt = FW_Under_1+FW1_4+FW15_49+FW5_14+FW50_64+FW65_Above-toPopDumpFW
Initial Value = 1160
compartment: TotalPop_MB Unconditional
dTotalPop_MB/dt = MB_Under_1+MB1_4+MB15_49+MB5_14+MB50_64+MB65_Above-toPopDump_BM
Initial Value = 1372
compartment: TotalPop_MW Unconditional
dTotalPop_MW/dt = MW_Under_1+MW1_4+MW15_49+MW5_14+MW50_64+MW65_Above-toPopDump_MW
Initial Value = 1190
compartment: TotalPopulation Unconditional
dTotalPopulation/dt = FemaleTotal+MaleTotal-F26

Initial Value = 5109
compartment: WhiteTotal Unconditional
dWhiteTotal/dt = TotalPop_FW+TotalPop_MW-F25
Initial Value = 2350

Appendix E. Reprint of Thomas, W. Barnes, B., and Szuba, T. (2007). "The Countryside Transformed: The Eastern Shore of Virginia, the Pennsylvania Railroad, and the Creation of a Modern Landscape" from *Southern Spaces: An Interdisciplinary Journal about the Regions, Places, and Cultures of the American South.*

Introduction:

When in 1884 the New York, Philadelphia, and Norfolk Railroad, a subsidiary of the powerful Pennsylvania system, extended its line south through the Eastern Shore of Virginia, it had been anticipated for over forty years. The coming of the Pennsylvania system's railroad to the Eastern Shore was catalytic. Combined with other technologies, cultural practices, speculative capital, and environmental changes, the railroad channeled development across the landscape. Its effects were predicted and unexpected, anticipated and far-reaching. One of the largest corporations in the United States, the Pennsylvania Railroad linked the remote peninsula to the largest cities in the East, accelerating changes in the landscape already underway on the Shore and spawning hosts of others.

Railroad cars carried Northward increasing quantities of Eastern Shore lumber, seafood, and farm produce and returned with all manner of raw, processed, and manufactured goods as well as with emigrants and tourists. A new infrastructure developed as towns grew up along the tracks, roads radiated from the towns, and eventually telephone and power lines followed the roads. Property values increased and population expanded. The emerging optimism of the people of the Eastern Shore found expression in the construction of wharves, warehouses, stores, houses, and public buildings; their growing sophistication in more frequent travel, the provision of better educational opportunities for their children, the adoption of up-do-date styles of architecture, the installation of indoor plumbing, and the purchase of automobiles, pianos, and other amenities. In general, the railroad and accompanying technologies made possible an enormous wealth in the countryside and brought sweeping changes in a remarkably short period of time. These changes produced drastic and far-reaching direct and indirect effects to the ecological systems of the Shore and, in turn, to its human residents.[1]

What we seek to accomplish here is a close reading of the creation of a modern landscape to capture the interaction of technologies, people, and environment.[2] The Eastern

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[1] An entirely new infrastructure around the railroad developed on the Eastern Shore in a tightly compressed period of time, about twenty-five years. The railroad came late to the Eastern Shore. In contrast, Lincoln, Nebraska, had a railroad nearly two decades before the Eastern Shore of Virginia, despite the latter's proximity to the large cities of the east. Perhaps only the Texas Panhandle vied with the Eastern Shore in the 1880s for the distinction of remaining so long unconnected to the nation's rail network. See Tiffany Marie Haggard Fink, "The Forth Worth and Denver City Railway: Settlement, Development, and Decline on the Texas High Plains," (Ph.D. Dissertation, Texas Tech University, 2004) for an analysis of town development that followed the railroad in the Panhandle.

[2] Computing digital technologies give us unprecedented capability to explore spatial relationships of the past in new ways. Through historical GIS and animation sequences, we hope to represent faithfully and accurately the development of this landscape, understanding the limits that the technology imposes. We have been guided in our idea of "landscape" and in ways of seeing the past by D. W. Meinig, ed. *The Interpretation of Ordinary Landscapes: Geographical Essays* (Oxford: Oxford University Press, 1979), especially Pierce F. Lewis, "Axioms for Reading the Landscape: Some Guides to the American Scene," and D. W. Meinig, "The Beholding Eye: Ten Versions of the Same Scene." We are interested here in the recent literature on regionalism, modernity, and human geography that stresses the "context" and "open multiplicity" in landscapes and the literature in crucial social theory that works to synthesize structural approaches with human agency. Of particular importance to this essay are the following works: J. Nicholas Entrikin, *The Betweenness of Place: Towards a*

Shore of Virginia, according to geographer Wilbur Zelinsky in a pioneering essay "Where the South Begins," was situated along the border of a settlement landscape that marked the northern limit of the South. Zelinsky examined architectural styles, town characteristics, and countryside features to determine a pattern in what defined or marked the Southern landscape. He considered Virginia's Eastern Shore "decidedly Deep Southern." Its landscape, structures, and their spatial arrangements made the region more like Georgia or Tidewater Virginia than Pennsylvania or even its neighbors, Delaware and the Eastern Shore of Maryland. Other characteristics Zelinsky examined confirmed for him its place in the South: the lexical traits, the propensity to vote Democratic, the high proportion of African Americans, and the high ratio of mules to horses. Although he could not find "physiographic" reasons for the boundary, Zelinsky drew his northern limit of the South at the Maryland-Virginia state line on the Eastern Shore, "an emphatic interstate and cultural boundary [that] match beautifully for unknown reasons."[3]

Geography of Modernity (Macmillan, 1991), esp. 27-59; Allan Pred, *Making Histories and Constructing Human Geographies: The Local Transformation of Practice, Power Relations, and Consciousness* (Boulder: Westview Press, 1990), esp. 126-170; Anthony Giddens, *Central Problems in Social Theory: Action, Structure and Contradiction in Social Analysis* (Basingstoke: Macmillan, 1979) and *The Consequences of Modernity* (Cambridge: Polity, 1990); Doreen Massey, *Spatial Divisions of Labor, Social Structures, and the Geography of Production* (New York: Routledge, 1984) and *Spaces, Place, and Gender* (Minneapolis: University of Minnesota Press, 1995).

[3] Zelinksy, Wilbur. "Where the South Begins: The Northern Limit of the Cis-Appalachian South in Terms of Settlement Landscape," in *Exploring the Beloved Country: Geographic Forays into American Society and Culture* (Iowa City: University of Iowa Press, 1994), 186, originally published in *Social Forces* 30 (1951), 172-178. D. Western identifies common characteristics of human-modified ecosystems, many of which apply to Eastern Shore Virginia between 1880 and 1920 (and ongoing), including: (1) high natural resource extraction (e.g., harvesting and exporting nutrients in produce), (2) habitat homogeneity (e.g., tightly managing forested lands), (3) landscape homogeneity (e.g., conversion to cropland), (4) large importation of nutrient supplements (e.g., fertilizers), and (5) global mobility of people, good, and services (e.g., linking local resources and interests to national

Although recognizably Southern in its settlement landscape, the Eastern Shore of Virginia during the late nineteenth and early twentieth centuries, was a highly complex and interdependent landscape. It was a liminal place, a zone of interpenetration, where the settlement patterns, speech, demography, and political outcomes defined its place in the South but its engagement with technology and rapid transformation of the landscape betrayed other allegiances, motives, forces, and effects. In this zone where the South "ends," we can understand more about the region's modern development because the contradictions at the heart of it stand in such stark relief.

Modernity came to the Eastern Shore of Virginia, as it did elsewhere in the South, in the form of a radical shift in the use of resources and labor relations, and in a transformation of the landscape.[4] The relationship between the railroad, market integration, and the environment, moreover, stood at the heart of their modernizing landscape: the reach of markets for both buying and selling nearly everything produced in the world, the expanding and tightening of worldwide communication, the fundamental alteration of widely held conceptions of space and time, and the visible and invisible reconfigurations of the region's natural system. But there was no simple correlation among these components. Eastern Shore residents had long felt the effects of the market, participated in Atlantic trading, and maintained long-standing shipping practices with major urban centers in the Eastern United States. They responded to the changing market conditions even before the railroad reached

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markets). D. Western, "Human-modified ecosystems and future evolution," *Proceedings of the National Academy of Sciences*, 98 (2001), 5458-5465.

[4] The term "modernity" has been variously defined. Here, we mean social, technological, and economic changes that opened localities to fast, far-reaching, integrated communication and transportation. Our concern is with this process of transformation on the Eastern Shore and to understand the varied contexts for this process even in a relatively small, but environmentally complex area. See especially Anthony Giddens, *The Consequences of Modernity* (Cambridge: Polity, 1990), 18-19.

the peninsula. Indeed, the railroad's penetration elsewhere, especially its linking of the Midwest with the major urban centers in the mid-Atlantic, had substantial repercussions along the Shore, as it brought new competition to established markets.[5]

The arrival of the railroad, though, marked an important moment.[6] It altered the geography of the Eastern Shore in fundamental ways and prompted unforeseen changes in the cultural and natural worlds of its residents. The Pennsylvania Railroad, the federal and state governments, alliances of local residents, and outsiders all acted upon the Shore's natural and human resources. Each extended networks across the landscape; each wanted to expose or exploit the landscape, nature, and human connections; and each confronted limits to its vision. On the geologically stable mainland, the myriad changes in the landscape (themselves intrinsically limited by nature) held steady for decades and became organized around new

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[5] The concept of "transformation" in the countryside is one that William Cronon pioneered in *Nature's Metropolis: Chicago and the Great West*. Rather than seeing the Shore as an outpost brought into the orbit of a major city for its natural resource advantages, we see instead a process that was directed both from within the region and without and that reconfigured the physical landscape, obliterated old commercial hierarchies, and spawned sweeping environmental changes. William Cronon, *Nature's Metropolis: Chicago and the Great West* (New York: W. W. Norton, 1991). See also Cronon's "Modes of Prophecy and Production: Placing Nature in History," *Journal of American History,* 76, no. 4 (March 1990), 1122-1131. Cronon calls for greater specificity in defining stability and instability; not all capitalist or modern forces can be considered destabilizing and not all traditional forces stabilizing. Market integration, and the railroad's role in it, has been a longstanding debate in Southern history. See Steven Hahn, *The Roots of Southern Populism: Yeoman Farmers and the Transformation of the Georgia Upcountry, 1850-1890* (Oxford: Oxford University Press, 1985) for an interpretation that stresses the shift from self-sustaining agriculture to dependency and monoculture in the upcountry cotton regions. See also, Steven Hahn and Jonathan Prude, ed., *The Countryside in the Age of Capitalist Transformation: Essays in the Social History of Rural America* (Chapel Hill: University of North Carolina Press, 1985).

[6] For another recent work of regional study in which the railroad's arrival figures prominently, see Benjamin Heber Johnson, *Revolution in Texas: How a Forgotten Rebellion and its Bloody Suppression Turned Mexicans into Americans* (New Haven: Yale University Press, 2003), 27-37. For Johnson the railroad penetrated the isolated region along the Texas-Mexico border and disrupted the "distinctive racial order" bringing with it segregation and drastic changes in the labor and land markets that were disastrous for Tejanos.

crops and markets that propelled the Eastern Shore for a time into the front ranks of agricultural success stories in the United States. The confluence of forces and energies, moreover, that sustained the enormous success of the region, did not last, and, ironically, the vestiges of this transformation dominate the landscape of the Shore today. Along the chain of ever-shifting barrier islands shielding the peninsula from the Atlantic Ocean, alterations in the landscape proved far less enduring. Human activity on the islands was one of advance and retreat before the forces of tide, current, and storm.[7]

On The Edge of Modernity:

The Eastern Shore of Virginia is geographically removed from the rest of Virginia. It extends south from the Pocomoke River, which separates it from the Eastern Shore of Maryland, to form the southern tip of the Delmarva Peninsula and sits between the largest estuary in the United States, the Chesapeake Bay, to the west, and the Atlantic Ocean, to the east. The Eastern Shore counties of Accomack and Northampton encompass approximately 480 square miles of surface area, which can be characterized as a peninsular mainland penetrated by bayside tidal creeks and buffered from the ocean by a string of low barrier islands and associated marshlands. Mainland terrain ranges in elevation from sea level to

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[7]On high modernist ideology and how governmental institutions have tried to "see" the landscape and its residents, see James C. Scott's innovative and excellent study *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven: Yale University Press, 1998). Contemporary science stresses the complex and interdependent character of human and natural systems. Technological advances and economic forces are recognized as principal factors driving modern environmental change (see, for example, Veldkamp and Fresco, "CLUE: A Conceptual Model to Study the Conversion of Land Use and its Effects," *Ecological Modelling*, 85 (1996), 253-270). The "new ecology" focuses on "people in places" as a way of framing the environment as both the setting and the product of human activities (see, for example, Scoones, "New Ecology and the Social Science," *Annual Review of Anthropology*, 28 (1999), 479-507; and the Millennium Ecosystem Assessment <www.millennimassessment.org> sponsored by the United Nations.

about sixty feet and runs approximately seventy miles from the southern tip of the peninsula at Cape Charles to the Maryland border to the north. Maximum width including the marshes and barrier islands is approximately fourteen miles.[8]

The Geophysical Landscape

The geophysical backdrop of the Eastern Shore of Virginia is predominantly one of change, both on long- and short-term scales. The current mainland-marsh-lagoon-barrier island complex has its origins in the sea level rise at the end of the last Ice Age (about 15,000 years ago), which released water from the polar ice cap and eventually inundated the Susquehanna River Valley. The melting slowed about 3,000 years ago, at which time the Chesapeake Bay took its current form.[9]

The pace of sea level rise began to increase around 1850 and yet again around 1920 until it approximated its current rate of about 0.14 inches per year at the mouth of Chesapeake Bay. Given the low relief on the Eastern Shore (although the highest point on the peninsula reaches an elevation over fifty feet above sea level, barrier islands average only about seven feet above sea level), these changes in sea level resulted in significant geomorphic alteration to low elevation marshes and barrier islands that buffer the mainland from the Atlantic Ocean. For example, marshlands declined 16 per cent between 1852 to 1960 due largely to sea level rise. Moreover, between 1872 and 1910 the south end of Hog Island eroded

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[8] *The Role of Agriculture-Agribusiness in the Economic Development of Virginia's Eastern Shore* (Blacksburg: Virginia Polytechnic and State University, 1971), 2, correctly divides the Eastern Shore into three main physiographic divisions: (1) the Mainland, (2) the Coastal Islands, and (3) the Marshes. The Mainland contains practically all cultivable, productive soils of the region; the Coastal Islands, low and sandy, occur as a chain along the Atlantic Ocean; and The Marshes are present in extensive tracts on both sides of the peninsula.

