Projecting agroforestry adoption and agroforestry water quality trading in the headwaters of the Chesapeake Bay, Virginia, USA

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ABSTRACT

Agricultural nonpoint source nutrient pollution is the leading cause of water quality impairment in the Chesapeake Bay. Agroforestry, the integration of trees with crops or livestock production, or both, achieves production and conservation objectives on a single plot of land. Agroforestry is recognized by the Chesapeake Bay Program's strategy as a means of reducing nonpoint source pollution to improve water quality in the Bay. Despite this, agroforestry adoption remains limited and agroforestry is not recognized in Virginia's water quality trading program. To understand the potential of agroforestry nutrient credit trading, I studied the prospects of agroforestry from both a social and biophysical perspective. First, I surveyed 1,436 randomly selected landowners in four 5^{th} level watersheds of the Chesapeake Bay in Virginia for a mixed-methods analysis of agroforestry adoption interest. Second, I used the Chesapeake Bay Assessment Scenario Tool to analyze the water quality implications of intermediate forest conversion scenarios on four initial agricultural land uses on respondent properties. From these studies, I recommend landowner characteristics, concerns, and objectives concerning agroforestry need to shape research and outreach messaging. Furthermore, agroforestry practices has potential to significantly reduce nonpoint source nutrient pollution in a manner that preserves agricultural production, but the terrestrial nutrient dynamics of agroforestry

will need to be better captured in modeling to aid in the design of these systems and to generate adequate and fair crediting standards.

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GENERAL AUDIENCE ABSTRACT

Pollution from farming is one of the largest threats to the health of the Chesapeake Bay. Retiring farmland is one method of reducing pollution. Water quality trading is a new strategy to encourage farmers to retire farmland. As part of this strategy, regulated polluters, such as a property developer, can offset their pollution by paying farmers to retire farmland and plant trees. Agroforestry practices involve the production of trees with crops or livestock on the same piece of land. These integrated systems could reduce pollution to the Bay while allowing farmers to continue farming, but few farmers have been willing to adopt these practices. Additionally, although agroforestry is recognized as part of a larger strategy to clean up the Bay, currently it is not recognized by Virginia's water quality trading program. To understand how agroforestry and water quality trading could help restore the bay, we asked farmers about their interest in agroforestry and used a computer program to estimate how increasing tree coverage on farms could reduce pollution to the Bay. We found that agroforestry could reduce a significant amount of pollution, while allowing farmers to continue farming to some degree. Though, knowledge of how agroforestry reduces pollution and technology that can assist in the design of these systems will need to advance for two reason. First, technology based on a better understanding of how agroforestry reduces pollution will allow us to properly

credit farmers for adopting agroforestry. Second, it will assist in designing these systems. Outreach, research, and development of agroforestry should be informed by landowner perceptions, concerns, and objectives.

Dedication

To my stepfather Stephen G. Thompson, may he rest in peace.

To the future of the human species and the hopes we decide not drowning or cooking in our own filth is in our best financial interests in time to do something about it.

To Vancomycin, Zosyn, Linezolid, and the hopes the American healthcare system evolves past its reliance on financial extortion of the unwell and into a form that is incentivized to manage Methicillin-resistant Staphylococcus aureus and our emerging collective challenges.

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Attribution

The research behind two of my chapters presented as part of this thesis was aided by several colleagues.

Chapter 2:

Katie Trozzo and Paxton Ramsdell designed and executed the mail survey and transcribed the resultant data.

Chapter 3:

Benjamin Addlestone defined respondent properties, developed forest coverage scenarios, and ran BayFAST analysis which produced raw nutrient outputs in excel file format.

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1.1 Introduction

Nonpoint source nutrient pollution from agriculture is the leading cause of surface water impairment in the United States (US) (Carpenter et al., 1998; U.S.E.P.A., 2018). Nonpoint source nutrient delivery to surface water is reduced on agricultural land by reducing nutrient inputs and inhibiting nutrient transportation (Carpenter et al., 1998; Dodd & Sharpley, 2016; Sharpley et al., 2013). This can be accomplished a number of ways through land retirement along streams, applying the optimal amount of fertilizer at the optimal time for crop uptake or the use of cover crops to name a few (Carpenter et al., 1998; Sharpley et al., 2006). These methods of reducing nonpoint source pollution are all examples of agricultural best management practices (BMPs), which are practices, procedures, or design features that prevent and/or mitigate the outflow of water pollutants from an operation (Sharpley et al., 2006). Implementation of BMPs for nonpoint source reductions are not compulsory in the US; rather, farmers may choose to implement BMPs voluntarily (Garnache, Swinton, Herriges, Lupi, & Stevenson, 2016; Reimer, Denny, & Stuart, 2018). Despite the availability of funds through programs such as the Conservation Reserve Program (CRP) and Environmental Quality Incentive Program (EQIP), adoption of pollutant abatement practices and the resultant beneficial water quality effects have remained limited (Garnache et al., 2016; Nowak, Bowen, & Cabot, 2006; Reimer et al., 2018).

Water quality trading is an emerging strategy for pollutant control that holds the promise of achieving water quality targets at least cost cases (Fang, Easter, & Brezonik, 2007; Garnache et al., 2016; Jones, Branosky, Selman, & Perez, 2010; McConnell & Hanson, 2008). Water quality trading allows polluters with high on-site water quality abatement costs to purchase abatement credits from other sources with lower abatement costs within a defined area in order to meet regulatory standards. E.g., this allows point sources, such as industrial plants, to purchase credits from nonpoint sources, such as agricultural operations. Agricultural producers generate credits for sale by implementing BMPs and/or through land conversion.

One form of land conversion that has the potential to reduce nonpoint source pollution is the conversion of land from conventional agriculture systems to agroforestry systems that integrate trees with livestock and/or crop production (Jose, 2009; Udawatta, Garrett, & Kallenbach, 2011). In fact, agroforestry has been recognized as part of the strategy to ameliorate water quality in the Chesapeake Bay (Claggett & Mawhorter, 2012). Agroforestry can help farmers both diversify, by introducing new production opportunities, and support existing agricultural production by modulating microclimatic factors (Gold & Garrett, 2009; Jose, 2009; Quinkenstein et al., 2009). By adding woody perennial cover to agricultural systems, agroforestry practices reduce nonpoint source pollution comparable to, or in some cases greater than pure forest or herbaceous cover in both upland and riparian contexts (Bambo, Nowak, Blount, Long, & Osiecka, 2009; Boyer & Neel, 2010; Dosskey, Hoagland, & Brandle, 2007; Narain, Singh, Sindhwal, & Joshie, 1997; Udawatta et al., 2011; Wei, Zhang, & Wang, 2007). Strategic agroforestry designs could allow farmers to balance both conservation and production objectives. The ability to balance multiple landowner objectives could be a leverage point for greater adoption of BMPs and attainment of desired water quality outcomes (Klapproth & Johnson, 2001; Robles-Diaz-de-Leon & Kangas, 1998).

Despite the potential for agroforestry systems to simultaneously support water quality and producer profit objectives, current water quality crediting policies often fail to incentivize their adoption. For example, in Virginia's water quality trading programs, land conversion crediting requires that conversion to forest must be 400 trees per acre with a deed restriction on future agricultural use (DEQ, 2008). This density of planting is well beyond that of typical alley cropping and silvopastoral systems, which require intermediate tree densities with sufficient space between trees for optimum ground-level crop or forage growth (Buergler et al., 2005; Quinkenstein et al., 2009). Moreover, the deed restriction on agricultural use prevents the integration of trees with livestock and crop systems. The structure of water quality crediting programs therefore creates a disincentive to adopt agroforestry systems.

In this thesis, I explore the potential of agroforestry and nutrient credit trading to provide a two-fold incentive to farmers for managing water quality on working-lands in the headwaters of the Chesapeake Bay. First, I analyze farmer interest in adopting agroforestry. Landowner agroforestry interest is assessed regarding agroforestry interest, demographic variables, and land management priorities. I use landowner reactions to the survey to pin-point landowner perceptions of limitations and elucidate potential leverage points for agroforestry outreach in the headwaters of the Chesapeake Bay. Second, I explore what the potential water quality impacts would be through agroforestry conversion. I explore the relationship between additional tree coverage scenarios and estimated nutrient reductions on four agricultural land uses in terms of relative pollutant removal efficiency as compared to full forest conversion. I compare the estimated nutrient reductions impacts of several forest conversion intensities on respondent properties to current and historic trading program standards for larger tributary and watershed areas.

1.2. Objectives

In this analysis, I explore how agroforestry and water quality trading could be combined and optimized to benefit both water quality management and agricultural livelihoods. To achieve this goal, I argue it is imperative to understand what drives agroforestry adoption interest, predict the potential water quality benefits of agroforestry conversion compared to current water quality trading standards, and explore how to best optimize water quality trading guidelines for agroforestry compatibility. Specifically, I define and address two primary research questions:

(1) How do landowner sociodemographic variables, land management objectives, and perceived obstacles or limitations influence adoption interest in the headwaters of the Chesapeake Bay in Virginia?

(2) How can emerging programs, such as water quality trading, be optimized to target farmland with disproportionate nonpoint source pollution and catalyze agroforestry adoption?

1.3. Overview of approach

To address my first research question, I administered a survey to landowners in the headwaters of the Chesapeake Bay, Virginia. The survey instrument addressed demographics, land-management priorities, and landowner interest in adopting three agroforestry practices. I use survey responses to test hypotheses that agroforestry interest varies by demographics and land-management objectives. I present Analysis of Variance (ANOVA) of agroforestry interest by respondent demographics and land management priorities. Open responses are open and axial coded with frequencies of underlying themes presented along with examples of representative responses (Glaser, 1967; Strauss & Corbin, 1990). I interpret these data with language from the Diffusion of Innovations framework (Rogers, 2003) and suggest further directions to actualize agroforestry adoption in the region.

To address our second question, respondents' properties were randomly sampled in two watersheds, and intermediate forest conversion scenarios based on extant agroforestry research plots were modeled on four assumed land uses on these properties in Chesapeake Bay Facility Assessment Scenario Tool (BayFAST). BayFAST was used to estimate nitrogen, phosphorus, and sediment loads of these scenarios to the nearest third-order stream and to the Chesapeake Bay. I discuss this output in terms of pollutant reduction efficiencies with increasing tree coverage and compare mean nutrient outputs of each scenario for the two watersheds with applicable historic and contemporary water quality trading program crediting standards. I conclude by discussing the implications of our analysis for agroforestry nutrient credit trading and suggest next steps in optimizing water quality trading to include agroforestry and engage farmers on working lands.

1.4. Background

In this section, I review the background literature relevant to the two research questions addressed in the thesis. I first discuss explore eutrophication and the effects of nutrient pollution (1.4.1). I then look at nutrient pollution from agricultural sources, regulation, and management concerns (1.4.2) and introduce the opportunities and limitations of water quality trading (1.4.3). From here, I introduce riparian buffers (1.4.4) to show how agroforestry builds on and differs from conventional practices and contemporary management of agricultural nonpoint source nutrient pollution (1.4.5).

1.4.1. Eutrophication

Cultural eutrophication is an ecological process triggered by excessive nutrient pollution of waterbodies from human activity. Nutrient enrichment of aquatic environments accelerates primary production leading to a corresponding boost in microbial aerobic decomposition that depletes dissolved oxygen and causes shifts in species composition and die-offs of aquatic animals (Carpenter et al., 1998). Anoxic conditions may lead to the release of methane, a potent greenhouse gas, from aquatic sediment (Beaulieu, DelSontro, & Downing, 2019; Gelesh, Marshall, Boicourt, & Lapham, 2016). Therefore, managing nutrient pollution to surface waters is not only essential for water quality, biodiversity, and local economies, but is also inextricably linked to other environmental challenges such as atmospheric greenhouse gas emissions and climate change (Beaulieu et al., 2019).

The main driver of eutrophication and thus the leverage point for managing eutrophication in a given area is the target waterbody's limiting nutrient. The concept of a limiting nutrient derives from the Law of the Minimum, developed by Carl Sprengel in the mid-1800s and later publicized by Justus von Liebig. The Law of the minimum states that plant growth is not dictated by the total nutrients available, but by the availability of the nutrient which is most scarce (van der Ploeg, Böhm, & Kirkham, 1999). The theory of mineral nutrition of plants and the law of the minimum was extended to aquatic algae with work of Alfred Redfield who studied the chemical content of marine phytoplankton and found a relatively consistent atomic ratio between carbon, nitrogen, and phosphorus of 106:16:1 (Redfield, 1934). The actual ratio may vary by factors including but not limited to phytoplankton taxa and location (Martiny, Vrugt, & Lomas, 2014). Nonetheless, the Redfield ratio is a commonly used benchmark to determine the limiting nutrient of algal growth in an aquatic system. When the ratio of 16:1 N:P is exceeded, a water body is considered phosphorus limited, and vice versa. Phosphorus tends to be the limiting nutrient in freshwater systems, while nitrogen eclipses phosphorus in importance in coastal systems (Carpenter et al., 1998; Schindler, 1974, 2006; Smith, 2006; Smith & Schindler, 2009).

In an estuarine system, the limiting nutrient changes from phosphorus to nitrogen as water moves from the headwaters to the ocean along the salinity gradient (Hartzell & Jordan, 2010; Jordan, Cornwell, Boynton, & Anderson, 2008). Although nitrogen is the primary management concern for estuarine systems, nitrogen influxes can be so high as to cause a seasonal phosphorus limitation, as seen in the Chesapeake Bay, which has been associated temporally in this waterbody with atmospheric methane release (Beaulieu et al., 2019; Fisher, Peele, Ammerman, & Harding, 1992). Therefore, it is important to manage both nitrogen and phosphorus in concert to meet water quality and other environmental objectives in both fresh and saline portions of the system (Paerl, 2009).

1.4.2. Agricultural non-point source nutrient pollution

The agricultural sector has been identified as the leading contributor of nonpoint source nutrient pollution to most surface waterbodies (Ator, Brakebill, & Blomquist, 2011; Carpenter et al., 1998; Oelsner & Stets, 2019; U.S.E.P.A., 2018). Nonpoint source nutrient loading to surface waters can be reduced on agricultural land, with varying degrees of effectiveness, through land-use change, the implementation of conservation practices, and changes in management regimes that reduce or alter nutrient inputs or transport of nutrients as runoff (Carpenter et al., 1998; Dodd et al., 2016).

Nonpoint sources, where pollutants flow from an indiscrete area, in contrast to point-sources, where pollutants flow from a discrete area such as an effluent pipe, are not directly regulated under the Clean Water Act (CWA) (Carpenter et al., 1998; Oelsner et al., 2019). However, reductions from agricultural non-point sources may be obtained at much lower costs than from other nonpoint sources or point sources in many cases (Fang et al., 2007; Garnache et al., 2016; Jones et al., 2010; McConnell et al., 2008). Implementation of BMPs for nonpoint source pollutant reductions are generally not compulsory in the U.S., rather farmers may implement BMPs voluntarily (Garnache et al., 2016; Laitos & Ruckriegle, 2001; Oelsner et al., 2019; Reimer et al., 2018). Voluntary pollution reduction programs include the Conservation Reserve Program, which offers farmers direct payments for periodic land retirement, the Environmental Quality Incentives Program, which offers cost-sharing for implementation of BMPs on working-lands, and other efforts funded under section 319 of the CWA. Despite large annual budgets for these programs, they have yielded limited success in reducing nutrient pollution from agricultural nonpoint sources across the landscape (Dodd et al., 2016; Garnache et al., 2016; Reimer et al., 2018; Sharpley, Kleinman, Jordan, Bergström, & Allen, 2009).

The mixed success of strategies designed to address agricultural nonpoint source pollution gave rise to the concept of watershed disproportionality, which recognizes that not all landowner properties and behaviors are equal in regards to potential nonpoint source pollutant loads (Nowak et al., 2006). For example, land with small headwater streams exert a disproportionate impact on water quality in a watershed (Bentrup, 2008; Schultz, Isenhart, Colletti, Simpkins, & Udawatta, 2009; Ward & Jackson, 2007). However, since these streams are small and may be ephemeral or seasonal, farmers in the headwaters are less likely than those along larger stream channels to manage their land for water quality (Armstrong, Stedman, Bishop, & Sullivan, 2012). Thus, given the mixed success of existing water quality programs and in order to maximize the effectiveness of agricultural nonpoint source pollution, interventions should be strategically targeted and aggregated around areas of highest potential pollutant contribution (Diebel, Maxted, Nowak, & Vander Zanden, 2008). However, the question of how best to engage owners of working lands must be considered if emerging water quality management strategies such as water quality trading are to effectively ameliorate nutrient concerns and support farmer livelihoods.

1.4.3. Water quality trading programs

Environmental quality trading emerged as an idea in 1968 and foundations were laid as the U.S. Environmental Protection Agency (EPA) and industry sought to reduce costs of air pollution abatement (Dales, 2002; Liroff, 1988; Shortle, 2013). The EPA instituted the “Bubble Policy” which switched regulatory priorities from individual emission points, such as individual smokestacks, to a theoretical bubble around a facility (U.S.E.P.A., 1979). The idea behind this arrangement was that regulating the emissions of a bubble instead of an individual emissions point would allow reductions to be achieved at lower costs elsewhere in the operation of the facility (U.S.E.P.A., 1979). Facility managers could make “controlled trades” of emission reductions from other parts of an operation to offset emissions from monitored points (Liroff, 1988; U.S.E.P.A., 1979). This concept was gradually expanded into authorizing trading between facilities and was eventually applied to water quality.

Water quality trading is an emerging strategy to reduce nutrient pollution. The first suggestion water quality trading emerged in 1968 (Dales, 2002; Shortle, 2013), but states did not begin constructing these programs until the mid-1990s in an effort to meet total max daily loads (TMDL) (Shortle, 2013). The EPA started releasing guidance in the late 1990s and continues to do so (Shortle, 2013; U.S.E.P.A., 2019; Woodward & Kaiser, 2002). In these schemes, a regulated point source with high abatement costs may purchase credits generated elsewhere in the watershed where abatement costs are lower (e.g. from nonpoint source agricultural producers) to achieve regulatory compliance (Shortle, 2013; U.S.E.P.A., 2019; Woodward et al., 2002). Government officials often serve as program referees, generating crediting rates, and tracking credit generation and exchanges though some tasks may be relegated to other parties (Woodward et al., 2002). Nonpoint source credits are generated by landowners when they install certain BMPs or convert or retire nutrient intensive agricultural land (DEQ, 2008). Crediting rates are generally estimated with terrestrial nutrient modeling for a unit of area relevant to water resource management such as a tributary basin or a variety of smaller watersheds (U.S.E.P.A., 2019). Direct regulation of agricultural nonpoint sources may be logistically or cost prohibitive so uncertainty is often accounted for in trading ratios where a point source is required to purchase a higher number of agricultural nonpoint source credit units than the amount of pollutant units they are required to reduce (Shortle, 2013).