[9] *Discovering the Chesapeake: The History of an Ecosystem*, eds. Philip D. Curtin, Grace S. Brush, and George W. Fisher (The Johns Hopkins University Press, 2001) argues convincingly that the basic geography of the Eastern Shore was established about 2,000 to 4,000 years ago when sea level rise slowed after the end of the last Ice Age.

landward (to the west) while the north end eroded seaward (to the east), eventually leading to the submergence of the village of Broadwater, which today lies more than a mile out into the Atlantic Ocean.[10]

In 1870 the Eastern Shore's level terrain comprised a patchwork of fields and woods penetrated by sinuous tidal creeks. The woods were predominantly loblolly pine (travelers often remarked on their "pungent odors") but also included shortleaf pine and hardwoods such as oak, hickory, and sycamore. The soils of Accomack and Northampton, mostly light, sandy loams, were well drained, easily cultivated, and receptive to the application of fertilizer. "Cultivation is exceedingly cheap," an agricultural expert reported, "as a one-horse plough is sufficient generally, and a horse requires no shoeing, and vehicles and farm utensils will last double as long as in the mountain regions. For 'trucking' purposes, it is unsurpassed." Another authority deemed the soils of Accomack and Northampton "among the most productive . . . of the Atlantic Coastal Plain." The Eastern Shore also enjoyed the agricultural advantages of a mild climate, abundant rainfall, and a long growing season.[11]

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[10] The Virginia Coast Reserve Long Term Ecological Research station has been funded by the National Science Foundation for the past 19 years to study the mosaic of transitions and steady-state systems that comprise the barrier-island/lagoon/mainland landscape of the Eastern Shore (see <http://www.vcrlter.virginia.edu/>). The fourteen coastal barrier islands of Eastern Shore Virginia, with their associated beaches, intervening inlets, marsh islands, mud flats, salt marshes, shallow bays and channels, are the only undeveloped barrier system on the eastern seaboard. For an explanation of sea level-marsh-barrier island dynamics, see J. Stevenson. and M. Kearney, "Shoreline Dynamics on the Windward and Leeward Shores of a Large Temperate Estuary," in *Estuarine Shores: Evolution, Environments and Human Alterations* (John Wiley & Sons Ltd., 1996); For a broad overview of environmental change on the Eastern Shore, see B. P. Hayden and J. Hayden, "The Land Must Change to Stay the Same," and P. Holleran "Islands on the Go," *Virginia Explorer* (Fall, 1994).

[11] E. H. Stevens, *Soil Survey of Accomac and Northampton Counties, Virginia* (Washington: Government Printing Office, 1920), 6-7, 9, 10, 12, 23, 36, 59, 60 (third quotation); "The Eastern Shore," New York *Evening Post*, April 25, 1885;

Because the mainland was so narrow – a mean of six to eight miles - no locality was remote from a wharf or landing or, after the coming of the railroad, a depot. Some of its bayside creeks and seaside inlets were deep enough to admit steamboats and all accommodated small sailing craft such as schooners and sloops. In 1880 the Eastern Shore customs district registered 358 sailing vessels, the largest registration of Virginia's seven districts. The navigation of the waterways depended on knowledge and skill. A few longstanding structures, such as house chimneys, served mariners as guideposts.[12]

The great majority of the peninsula's 28,455 people (12,690 of whom were black) made their living from the land. Their farms averaged 128.5 acres and were seated close to waterside landings and wharves. Eastern Shoremen were commercial farmers, having long participated in the commerce of the Atlantic coast. For generations their cash crops had been corn and, recently of more importance, oats. "We eat our own grain, and drink our own grain, and sleep upon our grain," a Northampton man had remarked in 1824. By the 1870s, Eastern Shore farmers found their oats undersold in their principal markets – Baltimore, Philadelphia, New York, and Boston – by those of the immense bonanza farms of the Mid-West. By the 1890s, moreover, Mid-Western economies of scale and the efficiency of the national transportation network insured that corn imported to Chincoteague Island from New York would undersell that grown on the adjacent mainland. Eastern Shore farmers responded

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"Our Peninsula," *Wilmington Morning News* in Accomac Court House *Peninsula Enterprise* (hereafter cited as *PE*), November 22, 1884 (first quotation); Orris A. Browne, "The Eastern Shore," *American Agriculturist* in *PE*, April 11, 1885;); *A Handbook of Virginia* (Richmond: Superintendent of Public Printing, 1879) (second quotation).

[12] Stevens, *Soil Survey*, 5, 9; *Annual Statements of the Chief of the Bureau of Statistics on the Commerce and Navigation of the United States, June 30, 1880* (Washington: Government Printing Office, 1880), 847.

to the new competition by gradually shifting over the 1870s and 1880s to the production of sweet and white potatoes.[13]

The Eastern Shore was overwhelmingly rural. Only Chincoteague, locus of the Chincoteague Bay oyster industry, and Onancock, where granaries lined the north branch of Onancock Creek, were worthy to be called towns. A few villages stood at wharves, at crossroads and at the heads of creeks. In 1883 a traveler found at the crossroad hamlet of Temperanceville in upper Accomack County "two stores, steam saw, flour and grist mills, a smith's shop, post office, etc. and about a dozen scattered dwellings."[14]

The Abstract Landscape: Pyle's "Peninsular Canaan"

In May 1879, Howard Pyle, a young writer and illustrator and a keen observer, headed down to the Eastern Shore of Virginia to write a story for *Harper's New Monthly Magazine*. Born in 1853 and raised in Wilmington, Delaware, Pyle admired the realistic writing of William Dean Howells. Pyle set out to capture the daily life and record what he considered the feel and experience of the landscape on the Eastern Shore. Pyle described the shore as "a peninsular Canaan," a place of almost unbelievable fertility where "the lightest labor" brings forth "abundant return from this generous soil." The waters "teem" with all

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[13] *The Statistics of the Population of the United States . . . Compiled from the Original Returns of the Ninth Census (June 1, 1870)* (Washington: Government Printing Office, 1872), 637; *The Statistics of the Wealth and Industry of the United States . . . Compiled from the Original Returns of the Ninth Census (June 1, 1870)* (Washington: Government Printing Office, 1872), 266, 270; Stevens, *Soil Survey*, 16-17; Claude H. Hall, *Abel Parker Upshur: Conservative Virginian* (Madison: The State Historical Society of Wisconsin, 1965), 28 (quotes Upshur); Barbara Jeanne Fields, *Slavery and Freedom on the Middle Ground: Maryland During the Nineteenth Century* (New Haven: Yale University Press, 1985), 170. For antebellum Eastern Shore agriculture see "Sketch of a Hasty View of the Soil and Agriculture of the County of Northampton," *Farmers' Register* 3 (1835), 233-240 and "Quantity and Value of the Exports of the County of Accomac," *Ibid.* 8 (1840), 255.

[14] "Onancock and Accomack County," Richmond *Times-Dispatch* in Onancock *Accomack News* (hereafter cited as *AN*), October 30, 1909; "The Eastern Shore," Richmond *State*, July 24, 1883 (quotation).

manner of wildlife: fowl, terrapin, snipe, fish, and the prized Chesapeake oyster. Separated from the rest of Virginia by the broad waters of the Chesapeake Bay, the Eastern Shore remained remote. "There is no railroad," Pyle explained. The peninsula was separated from the "vim and progress of modern utilitarianism," an island, as it were, cut off from "the outside world."[15]

For all of its rich bounty and stark beauty, the Eastern Shore was, according to Pyle, stuck in "a Rip Van Winkle sleep." It was a place where all that nature provided seemed to go unrealized and where modernity remained unclaimed. It was "sleepily floating in the indolent sea of the past, incapable of crossing the gulf which separates it from outside modern life."

Like many Americans of his day, Pyle saw the landscape as an expression of a human society and modernity as a geographic, as well as a social and economic system. In the case of the Eastern Shore, the landscape was in large part the product of an earlier time, the plantation South. Pyle saw vestiges of it everywhere he looked. The first signpost of an older order was a collection of old windmills in Northampton County. These were "landmarks of the past," "quaint," "abandoned," and representative of an outrageously outdated technology and society. Another "remnant" Pyle recorded was the "Negro burying ground." Although slavery was "a bygone thing," Pyle noted, its presence in the landscape was literally still visible in unruly clumps of trees that farmers ploughed carefully around.

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[15] Howard Pyle, "A Peninsular Canaan," *Harper's New Monthly Magazine* 58 (May, 1879), 801-817. On Pyle, see Lucien L. Agosta, *Howard Pyle* (Boston: Twayne Publishers, 1987), and Elizabeth Nesbitt, *Howard Pyle* (London: The Bodley Head, 1966).

These copses marked the final resting place, Pyle explained without irony, of "the planter's former faithful servants."[16]

Pyle told his readers that the "remnant" of the Southern past remained deeply embedded in the landscape of the Eastern Shore where "the old style farming" was still practiced. "There were only three crops raised in Virginia," Pyle deadpanned, "corn, hogs, and niggers, of which the hogs ate all the corn, and the niggers devoured all the hogs. One of these 'crops,' however, is removed from the list." Pyle's comments, delivered with a wink-of-the-eye to his mostly Northern readers, were meant to buttress the Northern understanding of slavery and its landscape as hopelessly inefficient, a sort of shell game in which the players long ago lost track of the nut. The resulting legacy was, according to Pyle, an impoverished white class, "woefully ignorant," and an unproductive upper class, "indolently unprogressive."

Pyle saw only one way to bring the natural fruits of the soil and sea to full development and to establish a correspondingly modern social structure on the Eastern Shore: change the landscape. The coming of the railroad, he expected, would inaugurate sweeping changes in social arrangements and physical properties. Poor whites and indolent upper classes, not to mention blacks, would only disappear from the social landscape when the geography of modern America penetrated the region. A few years earlier Pyle had taken an excursion to Chincoteague to report on the local society and the annual roundup of the wild ponies on the barrier island. He described the ferry ride from the mainland across Chincoteague Bay for the prospective traveler: it "separates him from modern civilization, its

[16] T. Abel and J. R. Stepp, "A New Ecosystems Ecology For Anthropology," *Conservation Ecology* 7 (2003), 12, and S. R. Cooper, "Chesapeake Bay Watershed Historical Land Use: Impact On Water Quality And Diatom Communities," *Ecological Applications*, 5 (1995), 703-723, are indicative of contemporary agreement of the generalization that "the landscape was in large part the product of an earlier time."

rattling, dusty cars, its hurly-burly of business, its clatter and smoke of mills and factories, and lands him upon an enchanted island, cut loose from modern progress and left drifting some seventy-five years backward in the ocean of time. No smoke of manufactories pollutes the air of Chincoteague; no hissing steam escape is heard except that of the [steamboat] 'Alice;' no troublesome thought of politics, no religious dissension, no jealousy of other places, disturbs the minds of the Chincoteaguers, engrossed with whisky, their ponies, and themselves."[17]

Pyle was not alone in his perception of the landscape of the South and its holdover social structures, nor was his understanding of the landscape and the railroad's possibilities novel. For Pyle in the 1870s the Eastern Shore and the rest of the South were part Arcadia, part wolf pit. Nineteenth-century Americans had long associated the use of and control over nature with enlightenment and civilization. Travelers to the South before the Civil War, among them Frederick Law Olmstead, observed land use patterns as inefficient. They focused their attention on the unimproved acreage, abandoned lands, and wild growth that consumed the typical farms. In his *A Journey in the Seaboard Slave States with Remarks on their Economy* published in 1857, Olmstead admitted to being a "fault finder." And although his travels opened with a visit to a well-kept Maryland farm, Olmstead's train ride south revealed an abandoned, apparently unproductive landscape "grown over with briars and bushes, and a long, coarse grass of no value."[18]

Olmstead, Pyle, and other travel writers tied the landscape of the South to the character of its inhabitants; the land was, after all, a product of human intentions. Pyle

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[17] Howard Pyle, "Chincoteague: The Island of Ponies," *Scribner's Monthly Magazine* XIII (April, 1877), 737-745.

[18] Frederick Law Olmstead, *A Journey in the Seaboard Slave States with Remarks on their Economy* (Samson Low and Son: London, 1857), 17 <http://docsouth.unc.edu/nc/olmsted/olmsted.html#p5>.

remained decidedly Victorian in outlook, ironically detached from the transformations underway around him. His stereotypical account was meant more to titillate Northern readers with a close-to-home adventure story than to describe accurately the society and landscape he entered. Yet for all his nostalgia, Pyle observed the landscape of the Shore before the great layers of intervention between 1870 and 1900 had been completed or their complex repercussions felt, and he accurately sensed the magnitude of impending change.

The Railroad and the Modern Landscape:

Layers of modern infrastructure came in waves upon the Eastern Shore, altering its landscape in a remarkably short time. The key catalysts to the Eastern Shore's landscape included: first, the intense mapping of the coastlines in the U.S. Coast Surveys of 1870-71, then the expansion of the U.S. Post Office and the U.S. Life-Saving Service, the development of the railroad in 1884, the River and Harbor Acts in the 1890s, and the creation of the Eastern Shore Produce Exchange in 1900. Each provided both extensive and intensive networking, while contributing to a substantial intervention in the physical landscape and an equally substantial one in the abstract landscape.

By the 1890s the effects of these layers were more clearly visible. Thomas Dixon, the prominent writer and Klan novelist, lived for several years in the mid-1890s in Cape Charles City, a bustling new town created around the railroad in lower Northampton County, but, like Pyle, he wished to ignore the activity of wharf and depot and their connections with the outside world. An avid outdoorsman, Dixon loved the barrier islands and the Broadwater, the expanse of marshes, bays, and channels that lay between the islands and the mainland. He hunted the Broadwater's waterfowl and shorebirds, dined on its oysters, and stood in the solitude of its vast marshes. "How far away the land world seems now," Dixon recalled of his trips out into the waters offshore, "fifteen miles from a post-office, telegraph line, or a railroad. We never see a newspaper, know nothing of what is going on in the big, steaming, festering cities and have ceased to care to know. Our world is now a beautiful bay, fed from the sea by two pulsing tides a day." Here, Dixon found "a world without railroad or mail." These symbols of modernity seemed corrupting to Dixon, but he deceived himself in dreaming of the Broadwater as a place where they had not yet reached. After all, the railroad had brought Dixon to Cape Charles City and mail boats traveled regularly from the mainland to post offices on Cobb's, Hog, and Chincoteague islands.[19]

What Dixon cherished about the Shore was its deeply Southern cultural landscape that possibly obscured for him the rapid change all over the region. Dixon appreciated the hunting lodges and the shooting and yachting life in part because it echoed the plantation era's racial and class hierarchy. Here, he could survey the great marshes from a duck boat poled by a black man and feast on large dinners prepared and served by black hands. Dixon could be taken back in time, or at least stop time, by moving away from the railroads, the mail, and onto the Broadwater. His associates in these lodges were similarly inclined, and the Eastern Shore of Virginia, whatever its transitions and modern developments, was to them the closest piece of the Old South to New York City.[20]

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[19] Thomas Dixon, Jr., *The Life Worth Living: A Personal Experience* (New York: Doubleday, Page & Co., 1905). *Record of Appointment of Postmasters, 1832-September 30, 1871*, Microfilm Publication M841 (Washington: National Archives, 1973).

[20] The plantation analogy should not be pushed too far. Both blacks and whites worked as guides and cooks, and out on the labyrinthian Broadwater even the wealthiest sportsman soon learned that the guide was master. For a recent assessment of Dixon, see Michele K. Gillespie and Randal L. Hall, *Thomas Dixon Jr. and the Birth of Modern America* (Baton Rouge: Louisiana State University Press, 2006), especially Fitzhugh Brundage's assessment that Dixon was eager to use the technology of the day, especially film and railroads (29-30).

The railroad's arrival on the Eastern Shore, however, offered a moment of particular consequence for the region.[21] If the pattern of railroad development in the United States was, according to Wolfgang Schivelbusch, first and foremost to extend water navigation and open these territories to markets, then on the Eastern Shore it proceeded instead in direct competition with water transportation.[22] If American railroads had been built generally with curves to engineer their way around obstacles and connect towns, the Eastern Shore line hewed like a broken compass needle to the spine of the peninsula, avoiding even the slightest curve. It was designed by the Pennsylvania Railroad to connect Philadelphia with the Deep South via Norfolk and to compete with steamboat companies for the freight. It bypassed every major town on the Eastern Shore, created its own private harbor and facilities, and developed no towns along its line. It was not meant to serve local interests at all, but the railroad's acceleration of time and reconfiguration of space had profound effects on the

[21] Historians of the South, as well as of the U.S. generally, have long determined that the railroads were widely significant and nearly every history of the region deals with railroads. For critical works that examine the railroads in the South, see Edward L. Ayers, *The Promise of the New South: Life After Reconstruction* (Oxford: Oxford University Press, 1992), Maury Klein, *History of The Louisville and Nashville Railroad* (New York: MacMillan, 1972), William G. Thomas, III, *Lawyering for the Railroad: Business, Law, and Power in the New South* (Baton Rouge: Louisiana State University Press, 1999), Kenneth Noe, *Southwest Virginia's Railroad: Modernization and the Sectional Crisis* (Urbana: University of Illinois Press, 1994), Allen Trelease, *The North Carolina Railroad, 1849-1871, and the Modernization of North Carolina* (Chapel Hill: University of North Carolina Press, 1991), and the classic John F. Stover, *History of the Railroads of the South, 1865-1900: A Study in Finance and Control* (Chapel Hill: University of North Carolina Press, 1955). There has not been a recent scholarly treatment of the Pennsylvania Railroad's history, see George H. Burgess, *Centennial History of the Pennsylvania Railroad, 1846-1946* (Pennsylvania Railroad Co., 1949). See also, Richard T. Wallis, *The Pennsylvania Railroad at Bay: William Riley McKeen and the Terre Haute & Indianapolis Railroad* (Bloomington: Indiana University Press, 2001).

[22] Wolfgang Schivelbusch, *The Railway Journey: Industrialization and Perception of Time and Space* (University of California Press, 1987). "The American railroad's original and fundamental task was to create transportation where no natural waterways existed" (111).

Eastern Shore's water-dominated landscape. However much the author Thomas Dixon might consider the Eastern Shore his own private "Peninsular Canaan," many of the local residents grasped the significance of the opportunities that the railroad made possible. They eagerly fashioned a remarkable new landscape around them, one that would last for generations.

Mapping the Waters--the U.S. Coast Survey

No one could travel across the Eastern Shore without crossing water, and for generations most places were reached only by boat. The traffic moved up creeks to well-established public and private wharves, across the Broadwater to the barrier islands, and out into Chesapeake Bay and the Atlantic Ocean. Beginning in 1870 the United States Coast Survey (U.S.C.S.) mapped in detail the seacoast of the Eastern Shore of Virginia. These surveys indicated marshes, channels, inlets, bars, islands, and soundings. They located lighthouses, buoys, markers, and other navigational aids. For the first time they formalized and opened to the public information for navigating the complex seascape of the region and provided comprehensive data for future navigational aids and instruments. For decades the War Department controlled seacoast mapping for military purposes, and the Civil War accelerated modern seacoast mapping along the Virginia Capes. In the 1870s the pace of U.S.C.S. work intensified and took on a scientific and exploratory character. The activities of the U.S.C.S. teams were followed with close scrutiny on the Eastern Shore. The U.S.C.S. hired local residents to help survey - what a newspaper editor termed "mapping out our waters."[23]

Taking full advantage of the newly documented information on the Shore and its complex waterways, private steamboat companies improved old networks of communication and established new ones. Immediately after the Civil War, steamboat companies out of

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[23] *PE,* September 10, 1887, April 30, 1887, and October 15, 1887. The U.S.C.S. had undertaken a less intensive mapping of the Eastern Shore coastline in the 1850s.

Baltimore and Norfolk increased the number of vessels and wharves on their Eastern Shore lines. By the early 1880s steamers called regularly at twenty-three wharves on the bayside of the peninsula and during the potato harvest at eight on the seaside. Baltimore dominated the bayside trade of Accomack and upper Northampton, while Norfolk captured that of lower Northampton. On the seaside the trade networks were also divided. From there, steamers out of several Atlantic coast ports carried produce to Philadelphia, New York, and Boston. Position, proximity, access, and history combined to divide the tiny Eastern Shore into numerous zones of trade and traffic.[24]

Postal Service

At the same time, post offices expanded their reach and operation. The post office network was more uniformly managed and provided in the early 1880s a powerful enhancement of the Eastern Shore's reach into the modern markets of information, commerce, and capital as well as a reconceptualization of space and time. Patronage politics combined with the coming of the railroad, quickening commerce, and a growing population to expand dramatically postal service on the peninsula. Between 1881 and 1884 the importunities of U.S. Senator William Mahone persuaded the administrations of Republican presidents James A. Garfield and Chester A. Arthur to increase from forty-four to sixty-seven the number of post offices in Accomack and Northampton counties. The advent of the railroad in 1884 further stimulated the establishment of post offices both along the tracks and

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[24] A. Hughlett Mason, *History of Steam Navigation to the Eastern Shore of Virginia* (Richmond: Dietz Press, 1973), 1, 12; Brooks Miles Barnes, "Triumph of the New South: Independent Movements in Post-Reconstruction Politics," Ph.D. Dissertation, University of Virginia, 1991, 14; John R. Waddy to William Mahone, January 23, 1882, William Mahone Papers, Manuscript Department, William R. Perkins Library, Duke University.

out in the countryside. By 1917, the number of post offices in the two counties had climbed to eighty-eight.[25]

Post offices opened every community on the Eastern Shore to the doings of the world. On Chincoteague in March 1884, thirty-three Northern daily newspapers arrived each day at the post office. Later that year (the year the railroad made its way down the peninsula), the citizens of the hamlet of Muddy Creek campaigned for a post office with feverish dedication. They cleared timber for a new road to Cattail Neck, and a Democratic storeowner in hopes of attracting the good favor of the new administration renamed his establishment "Cleveland" for the President-elect. Post offices established nodes on a greater network and, in effect, helped attract roads, banks, hotels, services, stores, and residences. Once a place obtained postal service, its citizens were equally determined not to lose it or see it curtailed. When one small town had its mail service to the Accomack County courthouse cut to three days a week, its citizens demanded "equal rights."[26]

The post office's effects on the ways local citizens understood their landscape were not confined to the race for town status. Postmasters, responding to federal requests, filled out annual reports on their offices' activities and reach. These reports grew in sophistication and detail over the 1880s and 1890s. By the turn of the century postmasters recorded postal routes and areas of service on a map of concentric circles showing the extensive and intensive

[25] Barnes, "Triumph of the New South," 213; Stevens *Soil Survey*, 12. On the concept of "reach" and for an excellent overview of the history of the Gilded Age, see Edwards, *New Spirits. S*ee chapter 2, especially p. 55 on the postal service, as well as p. 19 for the LSS. For the effect of the railroad on postal service see G. Terry Sharrer, *A Kind of Fate: Agricultural Change in Virginia, 1861-1920* (Ames: Iowa State University Press, 2000), 92. Rural free delivery, which began on the Eastern Shore in 1905, eventually reduced the number of post offices (James Egbert Mears, "The Eastern Shore of Virginia in the Nineteenth and Twentieth Centuries" in *The Eastern Shore of Maryland and Virginia*, ed. Charles B. Clark (New York: Lewis Historical Publishing Company, 1950), II, 596.

[26] *PE*, March 29, August 30, November 29, 1884, and for the loss of service and its implications see May 16, 1885.

network they oversaw. New understandings of space, time, service, and the perceived "rights" of citizens who interacted with the post office mixed in these years, yielding a modern world built on tangible and intangible networks.[27]

Imagining the Railroad

The railroad came to the Eastern Shore of the Chesapeake Bay after decades of planning. First proposed in the mid-1830s, a line was surveyed in 1837 by the War Department at the behest of a Senate resolution. Independently, the state of Maryland commissioned a study to explore the prospects for a line along the Eastern Shore 118 miles from near Wilmington, Delaware, to Tangier Sound on the Chesapeake Bay. The Maryland commissioners found that the region was full of marshes and "deficient of good roads," and as a consequence cut off from communication with the rest of the state. These "natural obstacles" led them to see the peninsula of Maryland and Virginia as uniquely suited to the railroad. The watercourses were so variable and "deeply indented" that the railroad's straight course might offer more efficient and "natural" means of transportation. With the extraordinarily flat landscape and abundant lumber for ties, the Eastern Shore appeared to be made for rails.[28]

To these advantages the commissioners added others. The lands of the Eastern Shore's interior, so far removed from water-born commerce, were ripe for planting. Their state of natural "manure" meant that these marginal lands needed only the railroad to unlock

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[27] U.S. Post Office Department, *Reports of Site Locations, 1837-1950*, Microfilm Publication M1126 (Washington: National Archives, 1980).

[28] Report of the Commissioners of the Eastern Shore Railroad to the Governor of Maryland, January 24, 1837, p. 7, in Report and Estimate in Reference to the Survey of the Eastern Shore Railroad, U. S. Senate, 24th Congress, 2nd Session, Document 218 (1837). See also James Kearney, "Report of the Engineer of the Eastern Shore Railroad," *Farmers' Register* 4 (1836), 552-554; G. L. Champion, "Eastern Shore Railroad," *Ibid.* 6 (1838), 246-247; Charles W. Turner, "The Early Railroad Movement in Virginia," *Virginia Magazine of History and Biography* 55 (October, 1947), 367.

their great potential. The railroad, furthermore, would place the region at the crossroads of American geography on the eastern seaboard. They were confident that the rush to build railroads "cannot fail to convey toward the seaboard." Indeed, they expected the Eastern Shore line to profit less from local traffic than from "the business which the railroads of the South will bring towards the Eastern cities."[29]

Little came of the commissioners' plans for an Eastern Shore line until well after the Civil War. Surveying for the line into Virginia began in 1874, as building proceeded through Delaware and Maryland. In September the white and newly enfranchised black citizens of Northampton County voted across racial lines to raise $10,000 for purchasing the right of way for the new railroad. The vote was 1,014 for the appropriation and just 35 against it. "Our people are delighted with the result," a Northampton man proclaimed, "and now we want to hear the whistle blow to put down brakes, and cry out, 'All aboard!'"[30]

The new sounds of the industrial age, however, took much longer to arrive than anyone thought possible. The depression of the mid-1870s slowed the railroad's progress to a crawl. In 1878 the Virginia legislature chartered the Peninsula Railroad Company to build a line along the Eastern Shore, but four years later local promoters were still waiting for the line to extend down the peninsula and erase "the doubts of those who have been most

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[29] U. S. Senate, 24th Congress, 2nd Session, Document 218 (1837).

[30] Better than three-fifths of Northampton's registered voters participated in the referendum. Registered black voters outnumbered white by nearly two to one (*Norfolk Landmark,* January 31, September 24 [quotation], 1874). In the 1850s and early 1860s several abortive attempts were made to build a railroad down the peninsula. William Mahone surveyed the line in 1854 (Nelson Morehouse Blake, *William Mahone of Virginia: Soldier and Political Insurgent* [Richmond: Garrett & Massie, 1935], 33-34; December 13, 1859, *Accomack County Legislative Petitions, 1776-1862*, microfilm, Library of Virginia, Richmond; Mears, "The Eastern Shore of Virginia in the Nineteenth and Twentieth Centuries," II, 589). The route was surveyed a final time in 1881 and 1882 (John C. Hayman, *Rails Along the Chesapeake: A History of Railroading on the Delmarva Peninsula, 1827-1978* [n.p.: Marvadel Publishers, 1879], 71).

persistent in saying that the 'railroad would never come.'" When finally it seemed as if the railroad would be built on the Eastern Shore, a local attorney pointed out that its origins were forty-six years old. Few residents could contain their excitement at the prospect. The railroad "will bring to light our undeveloped resources, improve our lands in productiveness and value," one predicted. "In a word, it will force us from the groove in which we have spun for two centuries and a half and put us upon a level with this progressive age."[31]

The Pennsylvania Railroad Comes

Finally, in 1884 the Eastern Shore not only had a railroad but also one of the largest corporations in the nation operating in its midst. The Pennsylvania Railroad had entered into a traffic agreement with the Peninsula Railroad, now renamed the New York, Philadelphia and Norfolk Railroad Company. With this powerful connection the Eastern Shore's transformation seemed foreordained to many residents. It was to become the produce "garden" of the cities, the place of rest and relaxation for urbanites, the orchard land of the east coast. William L. Scott, the Erie, Pennsylvania, coal magnate who was a leading investor in the N.Y., P. & N., expected that the railroad would bring a "great revolution" in the variety of agricultural products that would enter the Philadelphia and New York markets. He noted the gentle climate of the shore, which he compared with Marseilles, France, and the superb quality of the soil, which he said, exceeded that of Long Island.[32]

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[31] *PE,* January 19 (first quotation), February 23 (second quotation), 1882.

[32] *Peninsula Enterprise,* April 19, 1884; Hayman, *Rails Along the Chesapeake*, 70-72; "Our Peninsula – As the Hon. Wm. L. Scott See It," *Philadelphia Times*, April 18, in *PE*, April 25, 1885. The Pennsylvania Railroad did not purchase the capital stock of the New York, Philadelphia and Norfolk until 1908 (H. W. Schotter, *The Growth and Development of the Pennsylvania Railroad Company: A Review of the Charter and Annual Reports of the Pennsylvania Railroad Company, 1846 to 1926, Inclusive* [Philadelphia: Pennsylvania Railroad Company, 1927], 309-310).

The natural features of the region were not the only sources for the bright future that William Scott envisioned. At a cost of nearly $300,000, the N.Y., P. & N. was dredging a new harbor out of a large fresh-water lagoon between King's and Old Plantation creeks in lower Northampton County, and Scott planned to develop a new town around it called Cape Charles City. The appellation "City" for any place on the Eastern Shore was romantic, a vision of the future that the railroad might make possible. To dramatize the opportunities, Scott suggested, "Take a compass and draw a circle over the lower Chesapeake, within a radius of seventy-five miles of Cape Charles, and you will find that 18,000,000 bushels of oysters are gathered every year, while there are only about four millions taken from all other waters of the country."[33]

Cape Charles City and its harbor were planned as a hub for traffic flowing via steamboat and barge to and from Norfolk where numerous railroad lines extended South and West. Less than a year after its founding, a reporter described the place as "an embryo city . . . with a breakwater, long piers, and sundry warehouses and other buildings." In 1887 the Pennsylvania, the N.Y., P. & N., and the Wilmington and Weldon Railroad agreed on a traffic arrangement, the "Atlantic Coast Dispatch," which greatly facilitated the shipment northward of Southern early fruits and vegetables. A few years later the N. Y., P. & N.'s allies in Congress placed Cape Charles harbor in the River and Harbor Act. In 1890 the Corps of Engineers dredged the harbor basin, its entrance, and a channel through Cherrystone

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[33] "Our Peninsula - As the Hon. Wm. L. Scott Sees It" *Philadelphia Times*, April 18, in *PE*, April 25, 1885; Letter from the Secretary of War, Transmitting Reports on the Survey and Preliminary Examination of the Harbor and Approaches of Cape Charles City, Va., U.S. House of Representatives, 51st Congress, 1st Session, Document 29

Inlet and built stone jetties protecting the harbor outlet. By 1912 the Corps estimated that Cape Charles harbor handled 2,500,000 tons of freight a year.[34]

Over the next several decades the N.Y., P. & N. continued to expand and improve its infrastructure. Beginning in 1906, the railroad double-tracked its line using heavier rails and in 1912 completed an extension Southward from Cape Charles City to Kiptopeake. It installed a block signal system in 1908, substituted telephone for telegraph dispatching in 1912, and replaced manual signals with electric in 1923. It built new shops and offices at Cape Charles City in 1910 and all the while added and upgraded sidings. Boxcar capacity increased from 40,000 lbs. in the 1880s to 100,000 in 1901. Boxcars were equipped with ventilators for the shipment of seafood and vegetables and after 1913 were of all-steel construction.[35]

Where the earliest travelers on the new rail line had seen "little except pine forests, corn fields, fallow fields and here and there a farm house surrounded by a few fruit trees," those that followed soon after discovered "new settlements appearing, and buildings going up wherever a station has been built." From the new depots (eventually numbering twenty-eight) rail cars carried away seafood from the Broadwater, mine props from the swampy

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[34] "The Eastern Shore", New York *Evening Post*, April 25, 1885 (quotation); Howard Douglas Dozier, *A History of the Atlantic Coast Line Railroad* (Boston and New York: Houghton Mifflin Company, 1920), 124-125; James L. McCorkle Jr., "Moving Perishables to Market: Southern Railroads and the Nineteenth-Century Origins of Southern Truck Farming," *Agricultural History* 66 (Winter, 1992), 54; H.R. (51-1) Doc. 29; Letter from the Secretary of War, Transmitting, With a Letter from the Acting Chief of Engineers, Report on Examination of Chesapeake Bay, with a View to Straightening the North Side of the Channel at the Entrance of the Harbor at Cape Charles City, Va., and to Increasing the Width of the Channel 200 Feet, U.S. House of Representatives, 62nd Congress, 3rd Session, Document No. 1112.