Proponents of water quality trading, and the U.S.E.P.A. state that trading will provide new sources of revenue for credit generators and substantially reduce pollutant reduction costs (Jones et al., 2010; U.S.E.P.A., 2019). Opponents of water quality trading argue that criticisms of the EPA's bubble policy underlying market-based pollutant reduction schemes apply in that water quality trading may decrease pollution overall for a large area, often referred to as the "bubble," but that discrete point source hotspots could arise as more credits are purchased, concentrating pollutant loads in space and creating localized environmental justice issues (Corrigan, 2015). Opponents also argue that due to regulatory conditions on both the supply and demand side, sufficient demand for pollutant reduction credits, particularly from working lands, is unlikely to materialize (Breetz et al., 2004; Stephenson & Shabman, 2017). Furthermore, some suggest that agricultural landowners require a premium or enhanced incentives to overcome reluctance in entering a contract with a regulated point source (Breetz, Fisher-Vanden, Jacobs, & Schary, 2005; King & Kuch, 2003; Stephenson et al., 2017).

1.4.4. Riparian buffers

The riparian buffer is a common agricultural BMP for water quality management. A riparian buffer, which is a swath of land taken out of production along a watercourse, can reduce nonpoint source nutrient pollution to a waterbody or watercourse (Castelle, Johnson, & Conolly, 1994; Klapproth et al., 2001; Mayer, Reynolds, McCutchen, & Canfield, 2007; Peterjohn & Correll, 1984; Pinho et al., 2008). Riparian buffers can be fallowed or planted with desired species. Riparian buffers increase infiltration, slow or stop pollutant transport through plant and microbial metabolism or through acting as a physical barrier, decrease erosion and flood damage by stabilizing bank soil, while yielding other environmental benefits such as providing habitat for wildlife and sequestering atmospheric carbon (Bentrup, 2008; Lowrance et al., 1997; Mayer et al., 2007; Palone & Todd, 1997).

Guidance or requirements for the width of fixed-width buffers are somewhat arbitrary and may be a product of political acceptability rather than pollutant reduction efficacy (Castelle et al., 1994). This is pertinent as farmers may be reluctant to take productive land out of cultivation (Castelle et al., 1994; Robles-Diaz-de-Leon et al., 1998; Trozzo, Munsell, & Chamberlain, 2014; Trozzo, Munsell, Chamberlain, & Aust, 2014). Although buffer width is an important consideration in nonpoint source pollution abatement, soil type, subsurface hydrology, and biogeochemistry may cause significant variation (Mayer et al., 2007). A more efficient approach to riparian buffer design is to use high resolution, site specific data to optimize pollutant reduction efficiency, while minimizing the area a farmer must take out of production (Dosskey, Eisenhauer, & Helmers, 2005; Dosskey et al., 2015).

The pollutant abatement efficacy of riparian buffers may decrease over time as stored pollutants, particularly phosphorus, build up to high levels in the buffer area and become a legacy pollutant source (Dodd et al., 2016). Therefore, a diversified approach incorporating upland practices is necessary to maintain pollutant reduction efficacy into the future (Dodd et al., 2016; Mayer et al., 2007). Agroforestry presents an opportunity that may entice farmers into planting trees in riparian and upland areas by eroding the perception of a zero-sum game between conservation and production objectives.

1.4.5. Agroforestry

Agroforestry is the integration of commercially relevant woody perennial crops that yield timber and/or non-timber forest products (NTFPs), including fruits, nuts, florals, saps, syrups, oils, resins, herbal medicinal products, forage, and fodder in concert with crops and/or livestock in agricultural systems (Gold et al., 2009). The design of agroforestry systems can and should optimize beneficial interactions among components of the system and balance productive and environmental functions (Gold et al., 2009). Some common agroforestry systems include multifunctional riparian buffers, and, in the uplands: silvopasture and alley-cropping (Gold et al., 2009; Schultz et al., 2009).

Multifunctional riparian buffers differ in design from conventional riparian buffers by intentionally incorporating less intensively managed woody perennial crops within the riparian zone, which preserves a degree of potential revenue production (Barbieri & Valdivia, 2010; Robles-Diaz-de-Leon et al., 1998; Schultz et al., 2009; Trozzo, Munsell, & Chamberlain, 2014). As described previously, riparian practices are best utilized in combination with upland practices (Mayer et al., 2007; Schultz et al., 2009). Upland practices can be conceptualized as an "upland buffer," that is, trees can be planted on or slightly off contour in the uplands to enhance infiltration, reduce runoff, and combat nonpoint source pollution (Gold et al., 2009; Schultz et al., 2009). Upland agroforestry practices include silvopasture and alley cropping. Silvopasture is the combination of crop trees, livestock, and conventional forage species on the same plot of land. Alley cropping is the combination of trees and crops. Both of these systems can yield production and conservation benefits.

Though farmers may be hesitant to incorporate trees in pastures, the incorporation of trees in pastures can add valuable livestock benefits (Orefice & Carroll, 2017; Pent, Greiner, Munsell, Tracy, & Fike, 2019a, 2019b). As shade is more evenly dispersed in silvopastures compared to open pastures, livestock may spread out more, and be protected from heat stress due to a milder microclimate than in traditional pasture systems (Karki & Goodman, 2010, 2015). Competition for light can be ameliorated by choosing tree and forage species with complementary phenology and physiology. For example, cool season grasses that utilize the C3 photosynthetic pathway reach light saturation at 50% of full sun (Gardner, Pearce, & Mitchell, 2017). This enables these grasses to withstand substantial shading without impacting overall productivity.

Cool season grasses, when coupled with "warm season trees," (referring to their phenology and structure rather than their metabolism as trees all utilize the C3 photosynthetic pathway) that leaf out late, senesce early, and possess compound leaf morphology that provides diffuse shade can maximize overall productivity in a silvopasture system (Gardner et al., 2017; Jose, Walter, & Mohan Kumar, 2019; Pent & Fike, 2019; Sharrow, Brauer, & Clason, 2009). Furthermore, trees can yield additional forage and browse (Sharrow et al., 2009). For example, in one study with sheep on silvopastures, forage quantity was equal between open pastures and silvopastures with honey locust (*Gleditsia triacanthos*), while honey locust pods provided a supplemental feed source and increased daily weight gain over the open pasture treatment (Pent & Fike, 2019). Silvopasture also offers several environmental benefits such as carbon sequestration, soil conservation, decreased nitrate leeching, wildlife habitat, and aesthetic value (Bambo et al., 2009; Boyer et al., 2010; Shrestha & Alavalapati, 2004)

Alley cropping is the integration of widely spaced rows of crop trees in crop and hay fields. In alley cropping, hedgerows of woody perennials offer similar benefits to the crop layer as silvopasture systems. For example, extremes of evapotranspiration stress (i.e., light, heat, and soil moisture loss) are moderated by the addition of shade and wind protection (Kort, 1988; Nuberg, 1998; Quinkenstein et al., 2009). Alley cropping could be particularly useful for dry, unfertile lands such as post-mining sites with the use of nitrogen fixing trees such as Black Locust (*Robinia pseudoacacia*) (Quinkenstein et al., 2009; Wöllecke, Grünewald, Schneider, & Hüttl, 2005). Additionally, alley cropping can be designed to reduce soil erosion and runoff by planting woody perennial rows on or slightly off contour on sloping land (Sun, Tang, & Xie, 2008) and more evenly distribute snow cover and resultant infiltration (Quinkenstein et al., 2009; Scholten, 1988),

In contrast and in addition to conventional agriculture and agricultural BMPs, agroforestry stresses the importance of productive perennial cover to the agricultural system that yields on- and off-farm environmental improvements and economically relevant commodities (Robles-Diaz-de-Leon et al., 1998; Schultz et al., 2015; Smith, Pearce, & Wolfe, 2013). Although often more complex than conventional agricultural systems, these systems incorporate diversification and flexibility and can be designed to balance multiple landowner objectives and public goods on the same plot of land which could increase adoption interest (Klapproth et al., 2001; Robles-Diaz-de-Leon et al., 1998). In contrast to a traditional or simplified model of conservation where there is an apparent zero sum game between conservation and production, agroforestry could allow farmers to yield environmental benefits such as water pollution abatement while maintaining commodity production at intermediate levels of tree coverage on the same plot of land (Jose, 2009; Smith et al., 2013). Furthermore, practitioners confirm the environmental effects of agroforestry contributed to farm performance (Munsell et al., 2018). Despite the documentation of beneficial outcomes associated with agroforestry systems in the literature, adoption remains low in many parts of the world and traditional agroforestry systems have been disappearing with the intensification of agricultural production (Borremans et al., 2016; Nerlich, Graeff-Hönninger, & Claupein, 2013). How farmers rate potential benefits and limitations of agroforestry varies by location and context (Graves et al., 2009). Thus, it is imperative to discuss how adoption is conceptualized and which associations and limitations to adoption are observed in the literature.

1.5. Literature review

In this section, I review the agroforestry and agricultural conservation practice adoption literature. Common conceptual frameworks are discussed and findings from several studies are presented on variables that associate with adoption interest and potential limitations to adoption. I conclude with the implications of the adoption literature for agroforestry nutrient credit trading.

1.5.1 Diffusion of innovations

Various frameworks have been developed to predict behavior and technology adoption. For the purposes of this study, I will assess attitudes prior to the decision to adopt using Rogers' (2003) Innovation-Decision (ID) continuum (Figure 1.1). Rogers (2003) sought to understand how innovations (in this case a series of agricultural practices) are communicated among a social system over time though "prior conditions" and five communication channels: knowledge, persuasion, decision, implementation, and confirmation. "Prior conditions" refer to social norms, the practice or technology used prior, felt needs/problems, and degree of novelty associated with an innovation perceived by the potential adopter.

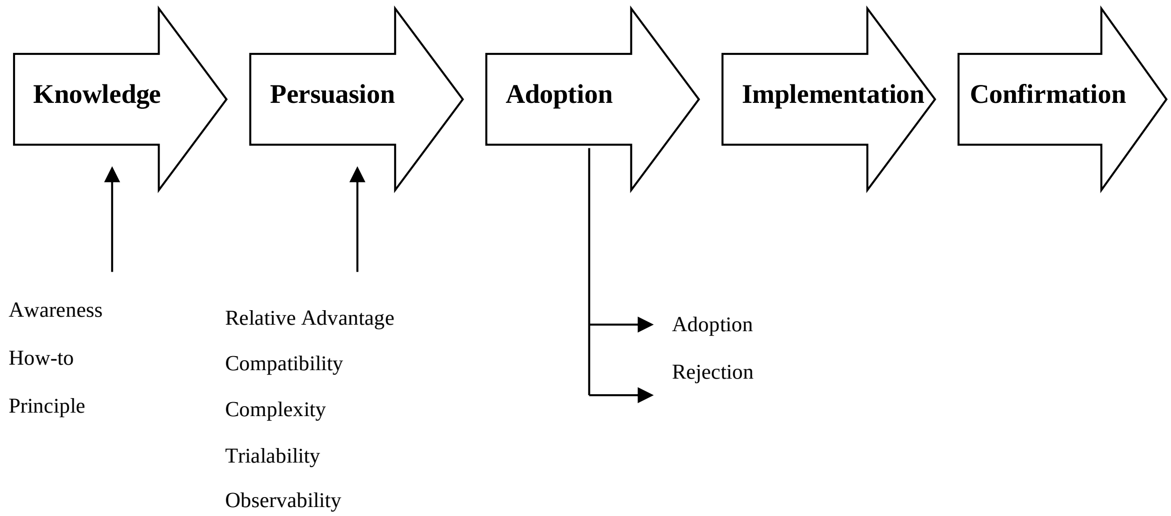


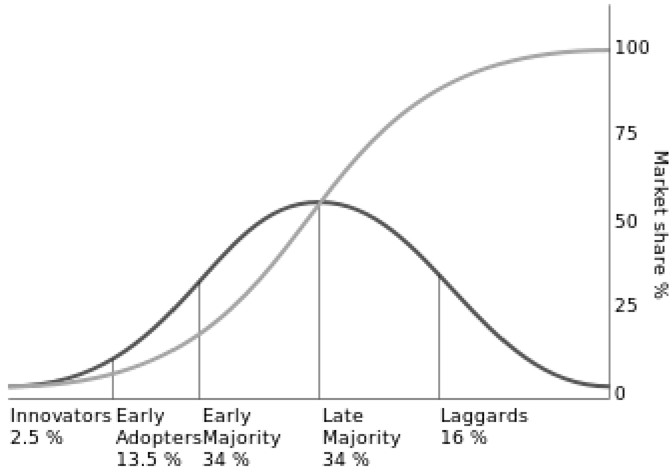
Figure 1.1: Diagram of the Innovation-Decision continuum as presented in Rogers (2003)

Rogers (2003) defines the five communication channels as follows. Knowledge is influenced by characteristics of the potential adopter and may include socioeconomics, personality, attitudes, and communication behavior. There are three types of knowledge: awareness-knowledge, how-to-knowledge, and principle-knowledge. At this stage, a potential adopter is initially exposed to an innovation, and can be said to have awareness-knowledge, but may or may not seek more information. If more information is sought out by potential adopters, it is information on how to effectively utilize the innovation effectively or "how-to-knowledge." Finally, principle-knowledge is that of how and why an innovation is effective. Though not seen as a necessity for initial adoption of an innovation, this factor could play a role in adaptation and retention of an innovation and in communication between adopters (Rogers, 2003; Sahin, 2006).

Persuasion concerns the characteristics of an innovation as perceived by the potential adopter. This is further subdivided into the concepts of "relative advantage," "compatibility," "complexity," "trialability," and "observability" (Rogers, 2003). Relative advantage refers to how a potential adopter perceives, as a matter of degree, the benefits of the innovation over that of a previous innovation. Compatibility refers to how a potential adopter perceives, as a matter of degree, the extent to which an innovation is consistent with the norms of the social system, perceived needs, and experiences. Complexity refers to a potential adopter's understanding of an innovation is sufficient to implement it successfully. Trialability refers to the degree that a potential adopter is able to implement a practice in a partial or experimental manner – the degree to which one can "give it a try". Observability is the degree to which a potential adopter may be able to witness the use of a practice through neighbors or demonstrations.

Rogers emphasizes the value of peer communication opportunities with the spectrum of persuasion. This leads to a decision to adopt, followed by implementation. Confirmation captures continuation or discontinuation of use of the innovation at future decision points. Furthermore, Rogers proposes that the relative temporal distribution of adopters varies by their characteristics, particular in regard to risk perception. Adopters are segmented into five typologies from early to late adoption: "innovators," "early adopters," "early majority," "late majority," and "laggards' (Rogers, 2003) (Figure 1.2).

Figure 1.2: frequency distribution (dark grey) of potential adopters with cumulative distribution shown in relation to percentage of market share (light gray) from Rogers (2003)

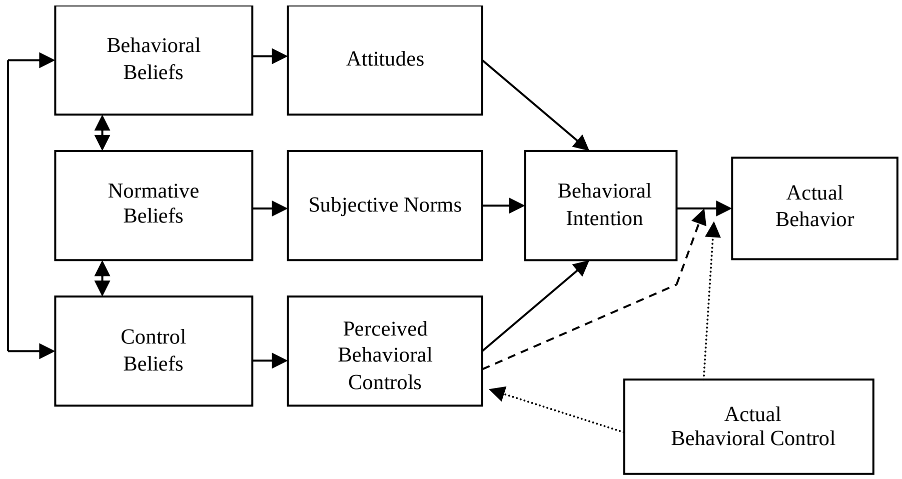


1.5.2. The Theory of Planned Behavior

The Theory of Planned Behavior (TPB) is another framework often used to study adoption behaviors particularly in the context of behavioral economics (Ajzen, 1991; Fishbein & Ajzen, 2009; Hansson, Ferguson, & Olofsson, 2012). The theory proposes that behavioral change is affected by three main constructs: social norms refer to conventional expectations or the influence of important others regarding a behavior; attitudes which are a culmination of objective knowledge, subjective perceptions, and abstract feelings about the behavior, and behavioral control which refers to one's feelings and predictions of self-efficacy regarding the successful implementation of a behavior (Figure 1.3) (Ajzen, 1991; Fishbein et al., 2009). Together these concepts are used to understand how a subject evaluates a behavior or technology comprehensively.

The TPB seeks to understand behavior while the ID continuums seeks to understand the adoption process holistically. Despite different scope of the two frameworks, there exists some overlap between the ID continuum and TPB in conservation practice adoption research. Both seek, at least in part, to understand how subjective perceptions of an innovation or behavior influences

Figure 1.3: Diagram of the Theory of Planned Behavior as from Ajzen (1991)



implementation of that innovation or behavior. As such, some authors generate novel conceptual frameworks informed by both TPB and ID continuum (Meijer, Catacutan, Ajayi, Sileshi, & Nieuwenhuis, 2015), others go on to posit overlap in the concepts of each framework for example, relating knowledge, perceptions, and attitudes to Roger's characteristics of an innovation (Borremans et al., 2016), while others explicitly relate characteristics of an innovation to specific concepts in the TPB (Reimer, Weinkauf, & Prokopy, 2012). Due to perceived overlap and the significance of both frameworks in the literature, they have often been used in tandem to inform study methodology, discuss, and interpret agricultural practice adoption as each offer insight into the adoption process (Adnan, Nordin, Bahruddin, & Tareq, 2019; Borremans et al., 2016; McGinty, Swisher, & Alavalapati, 2008; McGuire, Morton, & Cast, 2013; Meijer et al., 2015; Reimer et al., 2012; Thompson, Reimer, & Prokopy, 2015; Ulrich-Schad, García de Jalón, Babin, Pape, & Prokopy, 2017).

1.5.3. Agroforestry adoption

1.5.3.1. Demographics

Demographic characteristics of a farmer and their operation often are assessed to understand what drives adoption (or non-adoption) of agricultural innovations, though sociodemographic variables have been found to be unreliable determinants of adoption across contexts (Prokopy, Floress, Klotthor-Weinkauf, & Baumgart-Getz, 2008). Age appears to be associated positively with adoption of agroforestry in a review of studies sampled primarily from middle and low-income countries (Pattanayak, Evan Mercer, Sills, & Yang, 2003). However, younger farmers tended to adopt or have more interest in agroforestry and BMPs in studies from temperate, high-income countries (Baumgart-Getz, Prokopy, & Floress, 2012; Liu, Bruins, & Heberling, 2018; Strong & Jacobson, 2005; Trozzo, Munsell, & Chamberlain, 2014; Trozzo, Munsell, Chamberlain, et al., 2014; Valdivia & Poulos, 2009). Age and conservation practice adoption interest has significance in discussions of intergenerational land transfer and sustaining agricultural conservation practices into the future. In as much as intergenerational transfer may affect conservation practice adoption and maintenance into the future, no studies were found that assess the association of age in terms of generation on conservation practice adoption, though some assess intergenerational transfer as part of land tenure and succession (Parker, Moore, & Weaver, 2007).

In terms of gender, the review by Pattanayak et al. (2003) found that households with higher proportions of males were more likely to adopt agroforestry practices (2003). Studies find both positive (Druschke & Secchi, 2014; Ward, Bell, Parkhurst, Droppelmann, & Mapemba, 2016), negative (Tiwari, Sitaula, Nyborg, & S Paudel, 2008), and insignificant associations between being female and adoption or adoption interest (Liu et al., 2018; Matthews, M. Pease, Gordon, & A. Williams, 1993; McGinty et al., 2008). However, women appear to be more involved in components of agroforestry such as specialty crop production (Strong et al., 2005), women are more likely to acknowledge and to take action regarding environmental issues (Bord & O'Connor, 1997; Druschke et al., 2014; Goldsmith, Feygina, & Jost, 2013; McCright, 2010;

Semenza, Ploubidis, & George, 2011; World, 2009; Zelezny, Chua, & Aldrich, 2000), and women are a growing demographic as owners and decisionmakers on agricultural land in the U.S. (NASDA, 2019).

These factors suggest the increasing importance of studying potential gender differences in agroforestry and BMP adoption. The association between formal education (as opposed to practice-specific, extension, and environmental education) and adoption is unclear based on reviews and meta-analyses of the adoption literature (Baumgart-Getz et al., 2012; Gedikoglu & McCann, 2012; Liu et al., 2018; Pattanayak et al., 2003). The importance of specific education was evident in a post-adoption study of agroforestry adoption in which farmers reported their success was due in part to assistance with forest management (Munsell et al., 2018). Some authors theorize nonpositive associations between education and adoption or adoption interest are due to the higher opportunity cost of time and attention from the higher educated (Haghjou, Hayati, & Momeni Choleki, 2014; Pattanayak et al., 2003).

1.5.3.2. Resource endowments and finances

Resource endowments such as capital, income, percentage of income from farming, access to labor, gross farm sales, and relative farm size tend to have strong positive associations with adoption, suggesting the ability to absorb financial risk and economies of scale are important factors to consider when studying adoption (Baumgart-Getz et al., 2012; Liu et al., 2018; Pattanayak et al., 2003; Ulrich-Schad et al., 2017). Pattanayak et al. (2003) mentions two exceptions to the positive association between agroforestry adoption and income: small-holders with income that is primarily derived from farming may have more risk aversion when it comes to adopting agroforestry, and high-income households with a lower proportion of income from farming may have less interest in agroforestry. An exception to the association between farm size and BMP adoption comes from studies that found small-scale producers were more interested in improving the environment and less motivated by economic incentives (Liu et al., 2018; Perry-Hill & Prokopy, 2014; Ryan, L. Erickson, & De Young, 2003; Trozzo, Munsell, & Chamberlain, 2014; Trozzo, Munsell, Chamberlain, et al., 2014). Furthermore, some studies find no association between adoption and farm size (Ahnström et al., 2009; Liu et al., 2018) and one meta-analysis documented the heterogeneity in the relationships between adoption and farm-size variables (Baumgart-Getz et al., 2012).

1.5.3.3. Social norms and pressure

Social norms and pressures may positively or negatively mediate the adoption interest of agricultural innovations (Daxini, Ryan, Odonoghue, Barnes, & Buckley, 2019; Kurtz, 2000; Liu et al., 2018; McGuire et al., 2013; Montambault & Alavalapati, 2005; Rule, Flora, & Hodge, 2000; Sereke et al., 2016; Thompson et al., 2015; Wojtkowski, 1998). Fear of deleterious effects on a producer's reputation were found to be a significant barrier to the adoption of agroforestry practices in one study (Sereke et al., 2016). Social pressures and community may also increase adoption and long-term success of agricultural practices. For example, membership in a farmer or watershed group was found to be one of the largest significant drivers of practice adoption in a meta-analysis of the agricultural conservation practice adoption literature (Baumgart-Getz et al., 2012).

Farmers confirmed the role of an agroforestry group in contributing to their success (Munsell et al., 2018). Some suggest that early adopters are more motivated by financial incentives and regulations, while later adopters are more motivated by peers, neighbors, and early adopters (Nowak, 2009; Welch & Marc-Aurele, 2001). Having a neighbor, particularly a neighbor of high social standing, that adopts soil conservation BMPs is strongly associated with adoption in a number of studies (Liu et al., 2018; Turinawe, Mugisha, & Drake, 2015). Although there is a strong neighbor effect, one study found that farmers who perceive that implementation of a practice on their land will produce free benefits to their neighbor may be more hesitant to adopt (Wollni & Andersson, 2014).

Thompson et al. (2014) find that activation of a stewardship frame could be a key leverage point in BMP adoption. This finding is supported by the work of McGuire et al. (2013) who show that farmers who realized their pollution contribution took action to ensure what the authors define as a "good farmer" identity. When farmers with a greater "conservationist" orientation, defined as those who valued conservation objectives over profit, implemented practices to protect water quality, neighbors of a more "productivist" orientation, defined as those who valued profit over conservation objectives, were more likely to adopt BMPs (McGuire et al., 2013). Perhaps the most practical insights for entities interested in promoting agricultural innovations are that farmers discount information according to source and subpopulations of farmers may be more or less influenced by different sources of social pressure (Baumgart-Getz et al., 2012; Daxini et al., 2019; Genskow & Betz, 2012; Ulrich-Schad et al., 2017).

1.5.3.4. Environmental attitudes

Farmer environmental attitudes and awareness are correlates of BMP adoption attitudes in the literature. "Lifestyle farmers" or those of a more "ruralist" orientation with a lower percentage of income from farming, who tend to value conservation and lifestyle objectives over social, production, or financial incentives may have relatively higher adoption attitudes within a region or industry (Barbieri et al., 2010; Baumgart-Getz et al., 2012; Borremans et al., 2016; Liu et al., 2018; Perry-Hill et al., 2014; Prokopy et al., 2008; Ryan et al., 2003; Thompson et al., 2015;

Trozzo, Munsell, & Chamberlain, 2014). However, both Baumgart-Getz (et al. 2012) and Liu's (et al. 2018) reviews found a high degree of heterogeneity.

Baumgert-Getz (et al. 2012) suggested more specific aspects of environmental and stewardship attitudes should be measured as specific awareness of one's operation's pollutant contribution, specific education related to conservation BMPs, and contact with extension or attendance at a workshop tend to have stronger, significant, positive associations than formal education (Baumgart-Getz et al., 2012; Liu et al., 2018; McGuire et al., 2013; Prokopy et al., 2008; Ulrich-Schad et al., 2017). Whereas Liu et al. (2018) referenced the utility of a dual-interest framework developed by Thompson et al. (2015) which measures stewardship attitudes alongside farm-as-business attitudes on a 2-axis spectrum. This approach better captures the heterogeneity of farmer attitudes than simple divisions between those concerned primarily with business or stewardship attitudes common to previous studies (Chouinard, Paterson, Wandschneider, & Ohler, 2008; Floress et al., 2017).

1.5.3.5. Heterogeneity in adoption

Heterogeneity in significant factors for the adoption of practices, or adoption interest, could be due to the tendency for adoption studies to treat farmers as a homogeneous group (Chouinard et al., 2008; Hammond et al., 2017; Liu et al., 2018). Some farmers may be more or less interested in adoption of agricultural innovations for different reasons than other farmers (Daxini et al., 2019; Strong et al., 2005; Thompson et al., 2015; Trozzo, Munsell, Chamberlain, et al., 2014) and for reasons that differ from what researchers assume (Douthwaite, Manyong, Keatinge, & Chianu, 2002; Meijer et al., 2015). To deal with heterogeneity among farmers, some authors have chosen to use scales or multivariate statistical methods such as cluster analysis to further segment respondents into more homogenous groups (Barbieri et al., 2010; Beus & Dunlap, 1991;

Daxini et al., 2019; Hammond et al., 2017; Strong et al., 2005; Thompson et al., 2015; Trozzo, Munsell, Chamberlain, et al., 2014).

Thompson et al. (2015) used cluster analysis to understand how competing stewardship and profit-maximization attitudes effected current use of BMPs and beliefs regarding rural conservation planning priorities. One study found that different classes of farmers separated by operational and demographic characteristics had significant differences in their intentions to follow a nutrient management plan and may be more or less influenced by different sources of social pressures (Daxini et al., 2019). Segmentation can assist in exposing leverage points for practice adoption outreach such as targeting and messaging (Daxini et al., 2019; Gendall, 2002; Mattia, Lovell, & Davis, 2018; Trozzo, Munsell, Chamberlain, et al., 2014; Trozzo, Munsell, & Ramsdell, 2015; Tyson & Coulter, 1999).

1.5.3.6. Implications of agroforestry and water quality trading

Compared to other agricultural innovations, agroforestry is more complex, and requires more experimentation and adaptation to specific conditions which implies that the diffusion of agroforestry practices may take longer to be adopted throughout the biophysical and social landscape (Amacher, Hyde, & Rafiq, 1993; Barrett, Place, Aboudk, & Brown, 2002; Borremans et al., 2016; Mercer, 2004; Scherr, 1992; Workman, Bannister, & Nair, 2003). Additionally, the costs of producing environmental public goods from conversion to agroforestry are borne upfront to the farmer or rancher; meaning that even if agroforestry systems are profitable in the long term, there is a longer timescale required for a farmer to absorb cost and risk. (Benjamin, Hoover, Seifert, & Gillespie, 2000; Brownlow, Dorward, & Carruthers, 2005; Franzel & Scherr, 2002; Palma, Graves, Burgess, Van der Werf, & Herzog, 2007; Rigueiro-Rodríguez, Fernández-Núñez, González-Hernández, McAdam, & Mosquera-Losada, 2009; Scherr & Franzel, 2016;

Shrestha et al., 2004; Yates, Dorward, Hemery, & Cook, 2007). Studies suggest that internalizing positive environmental externalities of agroforestry, by providing farmers payment for environmental goods produced could increase agroforestry adoption particularly in temperate, high-income countries (Montambault et al., 2005). The availability of front-loaded revenue from water quality trading presents an opportunity to catalyze agroforestry adoption.

1.6. Outline of the thesis

The remainder of the thesis is structured as follows. In Chapter II, we present the quantitative and qualitative results of a mail survey of landowners in the headwaters of the Chesapeake Bay, Virginia on demographics, perceived limitations, and respondent land management objectives as they relate to pre-agroforestry adoption interest. In Chapter III, we present the results of a nested study on the terrestrial nutrient implications of intermediate forest coverage and compare different scenarios to historical and current water quality trading standards in Virginia and plot a course toward agroforestry water quality trading. In Chapter IV, I discuss the implications of this research and plot next steps for increasing economic opportunities for farmers in concert with water quality abatement on working-lands.

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Chapter 2: Landowner objectives and limitations as they relate to pre-adoption agroforestry interest in the headwaters of the Chesapeake Bay, Virginia, USA

Adam T. Beck

ABSTRACT

Agricultural nonpoint source nutrient pollution is the leading cause of water quality impairment in the Chesapeake Bay. Agroforestry, the integration of trees and crops and/livestock in agricultural systems, balances production and conservation objectives. Agroforestry is recognized by the Chesapeake Bay Program's strategy as a means of reducing nonpoint source pollution to improve water quality in the Bay. Despite this, adoption remains limited in the Bay's headwaters. Though some correlates of agroforestry adoption interest and landowner perceptions have been documented in the general agroforestry adoption literature, these factors may vary by context. In this study, we address who in the headwaters of the Chesapeake Bay is most interested in agroforestry production and what limitations to adoption they perceive. We ranked watersheds within in the headwaters of the Chesapeake Bay by one measure of agroforestry adoption likelihood and two biophysical indicators suggesting a need for conservation practices. We then surveyed 1,436 randomly selected land owners in four priority watersheds, collecting information on demographics, the importance given to eight potential benefits in land-use decision-making, and their interest in adopting three types of agroforestry systems (multifunctional riparian buffers, silvopasture, and alley cropping). We found that landowners ranked multifunction riparian buffers of greatest interest, followed by silvopasture, then alley cropping. We found that agroforestry interest differs by demographics and by the importance respondents placed on eight potential benefits in their land-use decision-making. The most common theme in landowner reactions to agroforestry systems were reservations about

incompatibility between trees and other elements of the agricultural system. In their responses, respondents anticipated tree failure, increased weed pressure, and expressed misgivings about the funding/execution of prior conservation programs. Future research, policy, and outreach should leverage extant associations with adoption interest and farmer desires while addressing farmer reservations, critiques, and social norms.

2.1 Introduction

The Chesapeake Bay is the largest estuary in the United States (US). Nonpoint source nutrient pollution from agriculture was found to be the leading threat to the majority of surface waters in the US, including the Chesapeake Bay (Ator et al., 2011; Cooper, 1995; Oelsner et al., 2019; U.S.E.P.A., 2018). Nutrient enrichment of surface waterbodies causes eutrophication which can lead to a decline in water quality, fishery yields, recreational opportunities, and biodiversity. Despite the scale of nonpoint source pollution impacts, they are not regulated under the Clean Water Act (CWA). Rather, programs that encourage and support voluntary implementation of best management practices (BMPs) on working lands, (e.g. the conservation reserve program, the environmental quality incentives program, and others), are funded under section 319 of the CWA and through the Farm Bill (Carpenter et al., 1998; Oelsner et al., 2019). Despite the success of these programs, adoption of agricultural nonpoint source BMPs remain limited and substantial improvements to water quality due to BMP adoption have yet to be seen (Dodd et al., 2016; Garnache et al., 2016; Reimer et al., 2018; Sharpley et al., 2009). Furthermore, farmers may be resistant to the prospect of decreased production from installing water quality BMPs (Castelle et al., 1994); and landowners with small streams, that have a disproportionate impact on water quality, are even less likely to install agricultural BMPs (Armstrong et al., 2012).

Agroforestry, the intentional integration of trees in livestock and cropping systems, has been identified as one means to address these issues and abate agricultural nonpoint source pollution in the Chesapeake Bay watershed (Claggett et al., 2012). Agroforestry practices can and should be designed to optimize the attainment of production and conservation objectives (Jose, 2009; Smith et al., 2013). Agroforestry can moderate microclimatic factors to enhance on-farm productivity (Feldhake, 2002; Kort, 1988; Munsell et al., 2018; Quinkenstein et al., 2009).

The ability to meet multiple landowner objectives on the same plot of land, such as commodity production, ecosystem service provision, recreational function, and aesthetics could be a key leverage point for adoption of agroforestry (Barbieri et al., 2010; Robles-Diaz-de-Leon et al., 1998; Schultz et al., 2009; Smith et al., 2013).

Despite the beneficial effects of riparian buffers on water quality and other ecosystem services, agricultural livelihoods rely on production; and farmers are resistant to take actions that detrimentally impact production (Castelle et al., 1994). Agroforestry's answer to this issue is the multifunctional riparian buffer, which builds on the ecosystem service provision of conventional buffers by incorporating low-input woody perennial crops, allowing adopters to potentially recoup revenue, with proper market development, from land taken out of annual crop production or pasture (Barbieri et al., 2010; Robles-Diaz-de-Leon et al., 1998). In managing for water quality, buffer practices should be combined with upland practices (Mayer et al., 2007; Schultz et al., 2009). Upland practices can be thought of as "upland buffers" in that these practices can reduce erosion and runoff before the riparian zone (Schultz et al., 2009; Sun et al., 2008). Upland practices include silvopasture and alley cropping (Schultz et al., 2009). Silvopasture is the combination of livestock, forage, and trees on the same plot of land. In addition to ecosystem service provision, silvopasture can beneficially alter microclimatic conditions resulting in decreased livestock stress (Broom, Galindo, & Murgueitio, 2013; Karki et al., 2010; Pent, Greiner, et al., 2019a, 2019b). When tree and forage species are selected prudently, productivity of conventional forage is maintained and trees provide a source of additional livestock browse (Pent & Fike, 2019; Shrestha et al., 2004). Alley cropping systems, in which trees are integrated between rows of crops, can be designed to ameliorate evapotranspiration stress and can offset nitrogen fertilizer requirements with the inclusion of nitrogen-fixing trees in cropping systems

(Quinkenstein et al., 2009). However, despite the potential benefits of agroforestry to the practitioner and society, farmers have been slow to adopt these systems and a vast body of literature has arisen to address why this is and what can be done about it.

2.1.1. Demographic variables and agroforestry interest

Socio-demographic variables, such as age, gender, education, and annual income, are typically assessed in regards to agroforestry adoption attitudes (Pattanayak et al., 2003). In a review of agroforestry adoption studies sampled primarily from middle and low-income countries, age was found to be positively associated with adoption (Pattanayak et al., 2003). However, in temperate, higher-income countries, younger farmers tended to adopt or have more interest in agroforestry and BMPs (Baumgart-Getz et al., 2012; Liu et al., 2018; Strong et al., 2005; Trozzo, Munsell, & Chamberlain, 2014; Trozzo, Munsell, Chamberlain, et al., 2014; Valdivia et al., 2009). Age is important in the context of intergenerational land transfer and adoption of agroforestry and agricultural conservation practices into the future. Intergenerational land transfer has been discussed in the context of how land tenure and succession associate with agricultural conservation practices (Parker et al., 2007). Although there is ample discussion of securing sustainable agriculture into the future in the context of intergenerational land transfer in popular literature and generational segmentation is frequently seen in marketing and political science, no peer-reviewed research was found that studied adoption behavior or attitudes in terms of generations or birth cohorts.

Income, percentage of income from farming, and capital had strong positive associations with adoption which implies that the ability to absorb risk and operate in economies of scale are key for adoption (Baumgart-Getz et al., 2012; Liu et al., 2018; Pattanayak et al., 2003; Ulrich-Schad et al., 2017). However, Pattanayak et al. (2003) suggest that general income variables mask the fact that smallholders, who depend primarily on farm income, and high-income households, with a lower reliance on farm income, may have less interest in agroforestry.