[35] Eastville *Eastern Shore Herald* (hereafter cited as *ESH*), June 1, 1906, March 29, 1912; Hayman, *Rails Along the Chesapeake*, 84; Kirk Mariner, "Remembering the Old Cape Charles Railroad," Tasley *Eastern Shore News*, April 19, 2006; *PE*, January 27, 1923; Frederic H. Abenschein, "Pennsy's Perimeter of Plenty," *The Keystone* 31 (Summer, 1998), 28.

forests of the upper Accomack bayside, and produce – onions, cabbages, strawberries, and sweet and white potatoes – from the peninsula's farms. "The stimulus of profitable trade piles up the stations with their produce," an Englishman observed, "for they are engaged in feeding populations numbering several millions, from 200 to 500 miles northward. The rapid trains for the quick delivery of produce go as far as Boston, and in some cases to Canada. In 12 hours the fresh and tempting fruits and vegetables are delivered in New York, in 20 hours in Boston, and in 30 hours in Montreal." A few of the depots remained villages busy only at the harvest, but others grew rapidly into towns.[36]

The towns developed as nodes on a greater network, as residents rearranged the landscape around the railroad. Local people, not the railroad corporation, developed most of the railroad towns. All were laid out in a more or less regular pattern with their business districts adjacent to and often facing the rail yard and their residential neighborhoods, developed by different people at different times, laid out in square or rectangular blocks. Cape Charles City and Parksley, planned by Northern investors, were more formally arranged. They were laid out in a grid with lots reserved not only for businesses and residences but also for a variety of community purposes. One of Parksley's founders boasted that "foresight was shown in the reservation of a five acre site to be maintained as a park on the west side of the railroad and a one acre lot on the east side to be used as a playground. An additional five acres were reserved for school buildings and two choice lots were granted to each church which applied for same."[37]

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[36] "Our Peninsula," *Wilmington Morning News* in *PE*, November 22, 1884 (first quotation); "New York, Philadelphia and Norfolk Railroad," London *Times*, October 11, 1887, in *PE*, January 7, 1888 (second quotation); Mears, "The Eastern Shore of Virginia in the Nineteenth and Twentieth Centuries," II, 592-593.

[37] *PE*, December 6, 1902; Jim Lewis, *Cape Charles: A Railroad Town* (Eastville, Va.: Hickory House, 2004), 9-11; J. B. H. Carter, C. W. Holland Jr., W. E. Johnson, and

A network of new roads soon connected the countryside to the railroad towns. Neither stream nor swamp discouraged the farmers, watermen, and lumbermen who yearned for more direct access to the rails. In 1898, for example, the haul between the seaside necks and the station at Painter was shortened by the bridging of the Machipongo River. Meanwhile, Slutkill Neck on the bayside was more directly linked to the depot at Onley by the building of multiple spans across the upper reaches of Onancock Creek. Before the coming of the railroad, the Eastern Shore's road pattern had resembled a grid with the north to south roads (known as the seaside, middle and bayside roads) crossing those running east to west from sea to bay. Now it more closely resembled a sequential series of webs emanating from each of the railroad towns. So intricate had the pattern become that an architectural historian writing in the 1970s mistakenly attributed its origin to medieval England.[38]

The Railroad's Direct and Indirect Effects:

In 1915 the leading agriculturalists in the nation took the railroad to the Eastern Shore of Virginia to study how the tiny peninsula had become a worldwide force in the potato market and in the process created a vital, wealthy, and by all accounts successful agrarian society. Clarence Poe, editor of the *Progressive Farmer*, was especially interested in the doings of the Eastern Shore Produce Exchange. He labeled it a "$5,000,000 truck marketing association" and proclaimed it one of the leading examples in the nation of the staggering

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C. L. Miller, "An Economic and Social Survey of Accomac County," *University of Virginia Record Extension Series* XIII (March, 1929), 5-6 (quotes H. R. Bennett).

[38] *PE*, June 25, October 15, 1898; Emma LeCato Eichelberger, "The Little Old Town of Quinby," *PE*, May 7, 1953; H. Chandlee Forman, *The Virginia Eastern Shore and its British Origins: History, Gardens and Antiquities* (Easton, Md.: Eastern Shore Publishers' Association, 1975), 5.

profits that were possible in agriculture. The tightly run exchange had shocked the financial establishments in Baltimore and Philadelphia when it declared a dividend of 70 percent.[39]

Steady economic growth had followed the coming of the railroad to the Eastern Shore but a boom awaited the end of the decade-long depression of the 1890s. Revived prosperity in the urban North now combined with a growing population, both native and immigrant, to increase demand for fruits and vegetables. Although possessing favorable geographic and transportation advantages, Eastern Shore farmers hitherto had failed to enjoy the returns that the expanding market seemed to promise. "In pre-prosperity days on the Eastern Shore," an observer later remarked, "the farmers knew how to grow potatoes and grew them. But they didn't know how to market them, and so they weren't marketed. They were consigned to their fate, which more often than not was a tragic one." On occasion returns were so small that farmers were paid in postage stamps. In 1900 a group of Eastern Shore farmers and businessmen sought to improve the region's position in the volatile national produce market by incorporating as the Eastern Shore of Virginia Produce Exchange.[40]

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[39] Clarence Poe, *How Farmers Cooperate and Double Profits* (New York: Orange Judd Company, 1915), 113-122; *PE*, November 22, 1902; "Big Dividends for Farmers: How Agriculturists of the Eastern Shore Combined for Self-Protection and How Their Combination Works," Baltimore *Sun*, December 7, 1902. For the best, recent examination of a farmer's cooperative, see Victoria Saker Woeste, *The Farmer's Benevolent Trust: Law and Agricultural Cooperation in Industrial America, 1865-1945* (Chapel Hill: University of North Carolina Press, 1998).

[40] *Twelfth Census of the United States, Taken in the Year 1900: Agriculture, Part II, Crops and Irrigation* (Washington: Government Printing Office, 1902), 311; Sharrer, *A Kind of Fate*, 147; McCorkle, "Moving Perishables to Market," 42-43; James L. McCorkle Jr., "Southern Truck Growers' Associations." *Agricultural History* 72 (Winter, 1998), 79-80; William Harper Dean, "Potatoes – F.O.B. Eastern Shore: What Their Exchange Did For the Virginia Growers," *Country Gentleman*, July 5, 1919, in *PE*, August 2, 1919 (quotation); Benjamin T. Gunter, "Farm Group Activities," *PE*, August 10, 1929; *Acts and Joint Resolutions Passed by the General*

The Eastern Shore Produce Exchange

The Eastern Shore Produce Exchange offered shares at $5 each to white farmers. No subscriber could own as much as one-tenth of the total stock and most of the shares were held in blocks of one to five. Black farmers were not allowed to participate as shareholders but could use the Exchange to market and sell their crops and were eligible for the frequently lucrative patronage dividend. By 1915 the organization had 2,500 stockholders and, extending its services to 1,000 non-stockholding farmers, controlled 75 percent of the potato crop on the Eastern Shore. The Exchange expanded the potential market for local produce by employing agents in cities throughout the North and Mid-West. Where once farmers had consigned their crops to a handful of commission merchants in five or six cities on the Atlantic coast, within two years of its founding the Exchange directly supplied over one hundred customers in more than twenty states. "By its system of distribution, in finding customers all over the country," an Accomack man noted, "it has contributed its part in relieving the demoralizing congestions of shipments to New York, Boston and Baltimore of a few years ago." By 1930 the Exchange had further extended its network to 616 cities in the United States, Canada, and Cuba. The Exchange improved the reputation of Eastern Shore produce by requiring that goods shipped under its Red Star brand be subjected to tight quality control (previous to the Exchange, some Eastern Shore farmers had packed pumpkins in the bottoms of barrels of sweet potatoes). Twenty-eight local boards organized and coordinated the activities of Exchange agents who inspected and graded the produce shipped from forty depots and wharves on the peninsula. The Exchange also bought seed potatoes in bulk and

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Assembly of the State of Virginia, during the Session of 1899-1900 (Richmond: Superintendent of Public Printing, 1900), 194-195.

negotiated with (and on occasion brought legal action against) the railroad and steamboat companies for better freight rates.[41]

The Produce Exchange invested in the latest technologies of the day. From its headquarters in Onley it ran a private telephone system between the local offices and shipping points. It used the telephone and telegraph to receive and monitor prices through its agents in major cities across the nation and world - Chicago, New York, Boston, Pittsburgh, Toronto, Scranton, Havana. The Exchange obliterated economic hierarchies. "Do not make the mistake of supposing that Baltimore can ever become the distributing point for Eastern Shore of Virginia goods," the general manager of the Exchange warned a Baltimore reporter. "The little country town of Onley, Va., is now the distributing point and will be such so far as man can see into the future. Don't you know, sir, that we can get as good rates from this point as Baltimore or Philadelphia or New York can possibly get?" The Exchange pooled the prices for each day’s sales and paid the farmers the prevailing price. The system assured farmers that they would not pay commissions for this service, that they could gain the highest average market price, and that their products would be marketed with a brand, “The Red Star," nationally recognized for quality. The Exchange could handle the sale of 200 to 350 rail carloads of potatoes each day with this system.[42]

Aggressive marking and improved quality control stimulated demand for Eastern Shore produce. “Better potatoes of better grades went out in better packages to better

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[41] Poe, *How Farmers Cooperate and Double Profits*, 113-122; Gunter, “Farm Group Activities,” *PE*, August 10, 1929; W. A. Burton, “A Review of the Potato Industry of the Eastern Shore of Virginia,” Chicago *Potato World* in *PE*, March 17, 1939; William Gordy, “The Organization and Development of the Eastern Shore of Virginia Produce Exchange,” *PE*, August 1, 1931; *PE*, August 9, 1902 (quotation); “Onancock: The Year One of Continued Prosperity on Eastern Shore,” Richmond *Times-Dispatch*, January 1, 1906. For an example of pumpkins packed in barrels of sweet potatoes see *PE*, September 25, 1897.

[42] Poe, *How Farmers Cooperate and Double Profits*, 113-122; “The Chesapeake Bay Trade,” Baltimore *Sun*, July 30, 1907 (quotes William A. Burton).

markets at better prices than ever in the history of the two counties," an observer declared. The value of real and personal property increased exponentially. Between 1870 and 1920 the average value of farmland and buildings per acre jumped in Accomack from $16 to $137 and in Northampton from $15 to $197. In 1910 Accomack enjoyed the highest per capita income of any non-urban county in the United States and in 1919 Northampton and Accomack led all American counties in value of crop per acre. Annually, the Produce Exchange alone amassed receipts of $6,000,000 to $7,000,000. The exceptional year of 1920 saw the Exchange's receipts climb to an astounding $19,000,000. The influx of cash encouraged the formation of new businesses. Between 1880 and 1928 the number of mercantile establishments in Northampton County increased from 46 to 306. Banks, hitherto nonexistent on the peninsula, opened in the larger towns. By 1919, total deposits averaged $7,000,000.[43]

The Richmond *News-Leader* ascribed the Eastern Shore's prosperity to the Produce Exchange, "adequate and quick transportation," and the willingness of the farmers to abandon the ways of the fathers, to experiment, and to plant "those products that promise most from the land." While the *News-Leader* was correct to identify agriculture as central to the peninsula's prosperity, it failed to note that the fisheries and lumbering industries were also, in the words of a Northampton man, "on the boom."[44]

Prosperity

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[43] Dean, "Potatoes – F.O.B. Eastern Shore," *Country Gentleman*, July 5, 1919, in *PE*, August 2, 1919 (quotation); Charles H. Barnard and John Jones, *Farm Real Estate Values in the United States by Counties, 1850-1982* (Washington: United States Department of Agriculture, 1987), 3, 100, 102, 104; Sharrer, *A Kind of Fate*, 184; *PE*, January 7, 1922; Gunter, "Farm Group Activities," *PE*, August 10, 1929; Richmond *News-Leader*, March 15, 1922, in *PE*, March 25, 1922; *Dun's Mercantile Agency Reference Book*, July 1880, July 1928; M. E. Bristow, "Banking on the Eastern Shore of Virginia," *PE*, December 26, 1925.

[44] Richmond *News-Leader*, March 15, 1922, in *PE*, March 25, 1922; *ESH*, August 10, 1906 (quotation); Baltimore *Sun* in *AN*, October 24, 1908;.

The good times encouraged young people to remain on the Eastern Shore and attracted strangers to the peninsula. Between 1870 and 1910 the population nearly doubled, growing from 28,455 to 53,322. In 1906 an official of the U.S. Department of Agriculture noted "the increase of population, especially of young married couples, seeking homes, making new settlements and improving old ones." An indicator of the Eastern Shore

prosperity was the growth of its black population. While the black population of Virginia grew by only 24 per cent between 1870 and 1910, that of the Eastern Shore grew by 78 per cent (the Eastern Shore's white population increased by 95 per cent). The demand for labor attracted black immigrants from North Carolina and the Western Shore of Virginia. "This is a promising field for good farm labor," an Eastville man advised, "prices ranging from $1 to $2.50 a day. There are some 500 watermen on the seaside waters getting on an average of $2.50 a day."[45]

With the local economy booming across the board, labor enjoyed a seller's market. The fisheries, farming, lumbering, and construction competed year-around for labor. In certain sectors demand peaked at the same time. Tourist resorts siphoned off agricultural workers during the summer, and the fall sweet potato harvest coincided with the opening of the oyster season. When times became slack in an occupational specialty, workers enjoyed opportunities elsewhere. At the close of the oyster season in the spring oystermen might clam or crab or fish pound nets. In May they might help with the strawberry harvest and in July pick up white potatoes. Or they might drive a timber cart or tend the saw at the local mill. During the winter they might leave the oyster grounds for a day or two to work as guides for Northern duck hunters. None of the labor forces was racially exclusive. Both

[45] Onancock *Eastern Shore News* (hereafter cited as *ESN*), October 11, 1940; *AN*, October 27, 1906 (first quotation); *Norfolk Landmark* (hereafter cited as *NL*), October 30, 1901 (second quotation).

black and white worked for wages in the fields, in the woods, or on the water. Lumbering was a male preserve and female labor in the fisheries was restricted to the packing houses, but the agricultural harvests, essentially races against spoilage, required the services of all available hands regardless of race, gender, or degree of kinship.[46]

The competition for and flexibility of labor created tensions between workers and employers. In the seafood industry these found expression in occasional and usually successful strikes of oyster tongers and shuckers. In agriculture, tension was especially high at the harvest when farmers worried that their crops might rot in the fields for want of hands to pick them. Racial animosity and distrust exacerbated the situation. A dispute over farm wages set the stage for a minor race riot at Onancock in 1907. As white potato production increased exponentially in the 1910s and 1920s, Eastern Shore farmers employed black migrant laborers to help with the harvest. The farmers themselves were, overwhelmingly, small holders well acquainted with the physical demands of farm labor. A woman who grew up on an eighty-acre farm at Nelsonia recalled that for her father "it was up with the sun all spring, summer, and fall, a short stop for lunch, then back to the farm until sunset. He tilled the fields, planted white potatoes, corn, sweet potatoes, hay, and rye. He scattered clover seed and together he and God raised the crops."[47]

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[46]Stevens, *Soil Survey*, 31; *PE*, May 17, 1884, May 22, 1886, May 28, 1887; Etta Bundick Oberseider, *So Fair a Home: An Eastern Shore Childhood* (n.p.: Author, c1986), 5, 22-23.

[47] *PE*, February 9, 1884, March 16, 1895; Brooks Miles Barnes, "The Onancock Race Riot of 1907," *Virginia Magazine of History and Biography* 92 (July, 1984), 336-351; Oberseider, *So Fair a Home*, 21 (quotation). The Bundick farm "was more than one man could take care of, and we always had one tenant, and sometimes two" (*Ibid.*, 5). Further research has shown that Barnes's analysis of the labor situation was far too facile. For migrant labor see Cindy Hahamovitch, *The Fruits of their Labor: Atlantic Coast Farmworkers and the Making of Migrant Poverty, 1870-1945* (Chapel Hill and London: University to North Carolina Press, 1997).

The expanding population put pressure on the supply of farmland. Farms were divided and sub-divided. As early as 1891 an Onancock man had discovered "a tendency to break up the larger estates of former days and divide them into small farms that can be easily cultivated by two or three men." Between 1890 and 1925, the number of farms in the two counties increased from 2,997 to 4,856 while the average acreage decreased from 86 to 46.1. Curiously, throughout the period the acreage under cultivation remained about the same. In Northampton County farmers brought only 646 new acres under cultivation notwithstanding the value of land increased by over 700 per cent. The farmers' need to preserve their woodlots thwarted the impulse to break new ground. The farmers valued their woodlots as windbreaks protecting the peninsula's level fields and as a source of lumber for building and repair, for fence, and for stove wood. They valued it as a refuge for insect-devouring birds and for the game they so loved to hunt. The farmers especially valued their woodlots as a source of pine needles. "Ever since truck raising displaced general farming, pine needles have been used as a substitute for straw as bedding and as a source of humus," a forestry expert explained. "A truck farm without an adequate supply of pine 'straw' or 'shats' could scarcely compete with its more fortunate neighbors. It would be difficult to place a monetary value on this resource, but it is generally recognized that the trucking industry, as now organized, is largely dependent upon forest litter as a source of humus." Although the Eastern Shore was wealthier in 1920 than in 1910, the latter year's population of 53,322 remained the peninsula's historic high. Farm size had reached its practical minimum. The smaller the farm, the more intensively it must be cultivated to achieve a decent standard of living. Prosperity could not be sustained by ever smaller farm units divided among an ever greater number of farmers. Population growth necessarily halted.[48]

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[48]"Onancock: The Year One of Continued Prosperity on Eastern Shore," Richmond *Times-Dispatch*, January 1, 1906; Frank P. Brent, *The Eastern Shore of Virginia: A*

Eastern Shore farmers compensated for the dearth of cropland by dramatically increasing the yield of their staple crops. From 1900 to 1924, sweet potato production increased from 2,529,339 bushels to 2,932.849 while that of white potatoes increased tenfold, from 1,269,055 in 1900 to 12,873,750 in 1924. "Back in 1907," a railroad official remarked in 1919, "we used to get a little chill of joy up and down our spinal columns if we could see a million barrels of white potatoes promised at harvest, if we don't get 3,000,000 barrels now we feel sick." In 1928 the Produce Exchange alone required 14,153 boxcars to move the white potato harvest, a logistical demand that tested the organization and ingenuity of the Exchange and of the railroad. Farmers achieved the increased production by a greater concentration on potatoes (although onions, cabbages, and strawberries remained important cash crops and corn was grown to feed livestock), by improved farm machinery, by the use of pesticides to control the Colorado potato beetle, and by the liberal application of fertilizer. Expenditures for fertilizer increased from $63,000 in 1879 to nearly $1,000,000 in 1909. The end of the open range in the early 1900s also helped by curtailing the depredations of foraging animals and by reducing the farmers' expenditures of time and money on the erecting and mending of fence.[49]

Description of Its Soil, Climate, Industries, Development, and Future Prospects (Baltimore: Harlem Paper Company, 1891), 4-5 (first quotation); Carter, "An Economic and Social Survey of Accomac County," 54; C. W. Holland Jr., N. L. Holland, and W. W. Taylor, "An Economic and Social Survey of Northampton County," *University of Virginia Extension Service Series* XII (November, 1927), 35, 37 (quotes Wilbur O'Byrne), 38; Wilbur O'Byrne, "More and Better Pines on the Eastern Shore," *ESN*, October 23, 1936. For the necessarily more intensive cultivation of small farms see John Fraser Hart, *The Rural Landscape* (Baltimore: Johns Hopkins University Press, 1998), 279.

[49] Dean, "Potatoes – F.O.B. Eastern Shore," *Country Gentleman*, July 5, 1919, in *PE*, August 2, 1919 (quotation); *PE*, January 19, 1929; Stevens, *Soil Survey*, 18, 20, 21, 24, 25; Sharrer, *A Kind of Fate*, 56; *ESH*, March 24, 1905. For the use of fertilizer in the South see Douglas Helms, "Soil and Southern History," *Agricultural History* 74 (Fall, 2000), 751-752.

The ramifications of these changes extended in a ripple effect across the peninsula. The closing of the open range in the early 1900s combined with the importation of cheap pork and beef by rail to prompt the peninsula's farmers to reduce their herds of hogs and cattle. With fewer animals rooting in the woods, the bones of dead animals were less frequently gathered from the woods' floor for grinding into fertilizer. Indeed, around 1910, the county boards of health ordered the timely interment of the carcasses of domestic animals. While the numbers of hogs and cattle declined, those of horses and mules increased in response to the demands of expanding farm, lumber, and seafood sectors. The importation by rail of horses and mules from as far away as Missouri doubtless introduced the diseases that so vexed and worried the owners of Eastern Shore horseflesh.[50]

The success of the agriculture and seafood industries placed tremendous pressure on the peninsula's forests. By 1917, farmers and watermen annually required nearly 4,000,000 barrels in which to ship their potatoes and oysters. Farmers also needed fence rails, shipping containers for other produce, and frames for sweet potato beds. Everyone needed stove wood (farm families consumed at least fifty cords a year) and lumber for repairs and construction. Eastern Shore forests also supplied the national market. Rafts of lumber and stove wood were towed from the peninsula's creeks and inlets to Northern ports, and beginning in the 1890s companies out of Scranton and Hazelton, Pennsylvania, sent mine props from the swampy lands of the upper Accomack bayside to the anthracite fields.[51]

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[50] *Acts and Joint Resolutions Passed by the General Assembly of the State of Virginia, during the Session of 1895-1896* (Richmond: Superintendent of Public Printing, 1896), 144; *Acts, 1901-1902*, 441-442; *PE*, September 6, 1890; Sharrer, *A Kind of Fate*, 111.

[51] Stevens, *Soil Survey*, 23; Holland, "An Economic and Social Survey of Northampton County," 37; Sharrer, *A Kind of Fate*, 84; *PE*, November 15, 1902, March 15, 1931, March 29, May 3, 1956.

Lumbering was almost as omnipresent as agriculture. At least one barrel factory stood in every railroad and waterfront town, portable steam sawmills moved constantly from woods to woods, timber carts passed frequently on the roads, and prop-laden cars filled the rail sidings of Parksley, Bloxom, Hallwood, and other upper Accomack depots. In 1891 Chincoteague Island alone handled 34,690 tons of lumber valued at $159,300. In 1917 the value of the lumber industry on the Eastern Shore was nearly $1,000,000. By the mid-1920s, faced with ever-increasing potato production and with the advent of the pulpwood industry, demand appeared poised to surpass supply. "The demand for barrels alone probably exceeds growth and any wood shipment out . . . must ultimately be replaced by wood grown elsewhere," a forester warned.[52]

The peninsula's sandy roads were excellent in the summer – "smooth enough for a race track," remarked a traveler who passed through in July – but often badly torn up, particularly by heavily laden timber carts, in the winter and spring. Growing commerce stimulated public demand for improved roads, and the coming of the motor truck in the 1910s give it greater urgency. By 1923 the Eastern Shore's best roads were of a sand-clay mixture with a few miles of oyster-shell and macadam in and near the larger towns. In that year began the construction of a concrete highway paralleling the railroad tracks down the spine of

[52] *Virginia: A Handbook Giving its History, Climate, and Mineral Wealth; Its Educational, Agricultural and Industrial Advantages* (Richmond: Everett Waddey Company, 1893), 193; *Ibid.* (1909), 83; *Ibid.* (1926), 131; *PE*, May 10, 1902; *AN*, May 4, 1907, January 11, 1908; *ESH*, May 10, 1907; Letter from the Secretary of War, Transmitting, with a Letter from the Chief of Engineers, Report on Examination of Chincoteague Inlet, Va., with Plan and Estimate of Cost of Improvement, with a View to Obtaining a Channel Depth of 15 Feet, U.S. House of Representatives, 62nd Congress, 3rd Session, Document No. 1094; Stevens, *Soil Survey*, 23; Holland, "An Economic and Social Survey of Northampton County," 37 (quotes Wilbur O'Bryne).

the peninsula. The new highway confirmed the inland corridor as the preferred route of business and communications.[53]

Town Life

The New York, Philadelphia and Norfolk Railroad immediately became the main artery of Eastern Shore trade, but the new towns that sprang up along its length did not prosper at the expense of older wharf and crossroad communities. The directors of the steamboat companies serving the peninsula early and correctly realized that the N.Y., P. & N. posed a threat to their business. The railroad soon forced them to curtail steamboat service on the seaside and abandon it altogether on the lower bayside. Still, the Baltimore steamers continued to call at numerous wharves on the upper bayside from which they annually carried away thousands of tons of seafood and farm produce. In 1929, although in the waning days of the steamboat era, the commerce of the eight wharves on Occohannock, Nandua, and Pungoteague creeks amounted to more than 20,000 tons.[54]

Saxis, Sanford, Marsh Market, Messongo, and Belinda – villages adjacent to Pocomoke and Tangier sounds – thrived on the Chesapeake Bay crab and oyster industries. In 1907 Sanford boasted of "nine stores, three saw-mills, one Town Hall, three churches and a barrel factory building and several new dwellings." Farther down the bayside on Pungoteague Creek, Harborton enjoyed the benefits of its large wharf and of a factory that

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[53] "The Eastern Shore," Richmond *State*, July 24, 1883 (quotation); Stevens, *Soil Survey*, 11; *AN*, April 27, 1907; *Virginia* (1923), 103; *ESH*, December 3, 1909; *PE*, June 17, 1922, November 17, 1923. The closing of the open range early in the century hastened communication by eliminating the need for livestock gates across the public roads (Forman, *The Virginia Eastern Shore and Its British Origins*, 206).
[54] John L. Lochhead, "The Boat Trains," National Railway Historical Society *Bulletin* 43 (1978), 19; Letter from the Secretary of War, Transmitting, Report from the Chief of Engineers on Preliminary Examinations and Surveys of Pungoteague, Nandua and Occohannock Creeks, Va., U.S. House of Representatives, 71st Congress, 2nd Session, Document 165. In 1894 the Pennsylvania Railroad gained control of the Baltimore steamboats (Abenschein, "Pennsy's Perimeter of Plenty," 40).

rendered fish into oil and fertilizer. A newly developed section of the town aptly took the name Menhaden Park. Onancock, the busiest of the bayside ports, grew by leaps and bounds. Confined since its founding in the seventeenth century between two branches of Onancock Creek, beginning in the mid-1880s the town expanded eastward and south-eastward and even sprawled across the creek into what became its Mount Prospect neighborhood. On the seaside the seafood industry fueled the growth of Franklin City, Greenbackville, Wachapreague, and Willis Wharf and encouraged the founding of Quinby, Oyster, and Brighton.[55]

The hamlets at the crossroads and the heads of the creeks also prospered. Numerous new post offices, schools, and churches – all established to accommodate expanding business and population – made the hamlets attractive to the people living in the surrounding countryside. Their stores, easily and abundantly stocked from nearby depots and wharves, served by day as emporia and by night as social centers where men gathered to discuss the local passions of hunting, horse racing, and baseball. In 1920, forty-six places in Accomack and Northampton counties counted populations of 100 or more. They were home to nearly forty per cent of the peninsula's people. Within two or three miles of each other, the railroad

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[55] Drummer, "Pocomoke Neck and Sykes," *PE*, July 23, 1887; *AN*, April 27, 1907 (quotation); *PE*, May 9, June 13, 1885, October 29, 1898, March 3, 1900, September 20, 1902; "Onancock: The Year One of Continued Prosperity on the Eastern Shore," Richmond *Times-Dispatch*, January 1, 1906; John R. Spears, "A Curious Virginia City," New York *Sun*, May 7, 1890; Kirk Mariner, *Wachapreague, Virginia: Then and Now* (New Church, Va.: Miona Publications, 1995), 9-14; Ernest Ingersoll, "The Oyster Industry," in *The History and Present Condition of the Fishery Industries*, ed. G. Brown Goode (Washington: Department of the Interior, 1881), 183; Letter from the Secretary of War, Transmitting, with a Letter from the Chief of Engineers, Report of Examination of Oyster Harbor, Virginia, U.S. House of Representatives, 58th Congress, 2nd Session, Document 202; U.S. Post Office Department, *Report of Site Locations*.

and wharf towns and the crossroad hamlets embodied an "archipelago of villages" across the Eastern Shore countryside.[56]

People moved into the larger towns to find work and to enjoy the amenities and novelties of town life. In 1907 an Onancock editor directed the attention of his readers "to the great number of homes erected here, more probably than in any year in its history." Prosperous farm families, the editor continued, "have moved into our town where their children can be educated and the social features of an up-to-date town can be enjoyed." Townspeople built their homes close to the street on deep, narrow lots. (Conversely, out in the countryside, farmers built their houses set back from the road behind spacious lawns.) Many of the towns laid sidewalks, erected street lamps, and provided water and sewage (which was flushed raw into the creeks). Power plants supplied electricity to the towns and extended the grid into the country. Telephone switchboards linked the towns to nearby farmsteads and to the greater world. Beginning in the early 1890s, large public cemeteries

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[56] Brent, *The Eastern Shore of Virginia*, 6, 8; *Virginia* (1919), 84; Carter, "An Economic and Social Survey of Accomac County," 31; Holland, "An Economic and Social Survey of Northampton County," 51. For the feverish building of churches after the coming of the railroad see Kirk Mariner, *Revival's Children: A Religious History of Virginia's Eastern Shore* (Salisbury, Md.: Peninsula Press, 1979), 240-637. The term "archipelago of villages" is Joel Kotkin's. See his *The New Suburbanism: A Realist's Guide to the American Future* (n.p.: The Planning Center, 2005) at www.joelkotkin.com (pdf). For a somewhat dissimilar process of layering and town development in a rural region, see Joseph Walden Baumli, "Prairie Trails, iron rails, and tall tales: the settling, town building, and people of Nodaway County, Missouri, 1839-1910," Ph.D. Dissertation, University of Missouri-Kansas City, 2004. Baumli charted the development of infrastructure in this northwestern Missouri border county, from schools to churches, rural mail delivery routes, roads, and railroads. He argued that the development pattern of the county in the nineteenth century emerged around the railroad between 1869 and the late 1880s. In this period town development centered on railroads, and earlier settlement towns went dormant while new towns exploded. Most of these new towns grew steadily but none of them "acquired any semblance of an urban landscape." (358) Baumli argued that the county remained overwhelmingly rural despite the new railroads, and that the towns were successively rearranged as the railroads arrived.

appeared on the edge of several of the towns. In numerous instances, ancestors, long the denizens of secluded family plots, were re-interred in the new cemeteries. Even the dead were coming to town.[57]

The landscape, town and country, was dotted with new homes and businesses. The traditional string style of local architecture was superseded by modern styles – the four-square and its varieties, the bungalow, even Sears, Roebuck manufactured houses shipped to the Eastern Shore by rail. "The dwelling houses a few years ago were unattractive, and many of them uncomfortable," a traveling salesman remarked in 1887. "To day they are not only comfortable but tasty." In 1920 a farmer left his six-room house in the crossroad hamlet of Nelsonia for a new home in the nearby railroad town of Bloxom. "This house had thirteen rooms, a sleeping porch upstairs, and a downstairs porch that ran three-quarters of the way round the house, plus a small porch in back," the farmer's daughter later recalled. "The house had a real bathroom and electric lights in every room." Frame structures predominated but brick and concrete houses and stores were not uncommon. When fire destroyed the business sections of Parksley and Onancock at the turn of the century, both were rebuilt almost entirely in brick. The new homes and businesses were fitted with modern heating and plumbing. On the farms modern windmills stood tall and angular among new barns, smokehouses, potato houses, and other outbuildings. So much construction left the domesticated landscape, particularly that of the new railroad towns, with a raw, unfinished look.[58]

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[57] *AN*, January 5, 1907 (quotation); Stevens, *Soil Survey*, 24; *PE*, May 7, 1892, September 11, 1897, September 10, 1898, November 22, 1902; *NL*, November 9, 1902; Mears, "The Eastern Shore of Virginia in the Nineteenth and Twentieth Centuries," II, 599; "History of Growth of the Telephone on E.S. of Virginia," *PE*, August 18, 1928.