There are mixed and inconclusive results for gender as studies find positive (Druschke et al., 2014; Ward et al., 2016), negative (Tiwari et al., 2008), and insignificant associations between being female and adoption or adoption interest (Liu et al., 2018; Matthews et al., 1993; McGinty et al., 2008). Pattanayak et al. (2003) found that households with higher proportions of males were more likely to adopt agroforestry practices. However, women are more likely to be involved in specialty crop production (Strong et al., 2005), are more apt to acknowledge and to take action regarding environmental issues (Bord et al., 1997; Druschke et al., 2014; Goldsmith et al., 2013; McCright, 2010; Semenza et al., 2011; World, 2009; Zelezny et al., 2000), and can be less sensitive to risk in agroforestry adoption (Trozzo, Munsell, & Chamberlain, 2014). Women are a growing demographic as owners and decisionmakers on agricultural land in the US, justifying further interest in gender-specific differences in adoption attitudes (NASDA, 2019).

In general, early adopters of innovations or technologies are thought to be more highly educated, but this may vary when it comes to the specifics of an innovation and the context of the decision (Rogers, 2003; Sahin, 2006). The association between degrees of formal education and adoption is mixed based on reviews and meta-analyses of the agroforestry and conventional agricultural BMP adoption literature (Baumgart-Getz et al., 2012; Gedikoglu et al., 2012; Liu et al., 2018; Pattanayak et al., 2003). Some authors theorize nonpositive associations between education and agroforestry, and agricultural innovation adoption or adoption interest are due to the higher opportunity cost of time and attention for more highly educated landowners (Haghjou et al., 2014; Pattanayak et al., 2003).

2.1.2. Stated landowner priorities and agroforestry interest

As multifunctionality is central to agroforestry and is seen as a potential leverage point in agroforestry adoption interest, it is imperative to understand how farmers prioritize a variety of environmental, aesthetic, financial, and productive benefits in land-use decisions and how that affects interest in adopting agroforestry systems. Studies suggest that environmental benefits are important in agroforestry adoption (Arbuckle Jr, Valdivia, Raedeke, Green, & Rikoon, 2009; Valdivia et al., 2009). One study found, despite additional costs and effort, landowners with stewardship objectives were more interested in agroforestry (Matthews et al., 1993). However, several studies suggest that active farmers express less interest in agroforestry in general (Arbuckle Jr et al., 2009; Barbieri et al., 2010; Trozzo, Munsell, & Chamberlain, 2014; Trozzo, Munsell, Chamberlain, et al., 2014). Studies from the general agricultural conservation practice adoption literature suggest farmers are not two-dimensional in how their stewardship and production objectives inform their adoption attitudes (Thompson et al., 2015). Farmer interest in and perceptions of agricultural innovations may differ substantially from the assumptions of research and extension personnel (Douthwaite et al., 2002; Meijer et al., 2015; Mercer, 2004), which suggests the importance of supplementing quantitative analysis of predefined survey items with unbounded farmer reactions to proposed practices in order to properly address farmer interests and perceptions in outreach initiatives.

2.1.3. Objectives

My objectives in this paper are: (1) to test how demographics and land-use priorities associate with agroforestry interest in the headwaters of the Chesapeake Bay in Virginia through one-way analysis of variance (ANOVA) tests; and (2) elucidate the most common themes in farmer reactions to the prospect of adopting agroforestry systems on their land to best inform future agroforestry research, policy, and outreach priorities. This work builds on previous work where Trozzo et. al (2015) surveyed landowners in the headwaters of the Chesapeake Bay in Virginia to target landowners for an agroforestry outreach workshop and to collect data for mixed-method analysis. I analyze these data to advance our understanding of factors involved with agroforestry adoption interest as we approach an era of payment for ecosystem services and a large intergenerational transfer of land. Understanding why farmers express or do not express interest in agroforestry is essential for societies seeking to provide ecosystem service provisions and support sustained farmer livelihoods concurrently on a limited land-base into the future through agroforestry. I propose that agroforestry adoption varies by socioeconomic characteristics and landowner objectives. I hypothesize that younger, more highly educated, and higher income landowners will express greater interest in adopting agroforestry systems. Additionally, I hypothesize that agroforestry interest varies by gender, with women expressing greater interest. I hypothesize that landowners who weight the importance of environmental, aesthetic, and resale value benefits in their land-use decision making will express greater interest in agroforestry. Based on previous work in nearby locales (Trozzo, Munsell, & Chamberlain, 2014; Trozzo, Munsell, Chamberlain, et al., 2014), I hypothesize that landowners who give more importance to income and agricultural production benefits will express lower agroforestry interest. Further, I anticipate open responses from farmers to illuminate leverage points and limitations to agroforestry adoption interest and guide next steps for agroforestry research and outreach in the headwaters of the Chesapeake Bay and surrounding region.

2.2 Methods

I build from the work of Trozzo et al. (2015) who, in 2013, distributed a mail survey to 1,436 randomly selected landowners in four 5th level watersheds in our study area in the headwaters of

Virginia's portion of the Chesapeake Bay watershed. The survey was executed following the tailored design method (Dillman, D., & M., 2011). Mailings consisted of an introductory letter followed by an initial copy of the survey with a cover letter. Those who had not responded in two weeks were sent a reminder postcard followed by a replacement survey and cover letter.

Four 5^{th} level watersheds in our study area were selected according to social indicators of agroforestry interest likelihood and biophysical indicators of water quality vulnerability. The four selected 5^{th} level watersheds are the highest ranked in each category for which data was available. Agroforestry interest likelihood was ranked using Esri Tapestry Segmentation. Water quality vulnerability was ranked by 5^{th} order watersheds were ranked by water quality vulnerability.

Esri's Tapestry Segmentation system classifies the population of an area into distinct groups of similar characteristics based on data from various sources including the US census and consumer surveys. The geospatial distribution of these segments is shown across the landscape in a layer in ArcGIS. The descriptions of Esri tapestry segments were coded and ranked for social indicators of agroforestry adoption interest. For these purposes, only predominately non-urban areas were used. High ranking segments consisted of those with higher income, greater educational attainment, more specific references to lawn & garden expenditures, greater and diverse recreational activity, and higher civic engagement. 5^{th} level watersheds in our study area were assigned a weighted average score for agroforestry interest likelihood by the occurrence of Esri Tapestry segments (Trozzo et al., 2015).

Water quality vulnerability of 5^{th} level watersheds were generated from a combined index of (1) total open marginal riparian land within 200 feet of a 1^{st}, 2^{nd}, or 3^{rd} order stream and (2) total open marginal land. For these purposes, "marginal land" was defined by Soil Survey

Geographic database (SSURGO) non-irrigated land capability ratings of III or higher which indicate soils with severe limitations that restrict the types of crops that can be grown and require the use of conservation practices (Trozzo et al., 2015).

The survey instrument addressed demographics, benefits prioritized in land management decisions, perceptions of trees on farms, and interest in scientific illustrations depicting multifunctional riparian buffers, silvopasture, and alley-cropping through quantitative items. The instrument concluded by asking respondents about their general reactions to the theme of the survey through a qualitative open response item. Sociodemographic variables were assessed such as birth year, gender, education, and annual income. Respondents were classified by generation with birth year cut-offs provided by the Pew Research Center (Center, 2018). Respondents were asked about the importance of eight potential benefits in their land use decision-making. These items addressed the importance of Resale, Income, Livestock, Crop Production, Wildlife Habitat, Soil Conservation, Water Quality, and Beautification benefits on 4-point scales with "1" being "not important at all" to "4" being "very important." The item "agroforestry interest" is a summated mean score of respondent interest in three agroforestry practices that are most applicable to water quality: multifunctional riparian buffers, silvopasture, and alley cropping. A summated scale is used here to increase reliability, precision, and better define the scope of respondents' agroforestry interest (Spector, 1992).

Quantitative data analysis was conducted in Stata/IC 15 (StataCorp, 2017). One-way Analysis-of-Variance (ANOVA) tests were used to detect significant differences in mean agroforestry interest between different respondent groups based on socioeconomic variables and the respondent-ranked importance of potential financial, production, environmental, and aesthetics benefits in land use decision-making. Bartlett's test of equal variances was used to verify the equal variance assumption of ANOVA (Bartlett, 1937). Levene's test was used in cases where the null hypothesis of Bartlett's test is rejected, and non-normality is suspected since Bartlett's test is more sensitive to non-normality than Levene's (Levene, 1960; NIST/SEMATECH, 2012).

One-way ANOVA was followed by post-hoc Bonferroni multiple comparison tests (MCTs) to further elucidate which group or groups from each categorical independent variable drive rejection of the null hypotheses from one-way ANOVA (Hartley, 1955). Bonferroni was chosen as it is regarded as conservative compared to similar tests in that it corrects for type I errors, or false positives, more conservatively than other tests such as the Tukey method (Tukey, 1994), but less conservatively than tests such as Scheffé's test(Armstrong, 2014; Lee & Lee, 2018; Scheffé, 1953). As a result, Bonferroni MCT is more likely than the Tukey method, and less likely than Scheffé's test to produce type II errors, or false negatives (Armstrong, 2014; Lee et al., 2018). I tolerate the prospect of increased type II errors, for decreased type I errors in this analysis as many independent variables, particularly sociodemographic variables, can be highly variable in their associations with adoption behavior and attitudes across contexts (Prokopy et al., 2008). .

The survey concluded with one open response item which asked, "Do you have any final thoughts or reactions that you would like to share?" Thematic groups were detected in open responses through open coding (Glaser, 1967). Open coded groups were further classified by axial coding into final thematically consistent groupings (Strauss et al., 1990). Statements indicative of coded themes are presented in results alongside raw frequencies. Respondent mentions of both desirable and undesirable species and products were tabulated.

2.3 Results

I first present results from the quantitative analysis, including descriptive statistics of sociodemographics, importance of potential benefits in land-use decision-making, and agroforestry interest, and results of one-way ANOVA tests. I then discuss qualitative results including most apparent themes and desirable and undesirable species mentioned by respondents.

2.3.1 Quantitative

The mail questionnaire yielded a 45.2% (n=649) response rate from a total of 1,436 randomly selected landowners. Over half of respondents (55.3%) were born during the “baby boom” from 1946 to 1964, while almost one third of respondents (30.0%) were of the “silent” generation born 1928-1945. This was followed by one tenth (10.8%) from “generation X” born 1965-1980 and less than 3% (2.8%) from the “Greatest Generation” born 1901-1927. Finally, just over 1% (1.1%) from the “Millennial” generation born 1980-1996.

Table 2.1 Tabulation of socio-demographic variables for the sample

Variable	Freq.	Percent
Generation		
Greatest 1901-1927	15	2.8%
Silent 1928-1945	164	30.0%
Baby boom 1946-1964	302	55.3%
X 1965-1980	59	10.8%
Millennial 1981-1996	6	1.1%
Gender		
Female	161	26.8%
Male	440	73.2%
Education		
Less than high school	11	2.0%
High school diploma	138	25.4%
Associate degree	62	11.4%
Bachelor's degree	154	28.4%
Graduate degree	178	32.8%
Annual Income in 2013		
Less than $24,000	16	3.6%
$25,000 to $49,999	58	13.0%

$50,000 to $99,999	136	30.5%
$100,000 to $149,999	87	19.5%
$150,000 to $200,000	47	10.5%
More than $200,000	102	22.9%

Males made up almost three quarters of the sample (73.21%), while females made up more than a quarter (26.79%). The majority had a bachelor's degree or a higher credential (28.85% and 31.99% respectively). Annual income was assessed on a 6-point ordinal scale, with the largest group reporting annual earning between $50,000 to $99,999 a year (30.49%) and the second largest group earning more than $200,000 a year (22.87%). Overall, income, resale, crop

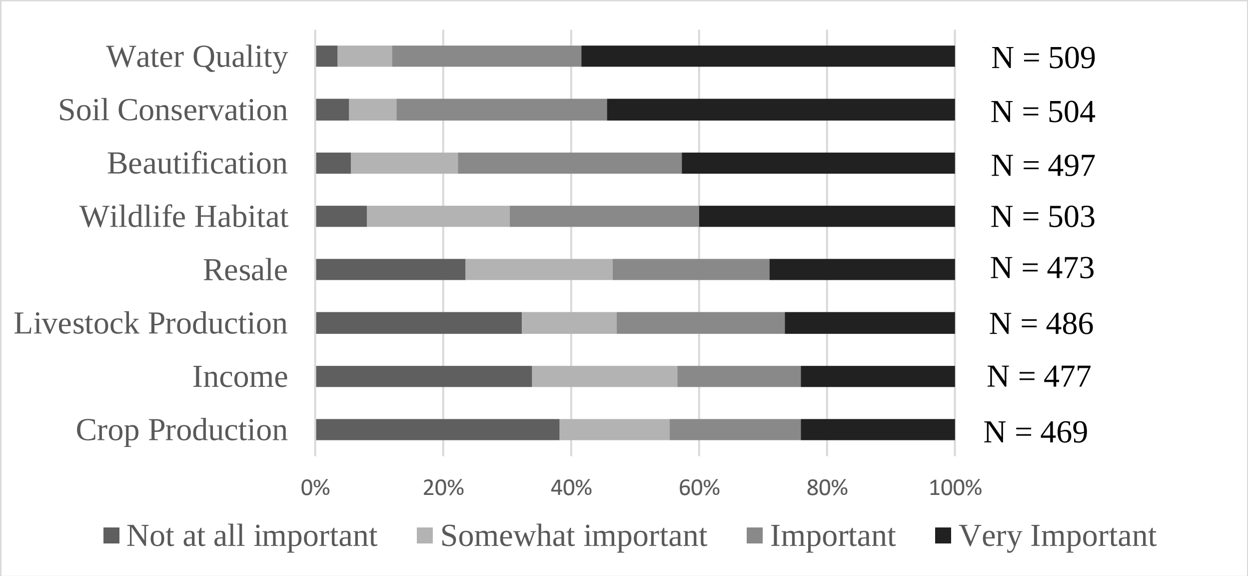

Figure 2.1 responses to 4-point ordinal item "Please indicate how important these potential benefits are to you when making land management decisions." from "1" being "not at all important" to "4" being "very important" expressed as relative percentages

production, and livestock benefits were ranked lower in importance to environmental and aesthetic items such as water quality, soil conservation, wildlife habitat, and beautification benefits. Of these items, respondents rated water quality and soil conservation benefits highest in importance overall.

In terms of agroforestry interest, more than half of respondents expressed planting trees on farms was a good or great idea. The data indicate that respondents were most interested in multifunctional riparian buffers, but less interested in silvopasture, and least interested in alley cropping, as shown in figure 2.5. The summed item "agroforestry interest," which is defined as a summed Likert scale variable generated from respondent interest in all three agroforestry practices, yielded a modest Cronbach's Alpha of 0.718 (Cronbach, 1951; Likert, 1932; Nunnally & Bernstein, 1994). Descriptive statistics are shown in Table 2.2.

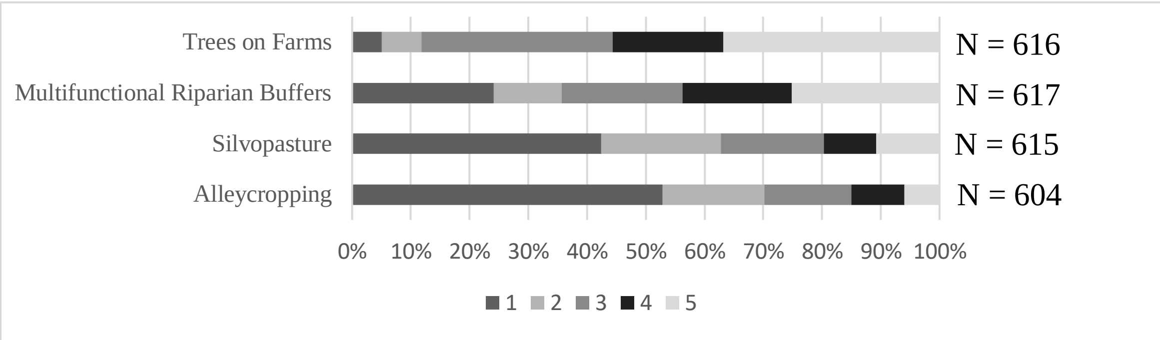

Figure 2.2: responses to 5-point ordinal items "Planting trees on farms is…" with "1" being "a terrible idea," "3" being "an ok idea," and "5" being "a great idea" and responses to 3, 5-point ordinal items featuring a scientific illustration of three agroforestry practices from "1" being "I am not interested" to "5" being "I am very interested" with a prompt in the middle informing respondents that "interest level increases from left to right" expressed as relative percentages

Table 2.2: Descriptive statistics for summed scale of agroforestry interest, which is a combination of respondents' interest in 3 agroforestry practices, multifunctional riparian buffers, silvopasture, and alley cropping, on 5-point ordinal Likert-scale items from 1 to 5 with 1 being "I am not interested" to 5 being "I am very interested" (Cronbach's Alpha: 0.718)

Variable	N	Mean	SD	Min	Max
Agroforestry Interest	601	2.43	1.10	1	5

2.3.1.1 One-way ANOVA: Agroforestry interest by socioeconomic variables

One-way ANOVA (α=0.05) was conducted on agroforestry interest in regard to sociodemographic groupings and how respondents ranked the importance of potential benefits in land-use decision-making (Table 2.3, 2.4). Agroforestry differed significantly at the α=0.001 level by generation with Baby Boomers, Gen X, and Millennials expressing higher mean values for agroforestry interest than the Greatest and Silent generations. Post-hoc pairwise Bonferroni analysis shows that these differences were driven mainly by Baby Boomers and Gen X. Baby Boomers differed significantly from the Silent Generation at the α=0.001 level. Gen X differed significantly from the Greatest and Silent generations (α=0.05 and α=0.001 respectively). Millennials showed no significant differences, but the sample size for this group is small (less than 10). These results were compared to those for ten-year birth cohorts and were determined to be robust (Table 7.2.1, 7.2.2).

Table 2.3: results of one-way ANOVA analyses on mean agroforestry interest by socioeconomic variables.
H_0 = Agroforestry interest does not vary by level of [variable]
*, **, and *** indicate H_0 is rejected at α=0.05, α=0.01, and α=0.001 levels of significance, respectively.*
† indicates null hypotheses of tests for equal variance are rejected by significant values for Prob>chi2 and Pr > F in Bartlett's and Levene's tests, respectively.
Groups with the same superscript or those lacking superscript do not differ significantly in terms of agroforestry interest (α=0.05)

Variable	Freq.	Percent	$\bar{X}$	SD
Generation***				
Greatest 1901-1927[ac]	15	2.8%	1.89	0.98
Silent 1928-1945[ab]	164	30.0%	1.96	0.93
Baby boom 1946-1964[cd]	302	55.3%	2.66	1.09
X 1965-1980[d]	59	10.8%	2.86	1.08
Millennial 1981-1996[abcd]	6	1.1%	2.72	1.41
Gender				
Female	161	26.8%	2.54	1.15
Male	440	73.2%	2.39	1.08
Education*				
Less than high school[a]	11	2.0%	1.94	0.73
High school diploma[a]	138	25.4%	2.31	1.09
Associate's degree[a]	62	11.4%	2.3	1.03
Bachelor's degree[a]	154	28.4%	2.56	1.12
Graduate degree[a]	178	32.8%	2.6	1.1
Annual Income†				
less than $24,000	16	3.6%	2.31	1.51
$25,000 to $49,999	58	13.0%	2.16	1.03
$50,000 to $99,999	136	30.5%	2.49	0.97
$100,000 to $149,999	87	19.5%	2.77	1.12
$150,000 to $200,000	47	10.5%	2.65	1.11
More than $200,000	102	22.9%	2.58	1.24

Although females had a slightly higher mean agroforestry interest (2.54) than males (2.39), the difference was not significant α=0.05 level. Thus, the null hypothesis was not rejected that agroforestry interest does not differ by gender. Mean differences in agroforestry interest varied significantly by education at the α=0.05 level from one-way ANOVA, but post-hoc pairwise Bonferroni analysis failed to detect significant differences between specific categories. This could be due to the increased type II error rate of the Bonferroni test itself (Armstrong, 2014; Lee et al., 2018; Nakagawa, 2004). Specific associations of each category of education and agroforestry interest are unclear. For the one-way ANOVA of agroforestry interest by annual income, Bartlett's test of equal variance and Levene's test were violated at the α=0.05 level of significance in this test and as such, the equal variance assumption of ANOVA was violated meaning these results are inconclusive and we fail to reject the null hypothesis that respondents differ in agroforestry interest by annual income.