[58] Kirk Mariner, *Once Upon an Island: The History of Chincoteague* (New Church, Va.: Miona Publications, 1996), 87; *PE*, December 16, 1899, November 22, 1902,

Race, Wealth, and Labor

Despite the widely shared prosperity, segregation developed on the Eastern Shore in the same way it did across much of the South and with the same restrictive effects. Separate schools were constitutionally mandated and separate churches the norm. In the towns, blacks lived in separate neighborhoods. In the countryside, white and black residences might be interspersed or in discreet settlements. Segregation by custom on local public transportation preceded the railroad. In 1882 the Eastern Shore Steamboat Company's new steamer "The Eastern Shore" was constructed with a 38-cylinder, 9-foot stroke engine and a hold capacity of 3,000 barrels of potatoes. It also featured spacious staterooms and cabins, "fitted up separately" by race and gender. In contrast, the New York, Philadelphia and Norfolk Railroad ran racially mixed cars for a well attended excursion to a circus at Pocomoke City in 1885. Not for another twenty years would Virginia require separate railroad coaches. The commonwealth effectively disenfranchised its black voters in 1902, smothering decades of intense political activism and engagement. On the Eastern Shore, as in other places of well-organized black political activity, some African Americans persisted in registering and voting, but their numbers were greatly reduced. In black-majority Northampton County only about a quarter of adult black males managed to hurdle the “understanding clause” and

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June 22, 1907; Drummer, “Pocomoke Neck and Sykes,” *PE*, July 23, 1887 (first quotation); Oberseider, *So Fair a Home,* p. 118 (second quotation); *ESH*, January 12, 1906, April 19, 1907; Stevens, *Soil Survey*, 24. For emerging styles of Eastern Shore architecture see Gabrielle M. Lanier and Bernard L. Herman, *Everyday Architecture of the Mid-Atlantic: Looking at Buildings and Landscapes* (Baltimore and London: Johns Hopkins University Press, 1997).

register. When an aspiring black voter was asked by the registrar the meaning of a section of the constitution, he replied, "It means the Negro is done voting."[59]

Eastern Shore blacks made less money than whites, were more likely to be day laborers, lived in poorer housing, possessed fewer amenities, were less well educated, and were less mobile. Nevertheless, Eastern Shore blacks enjoyed a higher standard of living, were more likely to have their ballots honestly counted, and suffered less from legal and extra-legal violence than their counterparts in many other Southern locales. Race relations in the South varied from region to region, state to state, county to county, doorstep to doorstep. For example, Somerset County on the Eastern Shore of Maryland was economically and demographically similar to Accomack on the Eastern Shore of Virginia, but blacks in Somerset were far more likely to be lynched or executed. From the end of the Civil War through 1935, only one black was lynched and two legally executed in Accomack (and two of the three incidents occurred before 1871). Meanwhile, in adjoining Somerset at least three were lynched and ten legally executed. Moreover, in 1906 the white sheriff and posse of Northampton County stood down a mob that had come by train from Somerset intent on lynching a young black man accused of raping a white woman in that county.[60]

African American migration onto the Eastern Shore picked up pace after the arrival of the railroad with job opportunities opening in its wake. Black population increased nearly as rapidly as white in Accomack and Northampton. Black people migrating to the Eastern

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[59] Mariner, *Revival's Children*, 135-144; *PE*, September 14, 1882, April 18, 1885, October 4, 18, 25, 1902; *NL*, August 21, 1903; *ESN*, June 24, 1949 (quotation). On Virginia's segregation and disenfranchisement, see Ayers, *The Promise of the New South;* Michael Perman, *The Struggle for Mastery: Disenfranchisement in the South, 1888-1908* (Chapel Hill: University of North Carolina Press, 2000); and Charles E. Wynes, *Race Relations in Virginia, 1870-1912* (Totowa, N.J.: Rowman and Littlefield, 1971).

[60] Brooks Miles Barnes, *The Gallows on the Marsh: Crime and Punishment on the Chesapeake, 1906* (Eastville, Va.: Hickory House, forthcoming).

Shore appear to have arrived in family groups (just as did white newcomers). They were drawn to the peninsula by abundant jobs at good wages. The black community's relative prosperity found tangible expression in the construction of numerous houses, churches, schools, businesses, lodge halls, and a bank.[61]

Although Virginia led the nation in the number and percentage of black landowner farmers, on the Eastern Shore the rates of black farm owners were well below the state average. Blacks were more likely to be agricultural laborers than tenant farmers, more likely to be tenants than landowners. In 1925, blacks owned 169 farms in each of the two counties – 15.6 percent of the farms in Northampton but only 5.2 percent of those in Accomack. Whites, if less likely to be laborers than farmers, were as likely to be tenants as owners. In 1925, 59.8 percent of the farms in Accomack and 45.7 percent in Northampton were operated by tenants. Because crops brought consistently high prices, Eastern Shore tenants preferred share to cash rental. No matter how they paid the rent, the booming agricultural economy brought them good returns for their labor. Most Eastern Shore farmers, black or white, were small operators as likely to know well the backside of a mule as the laborers, black or white, whom they employed. At the harvest, everyone, irrespective of race, gender, or age gathered the potatoes from the fields.[62]

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[61] Mariner, *Revival's Children*, 239-637; Frances Bibbins Latimer, *Landmarks: Black Historic Sites on the Eastern Shore of Virginia* (Eastville, Va.: Hickory House, forthcoming). For black migration to the Eastern Shore see above page 32.

[62] *PE*, December 20, 1930; Carter, "An Economic and Social Survey of Accomac County," 89; Holland, "An Economic and Social Survey of Northampton County," 140. On relative black tenancy and landownership, see the Historical Census Browser, University of Virginia for 1900 census data at: <http://fisher.lib.virginia.edu/collections/stats/histcensus/>. In 1900 black 43.22 percent of all black farmers in Northampton were share tenants and 26.09 percent were cash tenants. In Accomack the percentages were nearly reversed - 31.89 percent were cash tenants and 54.59 percent were share tenants.

In the fisheries, blacks worked as hands on oyster dredgeboats (skippers were overwhelmingly white), as independent watermen (oyster planters were white), and as shuckers and pickers in the seafood houses (seafood dealers were white). Whites also worked as dredger hands, independent watermen, and shuckers and pickers. Some workplace segregation was apparent. Oyster houses employed either black shuckers or white. The reputed world's largest oyster house on Folly Creek probably employed black shuckers while the houses on Chincoteague employed white. Black shuckers came from Delaware, Maryland, and North Carolina for the good wages on the Eastern Shore. Some oyster grounds were racially exclusive as the place name Tar Bay implies. In the lumber industry, both blacks and whites worked as timber cutters, cartmen, and sawmill hands. The crew chiefs usually were white and the lumber dealers exclusively so.[63]

Nearly every business and farm on the Eastern Shore needed good labor and African Americans took advantage of the opportunities around them. When white landholders organized to recruit immigrant workers in New York City, local blacks organized to counteract it with pressure of their own. The white landowners admitted that they could neither recruit enough immigrants to change the labor market nor could they always compete with the seafood industries where "at certain seasons of the year . . . larger wages are given them [African American workers] at the fish factories and in the oyster business than they [white landowners] can afford to pay." Thus, the Eastern Shore's mixed and booming economy gave laborers, black and white, leverage in their quest for better wages.[64]

The economic mobility and opportunity African Americans enjoyed on the Shore also came alongside rising political expectations and opportunities. In the 1880s Virginia

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[63] *PE,* February 23, 1882; Winthrop A. Roberts, "The Crab Industry of Maryland," *Forest and Stream* 65 (September 30, 1905), 275-276. See *PE,* November 21, 1891, on the employment of African Americans from Delaware.
[64] *PE,* March 23, 1882.

Senator William Mahone made the "Readjuster" movement into a biracial political coalition aimed at defeating the Conservative Democratic Party and its blend of white supremacy and elite class protection. Mahone's brand of Readjuster politics was especially attractive to the Eastern Shore's black voters. White Democrats there took notice, and they conveniently mistook the booming labor market for its political effects. Because of Mahonism, they sneered, "the negro seems to be above labor on the farm."[65]

Environment

Change in the arrangement and use of the land produced consequent and unexpected (and usually unnoticed) effects. Run-off of sand, clay, and other debris from the roads and of topsoil, fertilizer, and pesticide from the fields led to the silting of the upper reaches of Eastern Shore creeks (though more evident on the seaside than on the bayside where the compensatory effect of sea level rise was more pronounced) and, to varying degrees, the pollution of the lower reaches. Throughout the period the U.S. Army Corps of Engineers dredged the channels of creeks and inlets filled by silt and by sands shifted by current and tide, paddle and propeller**.** The run-off (and, probably, the dredging) affected adversely water clarity, oxygen content, and the survival of bottom-dwelling plants. It included traces of Paris Green, the potato grower's pesticide of choice, a deadly compound of arsenic and copper.[66]

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[65] *PE,* February 9, 1882. For the Readjuster Movement see Barnes, "Triumph of the New South," 1-265.
[66] "The Eastern Shore," Richmond *State*, July 24, 1883; Grace S. Brush, "Forests before and after the Colonial Encounter" in *Discovering the Chesapeake*, 57-58; Stevens, *Soil Survey*, 25; John R. Wennersten, *The Chesapeake: An Environmental Biography* (Baltimore: Maryland Historical Society, 2001), 149. C. F. Cerco, et al., "Nutrient and Solid Controls in Virginia's Chesapeake Bay Tributaries", *Journal of Water Resources Planning and Management*, 128 (2002), 179-189 report that cropland is the major source of nitrogen and phosphorous flow between the terrestrial

Increases in surface runoff associated with land clearing had changed the proportions of less dense fresh water and more dense salt water that mixed in the Chesapeake Bay, which intensified stratification (and decreased mixing between upper and lower levels in the water column that otherwise would transport oxygen from the surface to the depths). Moreover, an increased nutrient load in the runoff associated with terrestrial fertilizer use had fed algal blooms (a process commonly referred to as "eutrophication"), which blocked light from penetrating the water column and decreased habitat for submerged aquatic vegetation that otherwise would have produced oxygen as a byproduct of photosynthesis. The final assault on bottom water (benthic) oxygen levels in the Bay occurred when the algal blooms would die on a seasonal basis, settle to the bottom, and undergo an oxygen-consuming decay processes. These three developments associated with terrestrial land use (increased runoff and nutrient load, vertical stratification, and eutrophication leading first to decreased light penetration and second to oxygen-consuming decay) caused what is referred to in scientific language as "benthic anoxia" - a growing portion of Chesapeake bottom waters no longer had enough oxygen to support the oysters, crabs, green plants, and other life that had historically thrived in the benthic habitat. The unintended consequences of human land use practices that began with extensive early eighteenth century land clearing had changed the ecology of the Chesapeake Bay, the repercussions of which were felt by the watermen of the Eastern Shore in their poor hauls by the 1920s (although not scientifically documented until 1936).[67]

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and estuarine systems within the Chesapeake Bay watershed. For the frequent dredging of Onancock Creek see U.S. House of Representatives, 51st Congress, 1st Session, Document 83 (1889); 60th Congress, 1st Session, Document 652 (1908); 68th Congress, 1st Session, Document 219 (1924).

[67] To underscore the complexity of the system processes that had been damaged, it is now understood that a positive feedback loop had been initiated by the increase in surface runoff and nutrient load-not only had it caused the oyster population to declined due to benthic anoxia, but by doing so it also eliminated one of the only natural remedies to a polluted water column because the dwindling number of oysters

Throughout the Chesapeake Bay watershed during the late nineteenth century, human influences on the water quality and bay life included not only land use runoff but also drainage of raw sewage, based in large part on logic such as that espoused by Baltimore Sewage Commission when it advised in 1897 that there was “but little reason” not to take advantage of the Bay’s “diluting effect” and to keep dumping sewage. In 1924 a typhoid outbreak linked to tainted oysters arose in Chicago, New York, and Washington in which 1,500 cases of typhoid and 150 deaths were reported, causing major concern to those interested in protecting human health as well as the reputation and economic future of the seafood industry.[68]

In 1912 Charles Francis Adams, the New England man of letters, recalled a recent visit to the Eastern Shore. Citing Howard Pyle's 1879 essay, Adams noted that Pyle had written "the lifetime of a generation ago." Conditions on the peninsula, Adams continued, had "markedly changed." "The railroads had pushed their way south of the Maryland line and. . . . direct and easy lines of communication have been opened between a region of singular natural productiveness and the largest American markets." Having seen the Eastern

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grew less and less capable of filtering Bay waters; For a more detailed explanation, see Boesch, D., et al., (2001) Factors in the Decline of Coastal Ecosystems, Science, 293, 1589-1591; Newcombe, C. and W. Horn first documented findings from 1936 water sampling activities in the Bay in their groundbreaking publication, Oxygen-poor waters of the Chesapeake Bay, Science, 88(2273): 80-81 (1938). See also Tom Horton, *Turning the Tide: Saving the Chesapeake Bay*, rev. ed. (Washington: Island Press, 2003).

[68] Steven G. Davidson, Jay G. Merwin, Jr., John Capper, Garrett Power, and Frank R. Shivers, Jr. *Chesapeake Waters: Four Centuries of Controversy, Concern, and Legislation*, 2nd ed. (Centreville, Md.: Tidewater Publishers, 1997) 85 (quotation), 96.