2.3.1.2 One-way ANOVA: Agroforestry interest by benefits considered in land use decisions

Table 2.4: results of one-way ANOVA on mean agroforestry interest by responses to 4 distinct 4-point ordinal scores to the prompt 'Please indicate how important these potential benefits are to you when making land management decisions" from "not at all important" to "very important" (1-4) for income and productions benefit items

H0 = Agroforestry interest does not vary by importance of [variable]

, **, and * indicate one-way ANOVA tests were significant at □=0.05, □=0.01, and □=0.001 levels*

Importance levels with the same superscript do not differ significantly in terms of agroforestry interest (□=0.05) in post-hoc Bonferroni tests

Variable	Freq.	Percent	$\bar{X}$	SD
Resale				
Not at all important	108	23.5%	2.37	1.03
Somewhat important	109	23.8%	2.46	1.04
Important	113	24.6%	2.53	1.11
Very important	129	28.1%	2.68	1.16
Income**				
Not at all important[a]	156	33.7%	2.4	1.03
Somewhat important[b]	107	23.1%	2.82	1.113
Important[ab]	90	19.4%	2.5	1.05
Very important[a]	110	23.7%	2.34	1.11
Livestock**				
Not at all important[ab]	153	32.3%	2.42	1.1
Somewhat important[ab]	71	15.0%	2.56	0.92
Important[a]	126	26.6%	2.74	1.12
Very important[b]	124	26.2%	2.3	1.1
Crop Production***				
Not at all important[b]	173	38.1%	2.22	0.93

Somewhat important[a]	79	17.4%	2.98	1.11
Important[a]	95	20.9%	2.8	1.13
Very important[b]	107	23.6%	2.4	1.12

one-way ANOVA of agroforestry interest by importance of resale value was insignificant. The one-way ANOVA of agroforestry interest by income benefits was significant at $\alpha=0.01$. Post-hoc analysis suggested respondents who ranked income benefits as a “2” or “somewhat important” had significantly higher mean agroforestry interest than those who ranked income benefits as “1” or “not at all important” and those who ranked the same item as “4” or “very important” at $\alpha=0.05$ and $\alpha=0.01$ respectively. The one-way ANOVA on agroforestry interest by importance of livestock benefits was significant overall at $\alpha=0.01$ with post-hoc analysis yielding a significant difference between the highest and lowest scored groups in terms of agroforestry interest, “3” or “important” and “4” “very important” respectively ($\alpha=0.01$). One-way ANOVA on agroforestry interest by importance of crop production in respondent land use decision making was significant ($\alpha=0.001$). Post-hoc analysis showed significant differences between both middle categories, “2” “somewhat important” and “3” “important” and either extreme category. Respondents rating crop production benefits as “1” or “not at all important” had a mean agroforestry interest significantly lower than those who ranked “2” “somewhat important” and “3” “important” ($\alpha=0.001$). Conversely, those who ranked crop production benefits as “2” “somewhat important” or “3” “important” had a higher mean agroforestry interest than those ranking the item as “4” or “very important” ($\alpha=0.01$ and $\alpha=0.05$ respectively).

One-way ANOVA on agroforestry interest by importance of wildlife habitat benefits was significant ($\alpha=0.001$). The more important a respondent ranked wildlife habitat benefits, the higher mean agroforestry interest. Post-hoc analysis revealed that all relationships were significant (α=0.01) besides the difference between those who ranked wildlife habitat benefit as "1" or "not important at all" and "2" "somewhat important." One-way

Table 2.5: results of one-way ANOVA on mean agroforestry interest by responses to 4 distinct 4-point ordinal scores to the prompt 'Please indicate how important these potential benefits are to you when making land management decisions" from "not at all important" to "very important" (1-4) for environmental and aesthetic benefit items

H0 = Agroforestry interest does not vary by importance of [variable]

, **, and * indicate one-way ANOVA tests were significant at □=0.05, □=0.01, and □=0.001 levels*

Importance levels with the same superscript do not differ significantly from each other in terms of agroforestry interest (□=0.05) in post-hoc Bonferroni tests

Variable	Freq.	Percent	$\bar{X}$	SD
Wildlife Habitat***				
Not at all important[a]	41	8.4%	1.79	0.82
Somewhat important[a]	11	2.3%	2.1	1.02
Important[b]	148	30.3%	2.52	0.98
Very important[c]	188	38.5%	2.93	1.08
Soil Conservation***				
Not at all important[a]	27	5.5%	2.04	1.21
Somewhat important[ab]	37	7.6%	2.33	1.05
Important[a]	163	33.5%	2.27	0.92
Very important[b]	260	53.4%	2.75	1.12
Water Quality***				
Not at all important[ab]	18	3.7%	2.19	1.16
Somewhat important[a]	43	8.7%	2.1	0.9
Important[a]	149	30.3%	2.26	0.98
Very important[b]	282	57.3%	2.74	1.1
Beautification**				
Not at all important[ab]	27	5.6%	2.27	0.9
Somewhat important[a]	82	17.1%	2.23	0.99
Important[ab]	168	35.0%	2.48	1.09
Very important[b]	203	42.3%	2.7	1.12

ANOVA of agroforestry interest by respondent ranked importance of soil conservation was significant (P>0.001). Post-hoc analysis revealed that the respondent group that ranked soil conservation as "4" or "very important" had a significantly higher mean agroforestry interest than those who ranked soil conservation as "1" or "not at all important" and those who ranked it as "3" or "important" (P>0.01 and P>0.001 respectively). However, it should be noted that this analysis failed Bartlett's test for equal variances at the P>0.05 level, but passed Levene's test at the same level of significance meaning that detection of unequal variance in Bartlett's test was due to nonnormality rather than unequal variance and these results remain valid (NIST/SEMATECH, 2012).

The one-way ANOVA of agroforestry interest by respondent ranked importance of water quality in land use decision-making was significant (P>0.001). Post-hoc analysis revealed significant differences in mean agroforestry interest between those in groups who ranked water quality as "4" or "very important" and those in the "3" "important" and "2" "somewhat important" groups (P>0.001), while there was no statistically significant difference between the "4" "very important" and "1" "not at all important" groups. One-way ANOVA of agroforestry interest by beautification benefits was significant (P>0.01). Post-hoc analysis revealed a significant difference in mean agroforestry interest between those who regarded beautification benefits as "4" or "very important" over those who regarded it as "2" or "somewhat important" (P>0.01).

2.3.2 Qualitative

Categories of responses and frequencies are displayed in table 2.6 and discussed further in this section.

2.3.2.1 Incompatibility

Table 2.6: Themes from open responses to the prompt "Do you have any final thoughts or reactions that you would like to share?"

Theme	Frequency
Incompatibility	34
Has already planted buffer/trees	26
Information or assistance requested	14
Observed tree failure	14
Not involved on land	13
Weeds or invasive species concerns	11

Criticism of conservation plots	10
Financial limitations	10
Perceived waste of tax dollars	8
Wildlife predation on trees	8
Fraud concerns	7
Anti-government or agency sentiment	6
Time	5
Property is mostly forested	4
Livestock predation on trees	4
Sought sources for trees	4
Eyesore	3
Labor	1

The most frequent theme in the open response items had to do with incompatibility. Respondents addressed compatibility issues between all three agroforestry systems and extant property features and agricultural systems. Respondent sentiment about incompatibility addressed competitive incompatibility between trees and forage or crop production. Of silvopasture, one respondent expressed:

> *"In over 60 years of farming experience[,] farmers endeavor to keep bushy growth from pastureland. Maximum pasture yield is key to raising livestock."*

Of alley cropping one respondent stressed reservations about trees and crops stating,

> *"Trees are nice but are inconsistent with field crops (shade, moisture, and nutrient consumption) and should not be mixed."*

Respondents also stressed incompatibilities in terms of operational considerations. For example, one hay farmer wrote:

> *"[alley cropping] is crazy unless you want to spend days picking up sticks and still have them in your hay."*

2.3.2.2 Practices inapplicable to property, lifestyle, or satisfied with current practices

Some respondents expressed the practices described in the survey instrument did not apply to their property, are not involved on their property, or felt that they were already doing enough for conservation or recommended additional approaches. For those who felt the practices in the survey instrument did not apply, one responded noted

> *"my property is not suited for tree planting (Very Steep). 35 acres in forest/ trees, stream area compacted by power lines, no trees under power lines."*

Some noted they were not very involved on their property or in agriculture, are retired, or lease most of the land. Others had no involvement in agriculture such as:

> *"My land is mostly timber[,] and I am abiding by local land use laws. I don't have time to farm."*

Others felt they are already doing enough or do not wish to do more:

> *"I have a stream buffer now and see no need to do anything more[.]"*

Others felt they were doing more for conservation with different practices such as:

> *"Your approach to tree planting is so lim[i]ted. I began 25 years ago [with] creek management, rotational grazing, and best of all[,] a wildlife plot that surrounds our whole farm and does not affect our intensive farming program."*

Additionally, one respondent noted additional items the study could include:

> *"You should include other forest products[...]Others may be considering commercialization of such crops as mushrooms and ginseng."*

2.3.2.3 Requesting information and tree sources

Table 2.7: products and species either desired or already planted/produced by respondents from open responses to prompt " Do you have any final thoughts or reactions that you would like to share?"

Planted or desired commodities	Frequency
Grape *Vitis* sp.	11
Fruits	10
Timber	6
Nuts	6
Chestnut *Castenea dentata, Castenea* sp.	4
Apple *Malus* sp.	4
Hardwoods	4
Walnut *Juglans nigra, Juglans ailantifolia*	3
Peach *Prunus persica*	3
Sap/Syrup	3
Pear *Pyrus* sp.	2
Pecan *Carya illinoinensis*	2
Persimmon *Diospyros virginiana*	2
Oak *Quercus* sp.	2
Mushrooms	2
Cherry *Prunus* sp.	1
Locust *Robinia pseudoacacia, Gleditsia triacanthos*	1
Hops *Humulus lupulus*	1
Ginseng *Panax quinquefolius*	1

Many respondents asked for more information, workshops, and tree sources. For instance:

> *"I am willing/would love to grow native fruit and nuts, but [I] would need guidance on where/how to plant."*

Another requested workshops:

“I am a fan of the book Tree Crops[:a permanent agriculture (Smith, 1929)] and would like to see workshops encouraging the vision portrayed there.”

Others requested tree sources:

“[I] have planted many trees. More unusual native tree sources would be useful.”

Some suggested how to provide trees:

“I like this idea! I also think it would be a great idea to provide saplings at a low cost like soil conser[v]ation does.”

Woody perennial crops and forest products respondents were already growing or speak in a desirable fashion of are shown in table 2.7.

2.3.2.4 Observed and anticipated tree failure

In a similar vein, respondents expressed their risk perceptions by mentioning observed or anticipated failures of tree planting with a subsection of responses addressing tree damage by livestock and wildlife. Respondents mentioned tree survival rates of 25% and 10% with one respondent complaining about tree tubes:

“Probably one tube in 25 is successful… What happens to the empty tubes? …when the cre[e]k floods, the tubes end up on our property. We have to gather them and take them to the landfill.”

In regard to riparian buffers, some expressed their views that trees could be in fact detrimental to the water quality and soil retention goals of riparian buffers. One respondent mentioned:

“I've watched trees cause extensive damage along rivers and streams…”

and another:

> *"I think plant[ing] trees in creek bottoms will make dams at bridges with all of the debris that will come from trees when it floods."*

Respondent recalled a bad experience and related it with their current disposition. In regard to negative impacts of livestock on tree establishment:

> *"We planted willow trees in a pasture…the horses ate them!!!...planting trees where livestock graze is likely to fail."*

With regards to wildlife, one respondent wrote:

> *"…deer browsing off trees and shrubs even protected with 4' tubes…Why waste the time!!!…I am not as inclined to do things that just provide more deer habitat."*

2.3.2.5 Conservation plantings unattractive and a source of undesirable species

Table 2.8: undesired plant species mentioned in responses to the prompt " Do you have any final thoughts or reactions that you would like to share?"

Undesirable plant species	Frequency
Thistle *Cirsium* sp., *Silybum* sp.	6
Autumn/Russian Olive *Elaeagnus umbellata*/*E. augustifolia*	3
Multiflora Rose *Rosa multiflora*	2
Johnson Grass *Sorghum halepense*	2
Ailanthus *Ailanthus altissima*	1
Wild Cherry *Prunus* sp.	1

Criticisms of conservation plantings emerged in open responses as respondents connected ideas presented in the survey with what they've previously experienced or observed. These criticisms address conservation plots as unsightly and a source of undesired plant species. As one respondent illustrates:

"…neighbors on both sides of my property have conservation plots. They are unsightly and unkempt… We have a tremendous thistle problem on our fields right now, the result of the neighbors' conservation plots being overgrown by thistles and being left to seed."

Respondents mentioned specific undesired plant species in this context (Table 2.8).

2.3.2.6 Criticism of conservation programs, use of tax dollars, government, and government agencies

In addition to criticisms of conservation programs, respondents decried wastes of tax dollars, anticipated, and described instances of fraud or perceived fraud, complained about agency officials, and expressed anti-government or government-agency sentiment in regard to agricultural programs. For example, some responded generally about others:

"…these programs and tax deductions are being used by financially rich people to waste good farmland…"

and

"We have seen local "farmers" (landowners) take advantage of government programs for fencing out streams and waterers, that have no cattle…"

While others responded in a confessional manner:

"a lot of people I know grow something solely for the land use tax credits - I am one of them."

Some respondents complained about officials generally:

"…much of the WQ government officials really just wanting the area to become 'overgrown' is not appealing to many."

Some offered personal anecdotes about interactions with officials:

> *"I asked for help with erosion on my runbank a year ago and [official's name] came out and took pictures and have heard nothing fu[r]ther [about] stop[ping] the washout!"*

Some offered specific criticism of the Environmental Protection Agency and its policies:

> *"[I'm] very concerned about the direction of the EPA and their new navigable river ordinance which calls a ditch navigable."*

While some expressed general opinions about governance in general:

> *"I believe in local government not [a] federal run country!"*

Although ten respondents decried lack of funding and labor, for instance:

> *"we are interested in doing things to protect our environment and help wildlife[,] but we are limited in our ability to do the physical work or pay someone else to."*

some disagreed with the role of public funds in general:

> *"voluntary programs without government financial incentives are OK."*

2.4 Discussion

We found a significant difference in interest in agroforestry systems between younger generations such as the Baby Boomers and Gen X and older generations, while sample size was small for Millennials. This could be important in marketing agroforestry. Additionally, this has implications for agroforestry adoption, farmer stewardship attitudes, as we approach a large intergenerational transfer of land. Potentially illustrative of a generational divide, one respondent mentioned, *"We are nurturing locust [trees] - but don't let my dad know."*

Contrary to our hypothesis that active farmers would report lower agroforestry interest than nonproducers, we found that farmers who assigned moderate importance to crop and livestock production benefits in their land-use decision making expressed the highest mean values for agroforestry interest. In contrast to annual income, respondents who reported income benefits as "somewhat important" had the highest mean agroforestry interest. This result is consistent with suggestions by Pattanayak et al. (2013) that landowners with higher dependence on their land for income generation may have higher risk aversion, and those with little to no dependence on their land for income generation may not be involved enough with agriculture to express much interest in agroforestry.

In contrast to a relatively straightforward association of tree coverage and increased property values in residential contexts (Morales, 1980), we found no significant difference in mean agroforestry interest with more or less importance of resale benefits. Perhaps the effects of tree coverage on resale value of agricultural lands is more complicated related to concerns about management and compatibility. Respondent concerns over compatibility, livestock damage to young trees, and management are consistent with one study in the southeastern US (Zinkhan & Mercer, 1997), while farmer perceptions of increased weed pressures in agroforestry are observed in a study from the United Kingdom (Graves, Burgess, Fabien, & Dupraz, 2017). Our results stress the importance of environmental benefits such as soil conservation, water quality, beautification, and wildlife habitat provision in agroforestry interest. Though methodologies varied, our results differ slightly from a study in Europe where wildlife habitat/biodiversity was ranked highest, followed by livestock health and wellbeing, and then aesthetics, soil conservation, and other environmental items (García de Jalón et al., 2018); and from a study in

Florida, where benefits to water quality were ranked lower in importance on a large list of items by farmers (Workman et al., 2003).

Respondent criticisms of government agencies, programs, and spending has important implications for future policy or programmatic interventions to improve agricultural BMP and agroforestry adoption. One study found farmers were more likely to support non-governmental and voluntary approaches to water pollution from agriculture, and studies this issue in greater depth (Rissman, Kohl, & Wardropper, 2017). Perhaps an approach through nongovernment entities or peer groups that minimize government or government agency connections could be more compatible with the norms of this group of respondents. Additionally, emerging market-based strategies may take the government and public funding far enough out of the equation to appease this section of landowners.

In response to anticipated tree failures, fundamentals of successful tree planting should not be overlooked as a key part of agroforestry outreach as respondents noted the failure of their own and other's tree plantings as a factor that decreases their interest in planting. Concerns over the unkempt appearance of conservation plantings and the potential of these sites to act as a reservoir of weeds and invasive species has been studied as the "weed reservoir" hypothesis which states soil in tree rows which is not cultivated would host weedy species that would spread germplasm to cultivated soil (Boinot et al., 2019). Research could seek to address the weed reservoir hypothesis within the Chesapeake Bay headwater context, as one study did in Southwestern France and use this to inform efficient management regimes or design interventions to either put these concerns to rest or elucidate proper management (Boinot et al., 2019). It should be noted that one meta-analysis suggested in general, agroforestry does not increase weed abundance, however this may not be the case in specific contexts (Pumariño et al., 2015). Further work will determine whether this is a matter of perception or fact in the Chesapeake Bay watershed and surrounding region. Regardless, by planting economically important woody crops in buffers, fields, and pastures, the spread of weeds and invasive species can be suppressed by those who recognize the threat weeds can pose to their investment in the health and yield of their agroforestry systems into the future and manage this problem accordingly.

Agroforestry messaging could leverage extant interest in singular species and woody perennial crops. As grapes (*Vitis* sp.) were mentioned the most by respondents, programming could involve applying agroforestry principles to vineyard systems. Apples (*Malus* sp.) followed closely behind in terms of mention frequency. The incorporation of trees and livestock could be normalized in the region by promoting rotational grazing to control weeds and provide sanitation for pests and diseases such as Apple Scab (*Venturia inaequalis)* (Nunn, Embree, Hebb, Bishop, & Nichols, 2007). Tied with Apple in number of unique mentions, Chestnut (*Castenea* sp.) had enthusiastic appeal with respondents. In particular, one respondent mentioned participating with restoration efforts in the area by the American Chestnut Cooperators' Foundation to evaluate resistance to Chestnut Blight (*Cryphonectria parasitica),* which has devasted local populations and production capacity. Perhaps the extant appeal of American Chesnut (*Castenea dentata)* could be leveraged in a similar way to how conservation programs leverage charismatic umbrella species. Umbrella or flagship species are mostly animals with charismatic appeal that translates well into marketing value. These species are often used as a flagship, or main marketing focus to fund not only conservation of that species but, by extension, the conservation or restoration of regional biota with similar requirements as the flagship (Andelman & Fagan, 2000). When the conservation of a single species leads to conservation of other members of regional biota, conservation biologists' term this an "umbrella effect." In the case of agroforestry, the appeal of American Chestnut could potentially be leveraged in a similar way as a flagship or umbrella species in marketing to fund research and development of pest/disease resistant and productive varieties of woody perennials that could be used in agroforestry systems. This differs somewhat from the pure concepts in conservation biology, as the organization raising money would have to actively assure funding raised went to research in other species. Just as important as which species were mentioned, is which available species that may excel in agroforestry contexts are absent from responses. Programming around less familiar species could stress how they are compatible with landowner priorities such as wildlife habitat value, beautification, and commodity production in and of themselves while addressing design and placement considerations for soil conservation, water quality, crop, and livestock benefits.

In contrast to multifunctional riparian buffers, upland agroforestry practices did not have the same levels of interest in our sample. Thus, examples of success should be presented and used to form packaged or modular agroforestry systems that feature recommended management prescriptions, species lists, and design concerns, such as spacing and species pairings, for the region which can later be optimized to site-specific conditions. For example, the Honey Locust *Gleditsia triacanthos* and cool-season forage silvopasture system as presented in a study by Pent & Fike (2019) could meet livestock production goals without requiring much further market development for new tree products as the tree element produces browse that ultimately supports livestock production gains rather than a novel, standalone product. Likewise, further practical research and messaging in managing competitive interactions in alley cropping is needed. Perhaps success with Black Locust (*Robinia pseudoacacia)* based alley cropping systems on post-mining sites in Europe could be replicated in the headwaters of the Chesapeake Bay and the surrounding region (Wöllecke et al., 2005). Realizing the full production benefits of this system in the Chesapeake Bay watershed and surrounding region will require additional work. For example, though Black Locust is a valuable timber species and is valuable to the agroecosystem as a nitrogen-fixer, a serious hurdle to realizing the full value of this system will be the efficient management of Locust Borer (*Megacyllene robiniae),* which vectors heart rot and destroys the tree's commercial value (Kauffman & Kerber, 1922). Research could build on previous work on agroecosystem diversity as a deterrent or ecological control of pest species to increase whole-system productivity (Altieri & Nicholls, 2004; Pumariño et al., 2015).

2.5 Conclusion

The result of this analysis show that landowners who rate income, crop, and livestock benefits as moderately important and rate environmental benefits as highly important in their land-use decision-making express more interest in agroforestry. This overview reflects general literature trends, though the relative importance of items seen in our study site differs from those in other study sites. In this case, the presence and absence of concerns, desired species, funding, program structure, and requests for specific information could guide further interventions. Research and outreach would be correct in using general insight from the literature as a start, but region-specific feedback may provide further leverage points for how to articulate priorities and shape the direction of interventions.

The results from this analysis raised a variety of landowner concerns over including trees in agricultural contexts. Agroforestry outreach priorities in the headwaters of the Chesapeake Bay should advance by focusing on and addressing the most apparent themes. The most frequent theme of open responses was incompatibility of tree crops, row crops, livestock, forage, and riparian management. This degree to which this perception is factual will likely vary by species selection and site design. Further outreach should stress practical management concerns such as how trees are selected, placed, planted, and managed in the system to minimize competitive interactions between trees and other components of agricultural systems and land features. To expedite this process, examples of successful agroforestry systems in the region could be developed and packaged in a way to simplify establishment for potential adopters while allowing some flexibility to adapt to site conditions and landowner priorities. Respondents mentioned several species in a desirable fashion. Extant interest in woody perennial and tree crops should be leveraged and discussed in terms of the benefits of the plant itself and how best to utilize it in context. Species that are appropriate for agroforestry applications in the region were notably absent from open responses. Further research and outreach could center around publicizing the benefits of less familiar woody crops. A portion of landowners expressed anti-federal government and anti-agency sentiment, while others decried the use or misuse of tax dollars for working-lands conservation programs. Further research could look at funding and program structures acceptable to regional landowners that could catalyze agroforestry adoption and provide agroforestry-specific woody crop varieties in a cost-effective and logistically expedient manner.

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Chapter 3: Projecting agroforestry water quality trading in the headwaters of the Chesapeake Bay, Virginia, USA

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ABSTRACT

Nonpoint source nutrient pollution from agriculture is the leading threat to surface water quality in most water bodies in the United States. Best management practices for nonpoint source nutrient pollution abatement are largely voluntary in the United States. Despite annual funding for programs that support and promote agricultural best management practice adoption, successful abatement of agricultural nonpoint source nutrient pollution from agricultural best management practice has yet to fulfill its potential. This is partially due to cost and farmer reluctance to take land out of production. Water quality trading, where regulated pollutant sources with high abatement costs can purchase reduction credits from other pollutant sources who reduce nutrient pollution at lower costs, could be used to catalyze best management practice implementation in the agricultural sector. Typically, under water quality trading schemes that allow point sources to trade with nonpoint sources, agricultural operations that implement best management practices or convert land to forest can sell pollutant credits to developers. Agroforestry is the integration of woody perennial crops in agricultural systems and could be used to help farmers capitalize on water quality abatement without completely retiring annual production. However, typical trading program guidelines, including those in Virginia, do not recognize intermediate forest conversion that reflects functional agroforestry systems in credit generation. Since agroforestry presents a unique opportunity for farmers to balance conservation and production objectives, and water quality trading could offer front-loaded payments to farmers to engage in agroforestry, we modeled agroforestry tree-coverage scenarios on four

assumed land uses on properties within the headwaters of Virginia's portion of the Chesapeake Bay with the Chesapeake Bay Facility Scenario Assessment Tool. The goal of this study was to understand the relationship between different scales of agroforestry coverage and reductions in nitrogen, phosphorus, and sediment loads to the Chesapeake Bay and its tributaries. This analysis looks at the reduction efficiency of intermediate tree coverage scenarios and how mean pollutant pounds per acre reductions compare to water quality trading crediting standards. I found intermediate forest conversion of pasture reduced the percentage of nitrogen most efficiently at intermediate tree coverage applied, while the largest mean pounds per acre reductions of nitrogen, phosphorus, and sediment could be produced by agroforestry conversions on row-cropped and fertilized hay fields. This suggests silvopasture, the combination of woody perennial crops with forage and livestock, and alley cropping, the cultivation of crops between rows of woody perennial crops, could be effective water quality interventions worthy of water quality credit generation. Although better modeling tools and more research are warranted to determine how best to place trees and how agroforestry performs as a water quality practice in field conditions. We conclude agroforestry nutrient credit trading could offer significant benefits to support water quality and farmer livelihoods.

3.1 Introduction

Surface waterbodies, which human societies depend on for drinking water, fishing, recreation, and other important economic uses are under threat from cultural eutrophication. Cultural eutrophication is an ecological process driven by nutrient enrichment from human activity. Eutrophication is driven primarily by nitrogen in saline coastal systems and by phosphorus in freshwater systems, while a shift in importance between the two can be observed along the salinity gradient in estuarine systems (Carpenter et al., 1998; Schindler, 1974, 2006; Smith, 2006; Smith et al., 2009). Nutrient enrichment drives primary production to excessive levels in the upper depths of water bodies leading to a shift in producer species composition, the stimulation of often noxious algae, and a boost in aerobic microbial decomposition that depletes dissolved oxygens levels resulting in die-offs of aquatic animals. Furthermore, anoxic conditions may lead to release of the potent greenhouse gas methane (Beaulieu et al., 2019; Gelesh et al., 2016). Thus, managing nutrient pollution to surface water bodies is not only essential for water quality, biodiversity, and local economies, but is also inextricably linked to larger environmental challenges such as climate change (Beaulieu et al., 2019).

The agricultural sector has been identified as the leading contributor of nutrient pollution to most surface waterbodies in the US (Ator et al., 2011; Carpenter et al., 1998; Oelsner et al., 2019; U.S.E.P.A., 2018). Nonpoint source nutrient loading to surface waters can be reduced on agricultural land, with varying degrees of effectiveness, through land-use change, the implementation of conservation practices, and changes in management regimes that reduce or alter nutrient inputs or transport of nutrients as runoff (Carpenter et al., 1998; Dodd et al., 2016). In contrast to point sources, where pollutants flow through a discrete area such as an effluent pipe, non-point sources, where pollutants flow across an indiscrete area such as an agricultural field, are not regulated as stringently due to practical concerns, the associated costs, and the language of the Clean Water Act (CWA) (Carpenter et al., 1998; Oelsner et al., 2019). Implementation of BMPs for nonpoint source pollutant reductions are generally not compulsory in the US, rather farmers may implement BMPs voluntarily (Garnache et al., 2016; Laitos et al., 2001; Oelsner et al., 2019; Reimer et al., 2018). Programs that encourage and support voluntary pollution reduction include the Conservation Reserve Program, which offers farmers direct payments for periodic land retirement, the Environmental Quality Incentives Program, which offers cost-sharing for implementation of BMPs on working-lands, and other efforts funded under section 319 of the CWA and through the farm bill. Despite large annual budgets for these programs, and the fact that, in many cases, reductions from agricultural non-point sources may be obtained at much lower costs than from other nonpoint sources or point sources (Fang et al., 2007; Garnache et al., 2016; Jones et al., 2010; McConnell et al., 2008), success in reducing nutrient pollution from agricultural nonpoint sources across the landscape has been limited (Dodd et al., 2016; Garnache et al., 2016; Reimer et al., 2018; Sharpley et al., 2009). As not all polluters are equal in their pollutant contributions, current and emerging agricultural nonpoint source abatement strategies must target and engage farmers with disproportional pollutant impacts (Armstrong et al., 2012; Diebel et al., 2008; Nowak et al., 2006).

Water quality trading is an emerging strategy to reduce nutrient pollution. In these schemes, a regulated point source with high abatement costs may purchase credits generated elsewhere in the watershed where abatement costs are lower (e.g. from nonpoint source agricultural producers), to achieve regulatory compliance (Shortle, 2013; U.S.E.P.A., 2019; Woodward et al., 2002). Government officials often serve as program referees, generating crediting rates, and tracking credit generation and exchanges though some tasks may be relegated to other parties (Woodward et al., 2002). Nonpoint source credits are generated by landowners when they install certain BMPs or convert or retire nutrient intensive agricultural land (DEQ, 2008). Crediting rates are generally estimated with terrestrial nutrient modeling for a unit of area relevant to water resource management such as a tributary basin or a variety of smaller watersheds (HUCs) (U.S.E.P.A., 2019). Direct regulation of agricultural nonpoint sources may be logistically or cost prohibitive so uncertainty is often accounted for in trading ratios where a point source buyer is required to purchase a higher number of agricultural nonpoint source credit units than the amount of pollutant units they are required to reduce (Shortle, 2013). Some suggest that farmers require a premium or enhanced incentives to overcome reluctance in entering a contract with a regulated point source (Breetz et al., 2005; King et al., 2003). Thus, crediting standards need to incentivize abatement from disproportional polluters sufficiently and farmers should be allowed to continue to engage in low risk productive activities on enrolled land.

The riparian buffer is a common agricultural BMP for water quality management. A riparian buffer, which is a swath of land taken out of production along a watercourse, can reduce nonpoint source nutrient pollution (Castelle et al., 1994; Klapproth et al., 2001; Mayer et al., 2007; Peterjohn et al., 1984; Pinho et al., 2008). Guidance or requirements for the width of fixed-width buffers are somewhat arbitrary and may be a product of political acceptability rather than pollutant reduction efficacy (Castelle et al., 1994). This is pertinent as farmers may be reluctant to take productive land out of cultivation (Castelle et al., 1994; Robles-Diaz-de-Leon et al., 1998; Trozzo, Munsell, & Chamberlain, 2014; Trozzo, Munsell, Chamberlain, et al., 2014). Although buffer width is an important consideration in nonpoint source pollution abatement, soil type, subsurface hydrology, and biogeochemistry may cause significant variation (Mayer et al., 2007).

A more efficient approach to riparian buffer design is to use high resolution, site specific data to optimize pollutant reduction efficiency, while minimizing the area a farmer must take out of production (Dosskey et al., 2005; Dosskey et al., 2015). The pollutant abatement efficacy of riparian buffers may decrease over time as stored pollutants, particularly phosphorus, build up to high levels in the buffer area causing the buffer to eventually function as a legacy pollutant source (Dodd et al., 2016; Uusi-Kämppä, 2005). Therefore, a diversified approach incorporating upland practices and periodic management is necessary to maintain pollutant reduction efficacy into the future (Dodd et al., 2016; Mayer et al., 2007; Uusi-Kämppä, 2005). Agroforestry presents an opportunity that may entice farmers into planting trees in riparian and upland areas by eroding the perception of a zero-sum game between conservation and production objectives.

Agroforestry is the integration of commercially relevant woody perennial crops that yield timber and/or non-timber forest products (NTFPs), including fruits, nuts, florals, saps, syrups, oils, resins, herbal medicinal products, forage, and fodder in concert with crops and/or livestock in agricultural systems (Gold et al., 2009). The design of agroforestry systems can and should optimize beneficial interactions among components of the system and balance productive and environmental functions (Gold et al., 2009). Agroforestry consists of both riparian and upland practices (Schultz et al., 2009). Some common agroforestry systems include multifunctional riparian buffers, and, in the uplands: silvopasture and alley-cropping (Gold et al., 2009; Schultz et al., 2009).

Multifunctional riparian buffers differ in design from conventional riparian buffers by intentionally incorporating less intensively managed woody perennial crops within the riparian zone, which preserves a degree of potential revenue production (Barbieri et al., 2010; Robles-Diaz-de-Leon et al., 1998; Schultz et al., 2009; Trozzo, Munsell, & Chamberlain, 2014).

Accompanying upland practices can be conceptualized as an "upland buffer," that is, trees can be planted on or slightly off contour in the uplands to enhance infiltration, reduce runoff, and combat nonpoint source pollution, as well as render salable products associated with specialty species (Gold et al., 2009; Schultz et al., 2009). Upland agroforestry practices include silvopasture and alley cropping. Silvopasture is the combination of woody perennial crops, livestock, and conventional forage species on the same plot of land. Alley cropping is when crops are grown between rows of woody perennials.

The ability of upland agroforestry systems to reduce nutrient pollution is thought to be due at least in part to more efficient root colonization of the soil profile when compatible woody perennials, crops, and forage species are grown in concert. The "safety net hypothesis" posits that deeper woody perennial roots uptake nutrients below the rooting depths of herbaceous species (Huxley, Pinney, Akunda, & Muraya, 1994; Rowe, Hairiah, Giller, Van Noordwijk, & Cadisch, 1998). Though, the precise effects of species sequence and combinations may vary (Rowe et al., 1998; Schroth, 1995), support for enhanced nutrient capture in agroforestry systems is shown by a number of studies on alley cropping (Allen et al., 2004; Dougherty, Thevathasan, Gordon, Lee, & Kort, 2009; Ghosh, Kumar, Kabeerathumma, & Nair, 1989; Huxley et al., 1994; Sun et al., 2008; Wei et al., 2007) and on silvopasture (Bambo et al., 2009; Boyer et al., 2010).

The costs of producing environmental public goods from conversion to agroforestry are borne upfront to the farmer or rancher; meaning that even if agroforestry systems are profitable in the long term, there is a longer timescale required for a farmer to absorb cost and risk. (Benjamin et al., 2000; Brownlow et al., 2005; Franzel et al., 2002; Palma, Graves, Burgess, et al., 2007; Rigueiro-Rodríguez et al., 2009; Scherr et al., 2016; Shrestha et al., 2004; Yates et al., 2007). Studies suggest that internalizing positive environmental externalities of agroforestry, by providing farmers payment for environmental services could increase agroforestry adoption particularly in temperate, high-income countries (Montambault et al., 2005). The availability of front-loaded revenue from water quality trading presents an opportunity to catalyze agroforestry adoption.

3.1.1 Objectives

We sought to study the potential role of agroforestry water quality trading in a water quality abatement strategy. Our objectives were: (1) study the relationship between increasing forest coverage and pollutants reduced across four initial agricultural land uses; and (2) estimate potential water quality abatements of agroforestry conversion in the context of an existing water quality trading scheme. Understanding terrestrial nutrient dynamics of additional forest coverage is important for determining tree coverage levels that optimize the balance of water quality abatement and agricultural production. Analyzing terrestrial nutrient dynamics of intermediate forest coverage scenarios in the context of an extant water quality trading scheme prompts a discussion of how agroforestry could be incorporated in these schemes to improve water quality and support agricultural livelihoods on a limited land base into the future. Our study occurred in two sub-basins located within Virginia's portion of the Chesapeake Bay Watershed where an active water quality trading program has existed since 2009.

3.1.2 Context

The Chesapeake Bay is the largest estuary in the US. Water quality impairment, of which nonpoint source pollution from agriculture makes a substantial contribution, threatens the ability of the Bay to support biodiversity, an important fishing industry, and recreational uses (Bay, 2010; Cooper, 1995; U.S.E.P.A., 1982). To combat nutrient pollution, Virginia state legislature created the Nutrient Credit Exchange Program in 2005. This program allows tradable credits to be generated when farmers install agricultural BMPs or convert agricultural land to less nutrient intensive uses, in addition to adopting baseline best management practices (BMPs) per program guidelines (DEQ, 2008, 2020). These credits can be purchased by regulated point sources to achieve compliance within the same 4th order watershed (HUC 8) or in an adjacent HUC 8 if no credits are available (DEQ, 2020). Under the program, point sources must purchase twice the number of credit units from nonpoint sources per unit of pollution they are required to offset.