Shore in a seeming fever of human activity, Adams concluded that "the Rip Van Winkle sleep has manifestly come to an end."[69]

Nature's Limits:

The string of narrow barrier islands protecting the Eastern Shore mainland from the Atlantic Ocean is one of the most dynamic landforms on earth. Under pressure of current and tide they are continuously on the move, building on one end, diminishing on the other, all the while migrating gradually westward. Some of the islands are mere sandbars; others are heavily forested. Between the islands and the mainland lie the wide expanse of marshes, bays, and channels known as the Broadwater. The islands and adjacent marshes and waters teem with life and serve as a great nursery for creatures of the air and water.[70]

In 1870 humans resided on some of the islands. They made their livings by farming, herding, and market hunting. They also fished, clammed, and gathered oysters. Some gained temporary employment in "wrecking" – salvaging beached vessels and cargo or gathering debris from the wrack-strewn beach. The islanders sent their produce by steamboat and sailboat to Philadelphia and New York. On Cobb's and Assateague islands, resort hotels catered to bathers in the summer and to gunners and anglers the rest of the year.[71]

Beginning in the 1870s a tremendous increase in the volume of shipping along the Virginia coast demanded improved maritime safety. The United States Coast Survey

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[69] C. F. Adams, "The Kingdom of Accomac," Massachusetts Historical Society *Proceedings* 45 (1911-1912), 596-597. "Without [the railroad] today the Shore might be slowly succumbing to a lotus-diet of isolation and like many comparable sections of the Tidewater country . . . reflecting the loneliness of a vanishing era" (*PE*, August 8, 1936).
[70] Brooks Miles Barnes and Barry R. Truitt, "A Short History of the Virginia Barrier Islands" in *Seashore Chronicles: Three Centuries of the Virginia Barrier Islands*, ed. Barnes and Truitt (Charlottesville: University Press of Virginia, 1997), 6.
[71] *Ibid.*, 8.

mapping of the Eastern Shore coastline was a first step, but the bars and shoals of the Atlantic took an ever heavier toll in life and property. The federal government responded by improving the existing lighthouses on Assateague, Hog, and Smith's islands, by anchoring a lightship off Assateague, by erecting a lighthouse on Killick Shoals in Chincoteague Bay, by establishing a quarantine station on Fisherman's Island, and by surveying Chincoteague Inlet as a possible harbor of refuge.[72]

More important, in the 1870s and 1880s, the federal government established life-saving service stations on most of the barrier islands. Over the years the keepers and surfmen of the stations saved countless lives and millions of dollars in property. While the men of the life-saving and lighthouse services fought storms and shoals on behalf of mariners and their vessels, they fought a quieter battle against the insidious effects of current, tide, and shoreline migration. They had continuously to replace buoys and channel markers, to move or even abandon lighthouses and life-saving service stations. "The station buildings upon the coast are all constructed with a view to withstand the severest tempests," boasted the superintendent of the life-saving service in 1904. "This substantial construction also enables them to be easily and cheaply moved when threatened by the gradual encroachment of the sea, which upon many sections of the coast, effects in the course of years great changes in the configuration of the coast line." So rapid was shoreline migration on Cobb's Island in the

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[72] Richard A. Pouliot and Julie J. Pouliot, *Shipwrecks on the Virginia Coast and the Men of the United States Life-Saving Service* (Centreville, Md.: Tidewater Publishers, 1986), 4; Mariner, *Once Upon an Island*, 38-39, 65; *PE*, November 21, 1885, May 13, July 15, 1893; Letter from the Secretary of War, Transmitting, Report and Recommendations Concerning Improvement of Chincoteague Inlet, Virginia, by a Breakwater, U.S. House of Representatives, 51st Congress, 1st Session, Executive Document 207.

late nineteenth century that the life-saving station had to be moved in 1896 and again in 1898.[73]

Oystering

The railroad first touched the Eastern Shore seaside in 1876 when a line (soon to be part of the Delaware, Maryland and Virginia Railroad, a possession of the Pennsylvania) laid southeastward from Snow Hill, Maryland, reached its terminus just below the Maryland-Virginia boundary and next the Chincoteague Bay oyster grounds at what became Franklin City. The construction in 1884 of the New York, Philadelphia and Norfolk placed wharves all along the seaside within easy hauling distance of the rail depots. By opening innumerable new markets, the railroad vastly stimulated the seaside seafood industry. The fisheries attracted hundreds of people to the islands and the adjoining mainland. They came with their families from Maine, Long Island, New Jersey, Delaware, and Maryland. Several of the newcomers became leaders in the seafood trade, outside expertise and capital playing a much larger role in the fisheries than in agriculture.[74] Oystering was the most important of the seaside industries. From the late 1870s through the mid-1890s, the watermen of Chincoteague Bay harvested from 110,000 to 325,000 bushels of oysters annually. The oysters went almost exclusively to established markets in Philadelphia and New York, half

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[73] Pouliot, *Shipwrecks on the Virginia Coast*, 50, 107, 156; Ralph T. Whitelaw, *Virginia's Eastern Shore: A History of Northampton and Accomack Counties* (Richmond: Virginia Historical Society, 1951), I, 370; Robert de Gast, *The Lighthouses of the Chesapeake* (Baltimore: Johns Hopkins University Press, 1973), 143; Ron M. Kagawa and J. Richard Kellam, *Cobb's Island, Virginia: The Last Sentinel* (Virginia Beach: The Donning Company, 2003), 29 (quotes Sumner I. Kimball); *PE*, September 19, 1896, April 16, 1898.

[74] Hayman, *Rails Along the Chesapeake*, 34, 38-39, 133; John E. Bradford to William Mahone, August 5, 1882, Mahone Papers, Duke; Mariner, *Once Upon an Island*, 42. For prominent seafood dealers of Willis Wharf see the obituaries of John C. Walker (b. Oriole, Md.), Marcus Clarence Ballard (b. Oriole, Md.), Henry Miller Terry (b. Sayville, N.Y.), and Wade H. Walker (b. Oriole, Md.) in *PE*, March 23, 1929, March 7, 1941, September 1, November 10, 1955.

traveling by rail and half by sail. In 1890 a New York journalist observed a dozen men dressed in the "rough clothes" of the waterman awaiting the arrival of the mail train in Franklin City. "They open the envelopes, which have the names of well-known wholesale oyster dealers in New York and Philadelphia printed on the corners, and . . . out drop checks and statements comforting to look upon." The journalist learned that for these men in "brown-twilled overalls and long-legged boots, the average income is not far from $7,000 a year."[75]

Sailboats also engaged in the seed oyster trade, carrying small oysters from the Broadwater, Chesapeake Bay, and the James River for planting in Chincoteague, Johnson's, and Parker's bays. Paradoxically, they also ran Chincoteague Bay oysters to New Jersey and Connecticut for planting there. In 1884 a Delaware man estimated that since the coming of the railroad the number of oysters planted in Chincoteague Bay had climbed from 36,000 to 300,000 bushels annually. By 1889 more than one hundred vessels of from five to sixty-five tons and about two hundred decked vessels of under five tons participated in the upper seaside oyster trade. The growing commerce necessitated the construction of private wharves on Chincoteague Bay at Chincoteague Island, Franklin City, and Greenbackville and on its tributary Swan's Gut Creek.[76]

Since 1849, individuals had claimed portions of Chincoteague Bay as private planting ground. The Broadwater's lower bays, on the other hand, were largely commons. Almost immediately after the coming of the railroad, watermen began to worry that the free-

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[75]Ingersoll, "The Oyster Industry," 183; *PE*, June 2, 1888, July 20, 1889, April 5, 1890, June 2, 1894; John R. Spears, "A Curious Virginia City," New York *Sun*, May 7, 1890 (quotation).

[76] H.R., 48th Congress, 2nd Session, Executive Document 107; H.R., 51st Congress, 1st Session, Executive Document 207; *Acts and Joint Resolutions* (1881-1882), 164, (1885-1886), 17, 29-30, 156, 365, (Extra Session, 1887), 196, 263, (1887-1888), 97, 100, (1889-1890), 793, (1891-1892), 480-481, 481-482.

for-all on the Broadwater commons might exhaust the oyster rock. Their concerns coincided with those of Cheasapeake Bay oystermen, and in 1892 Captain James H. Baylor of the U.S.C.S. surveyed Virginia's oyster grounds. Meanwhile, the General Assembly passed legislation providing for the leasing of the barren commons to private interests. The commons identified by Baylor as productive oyster grounds remained in the public domain.[77]

Private leasing dramatically increased oyster harvests. "The development of the shipments of shucked oysters from the planting section on the ocean side of the peninsula has been marvelous," a correspondent told a Richmond newspaper in 1906. "Two cars are attached to the local express train every night to handle the receipts. Orders are received from over a greater part of the country. Chicago, Kansas City, Minneapolis, Omaha and many other large Western cities are large customers." When oyster dealers learned that they could earn a higher return by shipping oysters shucked rather than in the shell, shucking houses, including the reputed largest in the world, opened up and down the seaside.[78]

The privatization of the barren commons came at a cost. For along with greater yield, it also encouraged litigation, poaching, intimidation, and bloodshed. "A state of warfare developed between the lease holders protecting their property, and those called 'oyster pirates,' who believed they had an inalienable right to anything produced by the sea," recalled a conservationist. "In order to protect the planted oyster beds it finally became necessary to station guards armed with rifles along the shore during fall and winter. Small houses were built nearby for their accommodation." Around 150 of these watch houses

[77] Annabel Lynch, "Chincoteague Island," *AN*, August 11, 1916; Mears, "The Eastern Shore of Virginia in the Nineteenth and Twentieth Centuries," II, 615; Baltimore *Sun*, November 28, 1892; Nora Miller Turman, *The Eastern Shore of Virginia, 1603-1964* (Onancock, Va.: Eastern Shore News, 1964), 204-205.
[78] "Onancock: The Year One of Continued Prosperity on Eastern Shore," Richmond *Times-Dispatch*, January 1, 1906 (quotation); *Virginia* (1909), 81, 83; *Oysterman and Fisherman* IX (December, 1911), 9; *ESH*, August 1, 1913.

appeared along the seaside from Chincoteague Bay to Cape Charles. Oyster planters, usually wealthy, well connected men, hauled common oystermen into court for trespass, the sheriff of Northampton County was overpowered by depredating oystermen and marooned on a deserted island, and, on Mockhorn Island, a man shot and killed an old friend whom he accused of stealing his oysters. Meanwhile, on the public commons, the natural rock was in some places destroyed by illegal dredging, a problem exacerbated by the introduction of the gasoline power boat around 1905. The fierce competition put the oyster grounds, public and private, under intense stress. In the 1920s the strain became unbearable. Between 1920 and 1933, Eastern Shore oyster production (seaside and bayside combined) declined by 42 per cent, from 4,797,821 to 2,783,806 pounds.[79]

Seaside watermen also made their livings from other catch. They clammed, crabbed, and scalloped. They hauled seine and built pound nets for the capture of several species of table fish. They caught sturgeon for express shipment to Northern gourmands (in 1912 sturgeon roe sold on the dock at Oyster for $1.50 per pound; a single fish might provide roe worth $100) and supplied menhaden to factories for rendering into oil and fertilizer. The new technologies – power boats, ice plants, improved pounds and nets – that facilitated the harvest also hastened the decline of the fisheries. Between 1920 and 1933, production of fish and

[79] George Shiras 3rd, *Hunting Wild Life with Camera and Flashlight: A Record of Sixty-five Years' Visits to the Woods and Waters of North America* (Washington: National Geographic Society, 1935), II, 80 (quotation); Maude Radford Warren, "The Island of Chincoteague," *Harper's Monthly Magazine* 127 (October, 1931), 777; *NL*, September 17, 1902; *AN*, February 3, 1906; *ESH*, March 25, April 1, July 1, 15, 22, 1910; *Report of State Board of Fisheries to the Governor of Virginia, from October 1, 1905, to October 1, 1906* (Richmond: Superintendent of Public Printing, 1906), 5; *PE*, August 8, 1936.

shellfish fell in almost every category. Only crabbing and clamming made appreciable gains during the period.[80]

Market Hunting

Market hunting--the shooting or capture of wildfowl for sale to restaurants or at markets--opened up with new layers of infrastructure and access to markets. Such large-scale hunting picked up pace with the arrival of the railroad. Although it provided another source of income for both permanent residents and transients, the hunting ran a course of deep exploitation. The market hunters caught ducks in nets and traps and in the winter nights killed them by torchlight. After 1900 the hunters enjoyed the advantages of automatic shotguns and white powder shells. Corn for bait and the automatic with eleven-shot extension was “the most deadly combination against ducks ever devised,” one historian has concluded. Power boats, the ready availability of ice, and express rail shipments further abetted the slaughter. As if to add insult to injury, the waterfowl flights were disrupted by the roar of the boat engines and by potshots fired at them by bored guards from the catwalks of oyster watch houses.[81]

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[80] Marinus James, “The Parson Goes Deep Sea Fishing,” *PE*, September 29, 1928; Norfolk *Virginian-Pilot*, May 6, 1912; H.R., 62nd Congress, 3rd Session, Document 1094; Lynch, “Chincoteague Island,” *AN*, August 11, 1916; Margaret Ellen Mears, “Chincoteague and the Seafood Industry, *PE*, August 13, 1932; James Egbert Mears, “The Eastern Shore of Virginia in the Nineteenth and Twentieth Centuries,” II, 615-616; *NL*, December 10, 1902; *PE*, August 8, 1936. In the early 1930s scallops “disappeared suddenly when a mysterious blight attacked the sea grass in which they propagated” (James Wharton, “Virginia’s Drowned Village,” *Virginia Cavalcade* VII [Winter, 1957], 8).

[81] Alexander Hunter, *The Huntsman in the South, Volume I: Virginia and North Carolina* (New York: Neale Publishing Company, 1908), 313; Shiras, *Hunting Wild Life with Camera and Flashlight*, II, 67, 69, 80; *ESH*, February 2, 9, 1906; Harry M. Walsh, *The Outlaw Gunner* (Centreville, Md.: Tidewater Publishers, 1971), 25-27, 30 (quotation); L. C. Sanford, L. B. Bishop, and T. S. Van Dyke, *The Water-Fowl Family* (New York: Macmillan Company, 1903), 68-69; George Reiger, *The Wings of Dawn: The Complete Book of North American Waterfowling* (New York: Stein and

Every spring market hunters followed the flights of shorebirds and waterbirds north along the Atlantic coast. The waterbirds were valued for their plumage, which was used as ornamentation on women's clothing. On Cobb's Island the birds were killed on their nesting grounds. In the early 1900s an ornithologist learned of "1,400 Least Terns being killed in one day. . . . The birds were packed in cracked ice and shipped to New York for skinning; ten cents being paid for each one." Another ornithologist writing at about the same time reported that the Least Terns on the island "have been thoroughly annihilated." The fate of the terns, and of the willets, curlew, ducks, geese, and other species, along the Atlantic coast was in many respects the same as that of the bison in the American west. Hunters fanned out along the railroad, used the newly developed technology of ice packing, and connected into a booming urban market that catered to modern sensibilities, responded to advertising, and coursed with the new wealth of the consumer society.[82]

The diminished flights of shorebirds and waterfowl greatly concerned both conservationists and sportsmen. The two groups, within which the wealthy and influential were well represented, lobbied the local, state, and federal governments to protect the beleaguered birds. In 1894 an act of the Virginia General Assembly created the Eastern Shore Game Protective Association and gave it authority to license non-resident hunters and

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Day, 1980), 68. For studies of market hunting elsewhere see Louis S. Warren *The Hunter's Game: Poachers and Conservationists in Twentieth-Century America* (New Haven and London: Yale University Press, 1997) and Karl Jacoby, *Crimes Against Nature: Squatters, Poachers, Thieves, and the Hidden History of American Conservation* (Berkeley, Los Angeles, and London: University of California Press, 2001).