The nutrient credit program recognizes that nonpoint source nitrogen, phosphorus, and sediment are reduced by converting fallow, hay, pasture, and cropland to forest. Eligibility for credit generation is obtained by installing baseline BMPs such as a fixed-width 35-foot buffer. Land conversion in excess of baseline BMPs can be used to generate salable credits based on a per acre rate for pre-existing land uses for the area where the property is located. In the 2008 water quality trading guidance, nutrient reduction credits for nitrogen and phosphorus were generated based on the tributary basin and side of I-95 a property is located (DEQ, 2008). In the 2020 guidance, nitrogen, phosphorus, and sediment credits are generated based on the HUC 8 where a property is located (DEQ, 2020). Enrolled land is deed-restricted and management and profit-generating activities are limited (DEQ, 2008). Grassed buffers are usually the least expensive option for the 35-foot buffer and forest conversion upland of the 35-foot buffer yields the highest salable credits. This results in a situation where the least cost land conversion scenario is a 35-foot fallowed or grassed buffer and 400 trees per acre of inexpensive pine (*Pinus* sp.) planted in the creditable portion upland of the 35-foot buffer. There are concerns as to whether this program structure is adequate to engage working lands and to support agricultural livelihoods (Stephenson et al., 2017).

Despite recognition of agroforestry practices as part of the Chesapeake Bay Program's restoration strategy for the Bay (Claggett et al., 2012) and increasing recognition of agroforestry practices as part of USDA-NRCS Field Office Technical Guides in many locales, agroforestry, or intermediate tree coverage scenarios representative of agroforestry, are not explicitly recognized under Virginia's water quality trading program. Only a full conversion of creditable land from a preexisting land use class to forest, defined as 400 trees per acre, can be used to generate credits. Meaning at present, farmers considering the prospect of participating in the program are faced with a decision between maintaining their land in a productive capacity or retiring productive use of their land completely for credit generation. The water quality trading program guidelines for land use conversion in their current state present a framework where there is a zero-sum game between production and conservation objectives, and do not account for geographic disproportionality between and within fields in the same tributary and side of 1-95 in the case of the 2008 guidance or HUC10 in the 2020 guidance.

3.2 Methods

We modeled the relationship between five forest conversion scenarios (Table 3.1) and nonpoint source pollutant reductions on 124 properties in two HUC 10 5th level watersheds in Virginia's portion of the headwaters of the Chesapeake Bay. The scenarios were developed to explore the pollutant reduction efficiency of that occurs with increasing levels of tree planting on different extant land uses and they allowed us to compare the value of these treatments in relation to current Virginia water quality trading program crediting guidelines. Average pollutant reduction efficiencies for three nonpoint source pollutants (phosphorus, nitrogen, sediment) to the edge of the nearest fourth-order stream and to the Chesapeake Bay from four forest coverage scenarios were analyzed to investigate if marginal pollutant reductions diminish as forest coverage increases on each of the four land uses of interest.

Mean pollutant reduction values expressed in pounds per acre from each agroforestry conversion scenario on each assumed preexisting land use were compared to historic and current program guideline values. If forest coverage percentage exceeded a linear, 1:1 relationship with pollutant reduction percentages, this suggests a curvilinear relationship between additional tree coverage and pollutant reductions and the possibility of diminishing water quality returns as forest conversion intensity increases. We compare nutrient outputs from intermediate forest coverage scenarios modelled based on three extant agroforestry research plots with regionally determined trading standards to place our analysis in the context of current water quality trading program guidelines.

The Chesapeake Bay Facility Assessment Scenario Tool (BayFAST) was used to analyze terrestrial nutrient dynamics of intermediate forest coverage scenarios on randomly sampled properties in two HUC 10 5th level watersheds of the Chesapeake Bay Watershed. BayFAST utilizes phase 5.3.2 of the Chesapeake Bay Model, a geospatial interface that allows users to draw a polygon corresponding to existing property boundaries, and populates the initial acreages of several component categories of land use and land cover within drawn boundaries based on default or user-specified parameters. Default land use and land cover in BayFAST represents the proportion of historical land use types within a defined region wherein the query occurs. Thus, the percentage of default land uses assumed for the land under consideration reflects percent land use across a larger area. The default land use option was used in this analysis and the distribution of assumed pre-existing land uses evaluated reflect overall proportions of land use trends in the study regions.

BayFAST provides pollutant values in pounds of nitrogen, phosphorus, and sediment that is delivered to the edge of the nearest fourth order stream (edge-of-stream) and delivered to the Chesapeake Bay (delivered to bay). The model provides output that allows the user to compare pollutant dynamics of hypothetical BMP scenarios applied across all or to specific initial land use and land cover types. BMPs in our analysis consisted of additional forest buffer coverage and upland tree planting scenarios based on extant agroforestry demonstration plots (Table 3.1). Each of these scenarios was applied individually to four assumed land uses: hay without nutrients, hay with nutrients, pasture, and row crops. Acreages of assumed land uses in each HUC 10 5th level watershed are presented in section 3.3.

Table 3.1: percentages of additional forest coverage modeled in the buffer and uplands of respondent properties in each of 5 scenarios from our BayFAST modelling adapted from Addlestone & Munsell (2019)

Scenario	% Stream Buffer Tree Coverage	% Upland Tree Coverage
1	0	0
2	5.5	12
3	18	18.75
4	36	37.5
5	100	100

Pollutant reductions were obtained by subtracting corresponding pollutant outputs for additional tree coverage scenarios (scenarios 2, 3, 4, and 5 in Table 3.1) on each land use of each property singly from the baseline, zero percent additional tree coverage scenario (scenario 1 Table 3.1) on the corresponding assumed land use type on each property. The average pollutant reduction in pounds of each scenario per acre of each land use type from all properties in both HUC 10 5th level watersheds was used to calculate a value for relative pollutant reduction efficiency. Pollutant reduction efficiency is the percentage of a pollutant in pounds per acre reduced by intermediate tree coverage scenarios (scenarios 2, 3, and 4 in Table 3.1) relative to the corresponding pounds per acre pollutant reduction of the full forest conversion scenario (scenario 5 in Table 3.1) for each property. Mean pollutant reduction efficiency for each intermediate tree coverage scenario is presented alongside the percentage of additional tree coverage in each scenario in section 3.3.1. Margins of error and means of estimated per acre pollutant reduction values of each scenario as applied to each land use type in each HUC10 5th level watershed are compared to corresponding historic and current program guideline values in section 3.3.2.

3.3 Results

Of the four initial land uses of interest, pasture dominates both of our study areas followed by hay with nutrients, row crops, and hay without nutrients (Table 3.2).

Table 3.2: assumed acreage of respondent properties in total and in each of four land uses of interest from BayFAST analysis by HUC 10 5th level watershed

Sub-watershed	Facility	Hay without nutrients	Hay with nutrients	Pasture	Row crops
Carter Run	1910.4	45.4	224.4	416.4	132.2
Lower North	1928.9	52.6	394.5	610.5	283.8

3.3.1 Relative pollutant reduction efficiency

The results from our BayFAST analyses show that, with 2 exceptions, the percentage of possible pollutant reductions in relation to full forest conversion exceed a 1:1 relationship with additional percentage of forest coverage applied across land uses (Tables 3.3 - 3.6). The first exception occurs with both forms of nitrogen on preexisting land-use class “hay without nutrients” across all tree coverage scenarios. The second exception occurs across all pollutants under scenario 2 on preexisting land use classes “hay without nutrients” and “hay with nutrients” where a direct comparison of tree coverage percentage and nutrient reductions is difficult to make due to the difference in forest coverage percentages in the buffer and upland portions of this scenario (Tables 3.6 and 3.4, respectively). In contrast, scenario 4, where 36% and 37.5% additional forest coverage is modeled on the buffer and upland portions of respondent properties, yields

89.69% and 92.21% of possible nitrogen reductions for edge-of-stream and delivered to bay respectively for preexisting land-use class “Pasture” (Table 3.6).

3.3.1.1 Pasture

BayFAST output shows that pollutant reduction percentages exceed forest coverage percentages based on three functional agroforestry demonstration plots. The pollutant reduction efficiency of intermediate forest conversion on pasture suggests about 90% of the nitrogen reductions possible from full forest conversion can be achieved within the framework of a functional agroforestry system in which 36-37.5% of a pasture is converted to forest. Pasture is the dominant land coverage class in both watersheds on a per acre basis. Relative pollutant reduction efficiency for phosphorus and sediment exceeded a 1:1 relationship with addition forest coverage (Table 3.3).

Table 3.3:Average pollutant reduction by intermediate forest coverage scenarios based on extant agroforestry research plots as a percentage of the possible pollutant reductions of total forest conversion on pre-existing land-use class: “Pasture” from BayFAST analysis (n=124)

Scenario	Forest Coverage		Nitrogen		Phosphorus		Sediment	
	Buffer	Upland	Edge-of-stream	Delivered to Bay	Edge-of-stream	Delivered to Bay	Edge-of-stream	Delivered to Bay
1	0%	0%	0%	0%	0%	0%	0%	0%
2	5.5%	12%	16.0%	16.1%	13.2%	13.8%	12.1%	11.6%
3	18%	18.75%	46.6%	47.9%	30.7%	31.1%	29.4%	29.7%
4	36%	37.5%	89.7%	92.2%	59.2%	60.4%	57.2%	59.4%
5	100%	100%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

3.3.1.2 Row crops and hay with nutrients

BayFAST analysis suggests that ~18% additional forest coverage on fertilized hay fields can reduce ~30% of nitrogen, ~25% of phosphorus, and ~22% of sediment as compared to that reduced by full forest conversion. ~36% additional forest coverage on this same land use achieved ~59% of nitrogen, ~47% of phosphorus, and between ~42 and ~50% of sediment as compared to full forest conversion (Table 3.4). Forest conversions of ~18% and ~36% on crop fields yielded reductions of all pollutants of ~32% and 57% respectively as compared to full forest conversion (Table 3.5). This is significant because “hay with nutrients” and “row crops” represent a combined area in our sample of roughly the same area as that taken up by pasture.

Table 3.4: Average pollutant reduction by intermediate forest coverage scenarios based on extant agroforestry research plots as a percentage of the possible pollutant reductions of total forest conversion on pre-existing land-use class: “Hay with nutrients” from BayFAST analysis (n=124)

	Forest Coverage		Nitrogen		Phosphorus		Sediment	
Scenario	Buffer	Upland	Edge-of-stream	Delivered to Bay	Edge-of-stream	Delivered to Bay	Edge-of-stream	Delivered to Bay
1	0%	0%	0%	0%	0%	0%	0%	0%
2	5.50%	12%	10.91%	10.88%	10.75%	9.61%	9.05%	9.30%
3	18%	18.75%	30.00%	30.25%	25.50%	24.58%	22.31%	22.91%
4	36%	37.50%	58.70%	58.87%	46.86%	46.52%	42.48%	49.39%
5	100%	100%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 3.5: Average pollutant reduction by intermediate forest coverage scenarios based on extant agroforestry research plots as a percentage of the possible pollutant reductions of total forest conversion on pre-existing land-use class: “Row crops” from BayFAST analysis (n=124)

	Forest Coverage		Nitrogen		Phosphorus		Sediment	
Scenario	Buffer	Upland	Edge-of-stream	Delivered to Bay	Edge-of-stream	Delivered to Bay	Edge-of-stream	Delivered to Bay
1	0%	0%	0%	0%	0%	0%	0%	0%
2	5.50%	12%	14.30%	14.38%	15.05%	15.51%	14.84%	14.93%
3	18%	18.75%	31.64%	32.05%	31.85%	32.22%	31.39%	31.55%
4	36%	37.50%	56.82%	56.56%	56.68%	57.40%	56.54%	56.79%
5	100%	100%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

3.3.1.3 Hay without nutrients

Results of our analysis indicate an almost 1:1 relationship between percent additional forest buffer and upland tree coverage and percent nutrient reductions on land-use type “Hay without nutrients.” This relationship is closest to 1:1 for additional coverage and nitrogen removal. For both phosphorus and sediment, this relationship is slightly exceeded (Table 3.6).

Table 3.6: Average pollutant reduction by intermediate forest coverage scenarios based on extant agroforestry research plots as a percentage of the possible pollutant reductions of total forest conversion on pre-existing land-use class: “Hay without nutrients” from BayFAST analysis (n=124)

Scenario	Forest Coverage Buffer	Upland	Nitrogen Edge-of-stream	Edge-of-tide	Phosphorus Edge-of-stream	Edge-of-tide	Sediment Edge-of-stream	Edge-of-tide
1	0%	0%	0%	0%	0%	0%	0%	0%
2	5.50%	12%	5.68%	7.51%	8.64%	10.88%	9.84%	9.91%
3	18%	18.75%	17.81%	19.44%	22.94%	25.45%	23.99%	24.15%
4	36%	37.50%	35.89%	37.99%	46.37%	46.90%	45.31%	45.54%
5	100%	100%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

3.3.2 Mean pollutant outputs and program standards

Tables with mean pollutant outputs and relevant crediting standards from 2008 and 2020 guidances are presented below for each land use in the following order: hay without nutrients, hay with nutrients, pasture, and row crops in each 5th level watershed (HUC 10) (Tables 3.7 - 3.14). Carter run is presented first (Tables 3.7 – 3.10), followed by Lower North River (Tables 3.11 – 3.14). From our BayFAST analysis, almost all 2008 and 2020 pollutant standards are within the margin of error or are exceeded at the 100% forest conversion level. One exception occurred where the 2020 nitrogen standard for "hay/pasture" was not met by the delivered to bay nitrogen output on preexisting land use "pasture," where reductions decreased between scenarios 4 and 5 (Table 3.9). All six 2020 pollutant standards for preexisting land-use type "fallow" are met or exceeded at intermediate levels of forest conversion in both HUC10 5th level watersheds on preexisting land use "hay without nutrients" from our BayFAST analysis (Tables 3.7, 3.11) Furthermore, all standards for sediment on all preexisting land uses are met or exceeded from both HUC10s under intermediate forest coverage scenarios (Tables 3.7-3.14). The largest mean pollutant reduction values achieved are from scenarios on initial land-use class "row crops" (Tables 3.10 and 3.14).

Table 3.7: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Hay without nutrients" on 68 properties in HUC 10 #0208010302 "Rappahannock – Carter Run" compared to 2020 standards generated for forest conversion on preexisting land use class "Fallow" in HUC 8 #02080103 "Rapidan-Upper Rappahannock"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	2.33	0.26	7.38	0.32	15.34	0.33	43.62	0.54		
	Delivered to Bay	0.59	0.18	1.69	0.25	3.19	0.35	8.47	0.28	N/A	0.65
Phosphorus	Edge-of-stream	0.17	0.08	0.4	0.12	0.99	0.22	1.9	0.25		
	Delivered to Bay	0.17	0.11	0.38	0.16	0.69	0.16	1.46	0.24	N/A	0.58
Sediment	Edge-of-stream	101.7	17.98	248.18	170.01	467.26	313.3	1023.7	629.98		
	Delivered to Bay	356.31	62.98	867.78	143.85	1634.28	265.28	3579.33	586.49	N/A	311

Table 3.8: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Hay with nutrients" on 68 properties in HUC 10 #0208010302 "Rappahannock – Carter Run" compared to 2008 standards generated for forest conversion on preexisting land use class "Hay" in "Rappahannock Basin West of I-95" and 2020 standards generated for forest conversion on preexisting land use class "Hay/Pasture" in HUC 8 #02080103 "Rapidan-Upper Rappahannock"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	3.72	0.1	10.61	0.18	20.99	0.29	36.34	0.08		
	Delivered to Bay	0.74	0.06	2.1	0.05	4.12	0.09	7.1	0.06	3.85	5.23
Phosphorus	Edge-of-stream	0.15	0.03	0.42	0.05	0.83	0.06	1.95	0.215		
	Delivered to Bay	0.11	0.03	0.31	0.05	0.63	0.06	1.44	0.05	0.98	0.95
Sediment	Edge-of-stream	94.54	15.17	233.37	38.51	446.92	73.97	1002.81	154.33		
	Delivered to Bay	330.63	53.08	816.07	134.67	1562.63	258.66	3506.58	539.69	N/A	87.49

Table 3.9: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Pasture" on 68 properties in HUC 10 #0208010302 "Rappahannock – Carter Run" compared to 2008 standards generated for forest conversion on preexisting land use class "Pasture" in "Rappahannock Basin West of I-95" and 2020 standards generated for forest conversion on preexisting land use class "Hay/Pasture" in HUC 8 #02080103 "Rapidan-Upper Rappahannock"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	2.87	0.07	9.32	0.14	18.02	0.36	17.31	0.64		
	Delivered to Bay	0.56	0.14	1.84	0.2	3.53	0.07	3.38	0.12	0.74	5.23
Phosphorus	Edge-of-stream	0.22	0.03	0.52	0.02	1	0.02	1.54	0.04		
	Delivered to Bay	0.17	0.03	0.39	0.03	0.76	0.04	1.15	0.03	0.49	0.95
Sediment	Edge-of-stream	72.18	13.45	193.65	34.79	397.1	68.54	645.48	142.23		
	Delivered to Bay	252.41	47.06	677.07	121.7	1388.57	239.68	2257.15	497.35	N/A	87.49

Table 3.10: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Row crops" on 68 properties in HUC 10 #0208010302 "Rappahannock – Carter Run" compared to 2008 standards generated for forest conversion on preexisting land use class "Cropland" in "Rappahannock Basin West of I-95" and 2020 standards generated for forest conversion on preexisting land use class "Cropland" in HUC 8 #02080103 "Rapidan-Upper Rappahannock"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	10.45	0.13	23.11	0.133	41.26	0.12	74.24	0.18		
	Delivered to Bay	2.04	0.09	4.58	0.15	8	0.12	14.44	0.1	4.24	10.48
Phosphorus	Edge-of-stream	0.74	0.08	1.59	0.11	2.8	0.11	4.79	0.13		
	Delivered to Bay	0.59	0.07	1.16	0.07	2.09	0.09	3.57	0.09	1.35	0.88
Sediment	Edge-of-stream	268.5	37.38	567.16	78.81	1019.99	143.39	1793.38	254.77		
	Delivered to Bay	939.02	130.74	1983.08	275.56	3566.72	501.41	6270.87	890.89	N/A	929.69

Table 3.11: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Hay without nutrients" on 53 properties in HUC 10 #020700506 "Lower North River" compared to 2020 standards generated for forest conversion on preexisting land use class "Fallow" in HUC 8 #02070005 "Shenandoah/Potomac"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	3.33	0.33	10.35	0.58	20.15	0.83	54.87	2.30		
	Delivered to Bay	0.59	0.19	1.38	0.23	2.79	0.38	7.41	0.91	N/A	0.57
Phosphorus	Edge-of-stream	0.18	0.07	0.54	0.11	0.91	0.14	2.32	0.24		
	Delivered to Bay	0.09	0.04	0.24	0.07	0.41	0.09	0.96	0.14	N/A	0.34
Sediment	Edge-of-stream	264.62	19.62	644.76	46.69	1219.60	88.07	2701.88	199.21		
	Delivered to Bay	185.94	32.07	453.76	79.71	857.82	148.21	1895.85	319.25	N/A	476.49