[82] T. Gilbert Pearson, *Stories of Bird Life* (Richmond: B. F. Johnson Publishing Company, 1901), 66-69; Frank M. Chapman, *Camps and Cruises of an Ornithologist* (New York: Appleton and Co., 1908), 63-64 (first quotation); A. C. Bent, "Report of A. C. Bent, on Condition of Bird Colonies on Cobb's Island, Virginia, in 1907," *Bird-Lore* 9 (1907), 317 (second quotation). On the destruction of the bison, see Andrew Isenberg, *The Destruction of the Bison: Social and Ecological Changes in the Great Plains, 1750-1920* (New York: Cambridge University Press, 2000).

to employ wardens to enforce game laws. In 1900, the General Assembly authorized the county courts of Accomack and Northampton to appoint game wardens. The wardens, often employees of the life-saving service, were paid by the E.S.G.P.A. and by the Thayer Fund of the Audubon Society. Meanwhile, a series of federal statutes culminating in the Migratory Bird Treaty Act of 1918 imposed bag limits and banned egging, spring shooting, and the interstate shipment of game. A conservationist visiting the Broadwater in 1923 happily reported that "the Federal law had resulted in an increase in the number of most of the shore birds."[83]

Tourism

The trains that carried northward game and seafood returned with tourists – rusticators for the seashore, gunners and anglers for the bays and marshes. Many of the vacationers were middle class urbanites taking advantage of the nation's increased prosperity and leisure and its expanding transportation network. Between 1876 and 1905 hotels and boarding houses opened on half a dozen barrier islands and on the adjacent mainland. The buildings ranged in size from cottages to the fifty-two-room Atlantic Hotel on Chincoteague Island. Meanwhile, private lodges appeared on seemingly every island and on every high place in the marsh. Most were functional structures, but a few were the well appointed retreats of financiers and corporate lawyers and their families. The larger resorts included the Revel's Island Club founded by Washingtonians in 1884, clubs on Wallop's and Hog islands established by Philadelphians in 1886 and 1889, and the Accomac Club founded near Parramore Island by New Yorkers around 1890. The Wallop's Island establishment

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[83] *Acts and Joint Resolutions* (1893-1894), 794, (1899-1900), 552; Minutes, November 13, 1905, Eastern Shore Game Protective Association, Papers, 1896-1911, Eastern Shore of Virginia Historical Society, Onancock; William Dutcher, "Results of Special Protection to Gulls and Terns Obtained through the Thayer Fund," *Auk* 18 (1901), 77; Reiger, *The Wings of Dawn*, 71, 73; Shiras, *Hunting Wild Life with Camera and Flashlight*, II, 63-65, 96 (quotation).

embraced a commodious two-story clubhouse with veranda, guest cottages, a cookhouse, an icehouse, numerous outbuildings, and a steam launch for use as a pleasure craft.[84]

The effect of shoreline migration and a series of hurricanes in the late 1880s and the 1890s undermined these vacation retreats and made them increasingly untenable despite their elaborate infrastructure. The Cobb's Island Hotel, the most famous of the barrier island resorts, gradually fell into the sea, a wrecked symbol of the toll nature took on the islands. In 1890, the Cobb family, aware that over the past thirty years the surf had crept ever closer to the hotel complex, sold out to a Lynchburg, Virginia, syndicate that envisioned turning the island into a premier seaside destination. In 1896 a hurricane wrecked the hotel and in 1897 another destroyed the remainder of the complex. Similarly harried by tide, current, and storm, the rest of the hotels and lodges soon disappeared from the islands and the Broadwater.[85]

The watermen's communities on the outer barrier islands underwent a similar experience of expansion and retreat. The booming seafood and tourism industries attracted people to the island villages. Diminished seafood harvests convinced some to leave, the coming of the power boat encouraged others to exchange the isolation of the islands for the

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[84] Barnes and Truitt, "A Short History of the Virginia Barrier Islands," 10-11; Amine Kellam, "The Cobb's Island Story," *Virginia Cavalcade* XXIII (Spring, 1974), 23; Mariner, *Once Upon an Island*, 69. For middle-class vacationers see Cindy S. Aron, *Working at Play: A History of Vacations in the United States* (New York: Oxford University Press, 1999), 3-4

[85] *PE*, March 24, December 8, 1888, September 28, 1889, November 11, 1893, November 23, 1895, October 17, 1896, February 13, October 30, 1897, February 18, 25, March 4, 11, 1899; Richmond *Dispatch*, April 10, 11, 1889; Barnes and Truitt, "A Short History of the Virginia Barrier Islands," 12-13, 15; Brent, *The Eastern Shore of Virginia*, 8; *Prospectus and Subscription List of the Cobb's Island Company*, Special Collections, Alderman Library, University of Virginia, Charlottesville; Thomas Brown Robertson, "Historical Notes and Episodes of Northampton County" Ms. in Virginia Historical Society, Richmond, 386-389. For an early analysis of shoreline migration see J. R. Sturgis, "Cobb's Island," *PE*, November 13, 1897.

amenities of the mainland waterfront villages, and the shifting shoreline eventually forced off the rest. Broadwater village on Hog Island, home to 162 souls in 1920, lies today a mile out into the Atlantic Ocean. The barrier islands south of Wallops are now virtually devoid of human presence and their landscape contains few relics of a human past. And yet, while the primeval forces of tide, current, and storm precluded permanent human settlement on the outer islands, emerging technologies such as the railroad, the power boat, the ice plant, and the automatic shotgun enabled human exploitation of the surrounding waters.[86]

Prosperity's End

The Eastern Shore's economic boom came to an end in the late 1920s. The success of the peninsula's white potato industry encouraged new competition from Texas, Louisiana, Alabama, North Carolina, and other states. An increasingly glutted market brought lower prices and reduced profit margins, which, despite the admonitions of the officers of the Eastern Shore Produce Exchange, encouraged local overproduction. Meanwhile, the rise of the motor truck weakened the Exchange's ability to control supply by making it convenient for farmers to ship directly to urban commission merchants. In 1928, the cost of production of a barrel of white potatoes exceeded its market price. Farmers, who for years had routinely borrowed to pay for land, machinery, seed, and fertilizer and who just as routinely had retired the debts with money to spare, now found themselves unable to meet their obligations. The onset of the Great Depression in 1929 precluded chance of recovery. Between 1925 and 1940, the number of farms in Accomack and Northampton declined from 4,856 to 2,960.[87]

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[86] Northampton County 1920 Manuscript Census, 249-250; Wharton, "Virginia's Drowned Village," 10-11. For the advantages of the power boat see George Fortiss, "The Hunter and the Motorboat," *Outing* LV (March, 1910), 735-739.
[87] T. B. Manney, "What Farmers Say About Marketing Eastern Shore Potatoes and What Farmers Suggest for Better Marketing," *PE*, December 15, 1928; Burton, "A

Concurrently, the seafood industry continued to suffer from overfishing and, increasingly, from pollution. The planting of barren bottom, so controversial at its inception in the 1890s, helped sustain the oyster industry in the face of the ruthless looting of the common grounds. The lumber industry also declined. The barrel houses closed as farmers and oyster dealers switched from barrels to less expensive burlap bags. Happily, the move to burlap combined with the rapid regeneration of stands of loblolly pine to prevent the oft-predicted deforestation of the peninsula.[88]

The declining economy forced people off the Eastern Shore. From a high of 53,000 in 1910, population of the two counties fell to its twentieth-century low of 43,500 in 1970. The once bustling landscape now was haunted by ghosts – empty stores, abandoned houses, and boats rotting in the marsh.

Conclusion:

At first glance the Eastern Shore of Virginia in the late nineteenth century might have appeared a small and isolated peninsula on the edge of a huge country, yet any Rand & McNally map of the Pennsylvania Railroad system gave clues to a different story. The most remote farm on the Eastern Shore was intimately connected to a vast economic and social web that extended well beyond the borders of the United States. Agents of the Eastern Shore Produce Exchange marketed potatoes grown near Eastville to buyers in Boston, Cleveland, Toronto, and Havana. Farmers at Makemie Park purchased at neighborhood general stores beef slaughtered in Chicago. Ventilated cars carried Parksley strawberries to Pittsburgh and

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Review of the Potato Industry of the Eastern Shore of Virginia," Chicago *Potato World* in *PE*, March 17, 1939; *PE*, June 23, 1928; *The Role of Agriculture-Agribusiness in the Economic Development of Virginia's Eastern Shore*, 6.

[88] Mears, "The Eastern Shore of Virginia in the Nineteenth and Twentieth Centuries," II, 582-583; *PE*, August 11, 1928, February 2, 1929.

livestock cars brought in mules from St. Joseph, Missouri. Mine props shipped from Hallwood went to the coal fields of Pennsylvania and anthracite from Pennsylvania filled bins in Hallwood. Eastern Shore schooners carried white potatoes to New York in the summer and oysters to Baltimore in the winter. They returned with hardware founded in Bethlehem, grain grown in Nebraska, or shotguns manufactured in Ithaca.

Along with these changes came a form of modern confidence, a supreme conviction that the command of technology and the market gave these people unstoppable advantages. So it was that the general manager of the Eastern Shore Produce Exchange boasted that the little town of Olney had just as much advantage as Baltimore or even New York in the market.

Yet, much remained beyond the control of locals and, even, the Pennsylvania Railroad. Information flow and demographic patterns only rendered these interconnections more complex and contingent. A wave of immigrants in Boston, fresh orders for the steel mills of the Mahoning Valley, or a spring drought in Florida might mean high prices for Eastern Shore potatoes while a bumper potato crop in the Kaw Valley, a textile strike in New York City, or floods on the Mississippi might depress the market. People working for the railroad or seafood dealers or agricultural commission houses continuously moved on and off the peninsula. Middle class vacationers stopped at barrier island hotels or at bayside boarding houses. Wealthier visitors relaxed at shooting lodges or purchased second homes along the creeks. Other people settled permanently, especially in the railroad towns and seaside fishing villages.

These residents participated in a great compression of space and time on their landscape. The federal government, private capital, and huge corporations aided and abetted this process. The changes in the landscape were as rapid as they were far-reaching. In little more than a decade coastal surveys, lighthouses, life-saving stations, railroads, mail routes, roads, and post offices punctuated the Shore and coursed with the information and products of distant markets. Remarkably, some farmers on the Eastern Shore combined in the Eastern Shore Produce Exchange to harness these dynamic effects, however temporarily. Although divided by racial exclusion, Eastern Shore farmers managed to vault their counties into the top rank of agricultural wealth in the nation. Their agricultural technologies caused unanticipated run-off and changed the nutrient balances in the ecosystem. Benthic anoxia set in, itself a product of recursive changes in land use that the railroads made possible and profitable. At the same time, extractive industries, such as oystering and market hunting, opened in unprecedented ways with the confluence of technologies, markets, and natural systems. These boomed and collapsed in overharvesting and exploitation, in a chaotic market and against natural obstacles.

This mobility, this interconnection with the modern world, even on such a remote place as the Eastern Shore of Virginia in the American South, came in complex layers upon the local landscape. No matter how much nostalgia Thomas Dixon might cherish for an Eastern Shore cut off from the modern world of railroads, mail, and its attendant business, the place was abuzz from its dark marshes to its bright fields and new towns.

Appendix F. Nandua Core Isotope Results

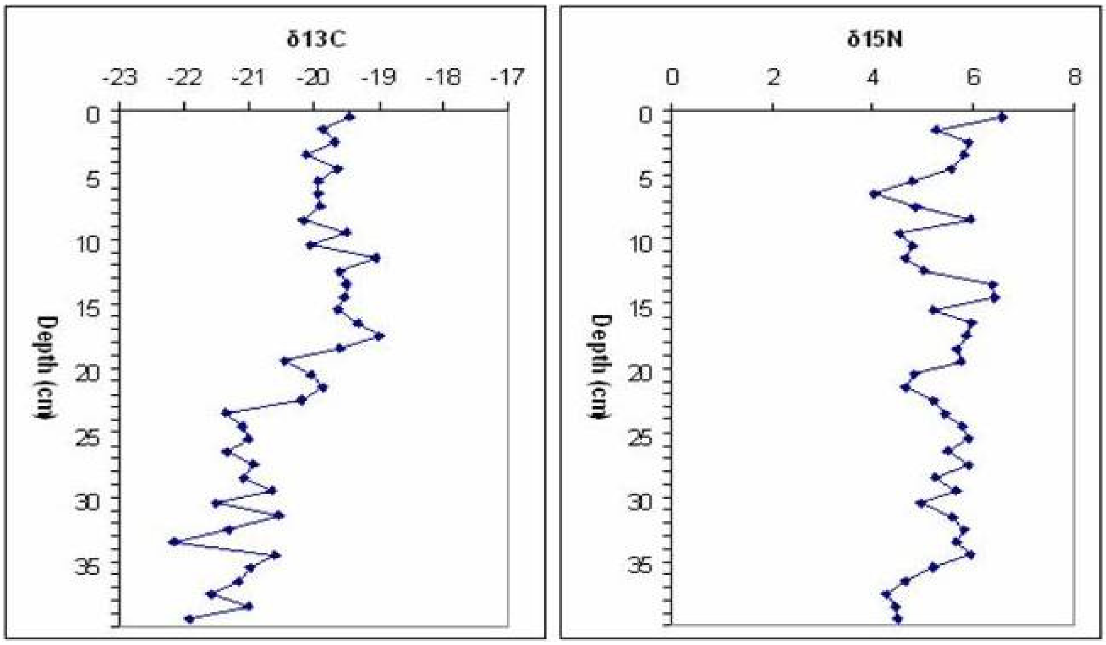
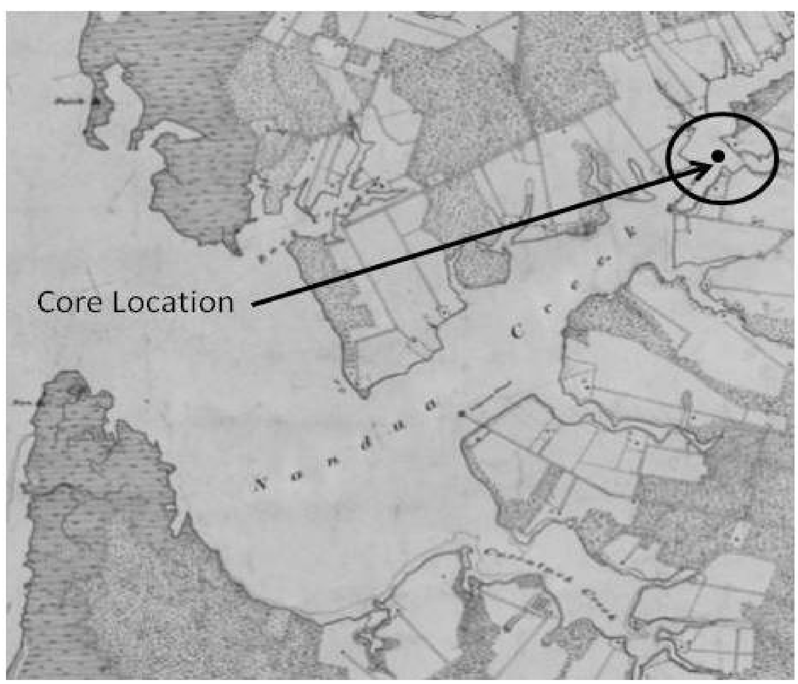


Figure F1. Carbon and nitrogen isotope data from a sediment core retrieved from Nandua Creek, a bayside tidal creek in southern Accomack County at latitude 37° 38’ 04 N and longitude 075° 49’ 58 W.

Figure F2. A sediment core was retrieved for carbon and nitrogen isotope analysis from Nandua Creek, a bayside tidal creek in southern Accomack County at latitude 37° 38’ 04 N and longitude 075° 49’ 58 W. Image from the U.S. Department of Commerce and Labor (1903) Coast and Geodetic Survey: Eastern Shore of the Chesapeake Bay (Craddock Creek to the Chesconessex), Plane Table Survey Register No. 2654.



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