Table 3.12: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Hay with nutrients" on 53 properties in HUC 10 #020700506 "Lower North River" compared to 2008 standards generated for forest conversion on preexisting land use class "Hay" in "Shenandoah-Potomac Basin West of I-95" and 2020 standards generated for forest conversion on preexisting land use class "Hay/Pasture" in HUC 8 #02070005 "Shenandoah/Potomac"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	5.71	0.19	15.20	0.52	29.41	1.48	49.27	1.53	4.53	4.98
	Delivered to Bay	0.75	0.09	2.03	0.22	3.93	0.46	6.53	0.69		
Phosphorus	Edge-of-stream	0.52	0.04	1.15	0.08	2.07	0.15	4.17	0.25	0.61	1.19
	Delivered to Bay	0.22	0.02	0.53	0.05	0.96	0.08	1.95	0.12		
Sediment	Edge-of-stream	260.26	18.20	641.47	45.61	1218.11	101.04	2932.79	221.86	N/A	83.84
	Delivered to Bay	184.25	34.24	452.21	80.11	1236.94	869.91	2046.87	323.10		

Table 3.13: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Pasture" on 53 properties in HUC 10 #020700506 "Lower North River" compared to 2008 standards generated for forest conversion on preexisting land use class "Pasture" in "Shenandoah-Potomac Basin West of I-95" and 2020 standards generated for forest conversion on preexisting land use class "Hay/Pasture" in HUC 8 #02070005 "Shenandoah/Potomac"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	5.68	0.17	15.19	0.48	29.10	0.97	36.20	1.64	0.91	4.98
	Delivered to Bay	0.75	0.08	2.02	0.22	3.88	0.42	4.82	0.55		
Phosphorus	Edge-of-stream	0.37	0.03	0.85	0.05	1.65	0.09	2.97	0.25	0.32	1.19
	Delivered to Bay	0.17	0.01	0.39	0.03	0.76	0.05	1.40	0.12		
Sediment	Edge-of-stream	323.75	29.62	765.51	66.13	1464.41	122.49	2626.83	269.44	N/A	83.84
	Delivered to Bay	217.44	21.62	517.75	54.39	994.73	109.48	1784.77	221.59		

Table 3.14: Average lbs/acre nutrient reductions from BayFAST analysis of additional forest coverage scenarios on land-use class "Row crops" on 53 properties in HUC 10 #020700506 "Lower North River" compared to 2008 standards generated for forest conversion on preexisting land use class "Cropland" in "Shenandoah-Potomac Basin West of I-95" and 2020 standards generated for forest conversion on preexisting land use class "Cropland" in HUC 8 #02070005 "Shenandoah/Potomac"

		Scenario 2 5.5% Buffer 12% Upland		Scenario 3 18% Buffer 18.75% Upland		Scenario 4 36% Buffer 37.5% Upland		Scenario 5 100% Buffer 100% Upland			
Pollutant	Fate	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	Mean	MOE +/-	2008 Standard	2020 Standard
Nitrogen	Edge-of-stream	13.05	0.49	28.87	0.99	52.20	1.73	89.69	4.45	10.91	9.91
	Delivered to Bay	1.72	0.17	3.79	0.35	6.80	0.64	11.66	1.15		
Phosphorus	Edge-of-stream	0.84	0.04	1.77	0.07	3.20	0.10	5.83	0.18	0.81	1.59
	Delivered to Bay	0.37	0.03	0.85	0.05	1.48	0.06	2.69	0.08		
Sediment	Edge-of-stream	732.19	45.98	1549.80	98.09	2793.54	175.89	4955.29	308.70	N/A	860.58
	Delivered to Bay	521.81	103.34	1104.37	218.56	1989.98	391.99	3518.23	667.12		

3.4 Discussion

3.4.1 Upland practices

Our analysis indicated that intermediate forest coverage (attained by converting 36% and 37.5% of riparian buffers and upland pastures) can efficiently remove about 90% of the nitrogen abated with 100% forest conversion. These results are supported by field studies in which nitrate leaching levels from silvopasture were lower than from forests and pastures(Bambo et al., 2009; Boyer et al., 2010). However, Boyer et al. (2010) reported greater levels of fecal coliform in leachate from silvopasture. Thus, a water quality trading program narrowly focused on nutrient levels could fail to manage this contaminant. It should be noted that in both of these studies silvopasture was established by thinning existing mixed hardwood forest (Boyer et al., 2010) and pine plantations (Bambo et al., 2009). The portion of nitrate immobilized by tree stumps and roots after cutting can be substantial (Bergholm, Olsson, Vegerfors, & Persson, 2015). Further study should be conducted to elucidate nonpoint source pollutant dynamics of silvopasture achieved from planting trees into existing pastures. Additionally, further study could elucidate the most effective species choices and spatial distribution of trees to maximize overall production from silvopastures while managing for water quality concurrently in the Chesapeake Bay Watershed and surrounding region.

Our results indicate that, in terms of total nutrient reductions, alley cropping in crop and hay fields could yield substantial nutrient reductions. Similar results were reported by modeling (Palma, Graves, Bunce, et al., 2007) and field studies on alley cropping systems that included silvoarable systems, contour intercropping, and hedgerow systems (Allen et al., 2004; Dougherty et al., 2009; Ghosh et al., 1989; Huxley et al., 1994; Narain et al., 1997; Sun et al., 2008; Wei et al., 2007). Furthermore, a review of several studies (Sun et al., 2008) suggests planting hedgerows on contour can reduce run off and soil erosion significantly, particularly when eroded soil from tillage is captured by the hedgerow over time and forms a terrace. The effect of contour planting and terracing is not captured by our modeling and could further enhance nonpoint source pollutant abatement from alley-cropping in hay and crop fields.

Much more research and development of alley cropping systems has taken place in tropical or subtropical contexts, which generally have a greater suite of suitable woody species to use. For temperate alley cropping research, further study should determine ideal species combinations and appropriate spacing to optimally balance production and conservation objectives. Appropriate species combinations will have fewer competitive interactions, and, to maximize water quality abatement specifically, roots of tree and row crops should colonize different soil depths to manifest the arrangement outlined in the "safety net hypothesis" (Huxley et al., 1994; Rowe et al., 1998). To date, some success has been achieved on former mining sites in Europe with black locust (*Robinia pseduoacacia*) alley cropping systems (Quinkenstein et al., 2009; Wöllecke et al., 2005). Though there are potentially many more suitable species for alley cropping in temperate North America, given the land-use history of the Chesapeake Bay headwaters and surrounding region, success with black locust alley cropping systems on post-mining sites in Europe may be mimicked.

3.4.2 Multifunctional Riparian Buffers

Our analysis suggests that forest coverage has a relative advantage in pollutant reduction over a simple fallowed/grassed buffer as the current policy allows. Thus, farmers should receive higher credit values for planting trees in this zone over fallowing or planting grass. This is supported in several studies (Søvik & Syversen, 2008; Udawatta, Garrett, & Kallenbach, 2010; Udawatta et al., 2011). However, this again may be sensitive to the type of pollutant. Although agroforestry buffers, (comprised of four rows of eastern cottonwood (*Populus deltoides),* and an herbaceous understory (tall fescue (*Festuca arundinacea*), Korean lespedeza (*Kummerowia stipulacea*), and red clover (*Trifolium pretense*)) out-performed buffers containing the same herbaceous) in terms of sediment capture, the herbaceous buffers had a slight advantage for nitrogen removal (Udawatta et al., 2010). This may be a function of age and germplasm type of eastern cottonwood which has variable rooting habit among available cultivars and landraces (Cooper & van Haverbeke, 1990). It may also reflect competitive inhibition of tall fescue by eastern cottonwood leaf litter (Clavijo, Cornaglia, Pedro, Nordenstahl, & Jobbágy, 2010), but is likely not due to allelopathy between the two species (Orr, Rudgers, & Clay, 2005). Another study did not find significant differences in grassed or forested buffers for nutrient removal (Syversen, 2005). However, and similar to Udawatta (et al. 2010), Syversen (2005) found enhanced sediment retention in the forested buffer. In other work, grassed and agroforestry buffers had similar pollutant abatement rates at least 10 years from establishment (Dosskey et al., 2007), and riparian buffers can become legacy sources of reactive phosphorus over time (Uusi-Kämppä, 2005).

The water quality trading program currently requires a fixed-width 35-foot buffer to be eligible for credit generation in a landowner's upland property. However, the headwaters of the Chesapeake Bay in Virginia have varying topography which can produce spatially non-uniform runoff. A fixed-width buffer, although simple to verify from aerial photography by program referees, is not the most efficient tool for spatially nonuniform runoff (Dosskey et al., 2005; Dosskey et al., 2015). Design concerns for a multifunctional agroforestry buffer are similar for alley-cropping in that tree root morphology and tolerance to root competition with herbaceous component species must be compatible to yield the water quality abatement effects described in the "safety net hypothesis (Huxley et al., 1994; Rowe et al., 1998)." Pollutant removal efficiency can be enhanced through irregular design to optimize performance under spatially-nonuniform runoff conditions (Dosskey et al., 2005; Dosskey et al., 2015). Perhaps this approach could be expanded to account for mixed-vegetation, agroforestry buffers and into the uplands to provide a design scaffold with which to base agroforestry conversions for production and water quality.

3.4.3 The Future of Agroforestry Nutrient Credit Trading

Neither our analysis nor the analyses used to generate crediting standards are based on the most precise spatial information, nor do they account for potential synergistic relationships between woody perennials and understory crops and livestock produced together on the same plot of land. Assuming technology and technological capacity improves into the future, an automated geospatial tool could be used to generate the optimum design and composition of a buffer for the greatest pollutant reduction efficiency on agricultural operations. AgBufferBuilder a model developed by the USDA's National Agroforestry Center showcases the base capabilities needed to design a grassed buffer of minimal area optimized for sediment trapping under spatially nonuniform runoff (Dosskey et al., 2015). Access to higher-resolution LiDAR geospatial datasets, better data concerning the pollutant reduction efficiency of trees and mixed buffers (compared to simple grassed buffers), and the addition of nitrogen and phosphorus runoff dynamics could be used to optimize buffer design. In turn, credit generation could more accurately represent performance, and farmers would have to devote less productive land to conservation credit generation. Both geographical/biophysical and social/behavioral aspects of disproportionality could be better addressed by offering higher crediting incentives for well-defined areas of higher pollution reduction importance and minimizing the upfront investment in tree establishment and opportunity cost of land taken out of the preexisting mode of production. Furthermore, a GIS layer could be produced to simplify verification of these non-uniform designs by program referees.

Recent changes in Virginia's water quality trading program involve moving away from standards where credits are assigned according to which side of a geographic fall line the property is located on (2008 guidance) to crediting based on HUC 10 basins (2020 guidance). Reductions are now targeted with greater crediting incentives in HUC 10 basins where potential pollutant loads are higher. Taking this momentum to its logical conclusion and following the discussion of increasingly more accurate geospatial datasets, the development of better tools, and higher proficiency with technology among program referees and advisors, the prospect of converting a large area to a certain percentage of tree coverage will be made obsolete. With an increased geospatial resolution for determining credit values and a tool that can accurately model the most efficient land conversion design on a given property, the water quality trading program will be better equipped to account for nonpoint source disproportionality and upland hotspots. This suggests impactful water quality gains could be made with smaller investments in land conversion, and under the framework of agroforestry, these conversions could provide farmers the ability to experiment with alternative productive enterprises without completely retiring existing forms of land use.

3.5 Conclusion

Additional forest coverage offers significant opportunities to reduce nonpoint source pollutants to the Chesapeake Bay. Reductions can be credited and sold to regulated pollutant sources elsewhere in the Bay. Significant reductions can be achieved at intermediate levels of forest conversion. These intermediate levels of forest coverage could be achieved in the context of productive agroforestry systems. If agroforestry systems were adequately credited in the water quality trading program such that the disproportional assessment and design are most significantly rewarded, this could engage farmers to further manage for water quality while maintaining commodity production on working lands. Existing tools could be modified to better target fields within the watershed and even sites within fields of greatest priority for water quality-based agroforestry conversions. With more accurate estimates of pollutant contributions on the field level or smaller, credits will be assigned more fairly among landowners within the same area that standards are generated for. Future research could help inform farmers about what to plant in these priority areas to meet both production and conservation objectives. Front-loaded revenue from credit generation could help offset establishment and maintenance costs. Agroforestry nutrient credit trading could offer a win for farmers, regulated pollutant sources, and local ecosystems.

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4. Conclusion

In chapter 2, I analyzed respondent demographics and land management objectives in regard to agroforestry interest. Qualitative reactions were analyzed to elucidate underlying themes of open responses to the themes of the survey. I found that landowners differed significantly in agroforestry interest with Baby Boomers and Gen X more interested than previous generations, while younger generations likely do not own much of the land yet. I found that landowners who rated environmental and aesthetic items highest in importance in their land-use decisions-making had higher mean agroforestry interest while landowners who rated production and income items moderately had higher agroforestry interest than those who rated them as not important or very important. The most common theme in landowner reactions to agroforestry systems were reservations about incompatibility between trees and other elements of the agricultural system. In their responses, respondents anticipated tree failure, increased weed pressure, and expressed misgivings about the funding/execution of prior conservation programs. Further research and study could go into developing and packaging agroforestry systems that minimize incompatibility and weed reservoir concerns. Further outreach and policy should investigate approaches that minimize government involvement and funding in favor of other source such as non-governmental organizations and market-based water quality abatement schemes.

In chapter 3, pollutant reductions and pollutant reduction efficiency of nitrogen, phosphorus, and sediment from intermediate forest conversion scenarios based on agroforestry demonstration plots were modeled on 4 assumed extant land uses on respondent properties. Pollutant reductions were compared to current and historic program standards. In chapter 3, I found that the percentage of pollutants reduced by additional forest coverage scenarios generally exceeded the percentage of additional forest coverage in each scenario except for low additional tree coverage scenarios and for nitrogen on hay without nutrients across all intermediate tree coverage scenarios. Additional tree coverage of 36% in the buffer and 37.5% in the uplands yielded the highest reduction efficiency of about 90% of the nitrogen reductions of a complete forest conversion scenario on pasture. Compared to both historic and program standards, our analysis suggests most sediment standards are achieved by low density forest coverage scenarios such that sediment is likely under-credited. The lowest density forest conversion scenario exceeded program standards for nitrogen on land-use class hay without nutrients, meaning tree plantings on hay without nutrients are likely under-credited. Program standards for forest conversion differ from our analysis, with many being achieved at intermediate forest coverage levels the extent to which varies. Further research and development should look to incorporating agroforestry specific terrestrial nutrient dynamics into modeling and developing geospatial design tools that use precise information to generate buffer and upland tree planting designs that can be used as the basis for agroforestry conversion. Further policy should look to credit neighboring fields more accurately for their pollutant abatement and allow low risk productive land uses such as agroforestry.

In general, agroforestry nutrient credit trading presents several opportunities for water quality management and farmer livelihoods in the Chesapeake Bay. Water quality trading could present an alternative conservation strategy to engage landowners who have negative perceptions of government and government programs, are averse to the use of tax dollars, suspect fraud, and are repelled by other aspects of past conservation programs. To succeed, crediting policy will need to recognize and properly credit intermediate forest coverage and landowner concerns will need to be addressed in outreach. Further study could survey landowners further along the decision process, present the prospect of agroforestry water quality trading, and further explore leverage points and limitations for adoption. Future field studies could seek to develop regionally appropriate examples of agroforestry systems, optimal species combinations, and design parameters to optimize the balance of production and conservation objects. The communication of these systems could then be made more efficient by developing packaged systems which could be adapted to site conditions. As this study was limited in geographic scope, surveys and terrestrial nutrient modeling could be extended to other watersheds. For the future, extant geospatial tools could be retrofit or redesigned to take into account future data on water quality implications of agroforestry adoption in order to inform the design of agroforestry systems for water quality and properly credit these systems in a more refined spatial context.

5. Summary

In summary, agroforestry water quality trading has potential to simultaneously support agricultural livelihoods and water quality. In order to realize this potential, landowner concerns and objectives concerning agroforestry need to inform research and development as well as be addressed in the content and delivery of messaging. Landowners will likely favor an approach that limits the role of government regulation and public funds such as water quality trading. For agroforestry water quality trading to be successful, terrestrial nutrient dynamics of agroforestry conversions should be better captured in modeling used for crediting. To simplify the design process, geospatial tools could be retrofit or developed to use precise site information to minimize the amount of land needed to be converted for water quality, have crediting more accurately reflect water quality performance, and produce a shape file to facilitate verification by program referees.

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7. Appendix

7.1 Survey Instrument

Trees in Farm Fields, Pastures, and Creek Sides

What do you think?

A Short Survey for Virginia Landowners

Whether you think the idea is great or terrible, your responses to this **short 3-page** questionnaire matter. They will help us piece together an honest picture of what Virginia landowners think about planting tree crops on farms, open fields and creek sides. The survey should take less than 10 minutes to complete and by law your responses will remain confidential. Thank you very much for participating. We would be happy to send you a general summary of the results if you enclose your name and address.

VirginiaTech
Invent the Future

1. What are the **<u>top 3 reasons</u>** you own land? **(Please check only 3)**

- ☐ Beauty
- ☐ Hunting
- ☐ Leisure
- ☐ Investment
- ☐ Farming (livestock, hay, crops, etc.)
- ☐ Family
- ☐ Home
- ☐ Wildlife
- ☐ Timber
- ☐ Something else? ______________________________

2. How many years have you owned land? ________ **Years**

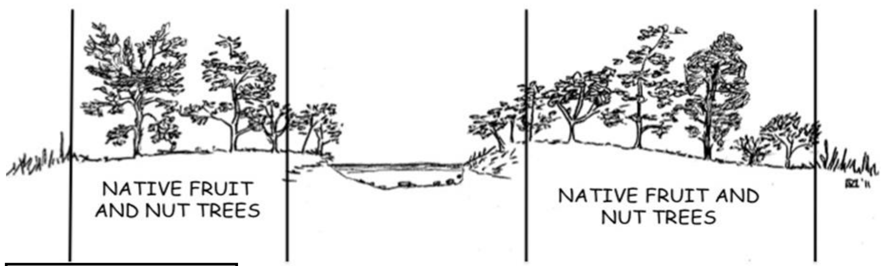
3. Please indicate your interest in the tree crop projects displayed in the drawings below

First Picture – Growing fruit and nut trees and shrubs on your creek sides **(Please circle only one number)**

Interest level increases from left to right

I am not interested ——————————→ I am very intereste

1 **2** **3** **4** **5**



First Picture

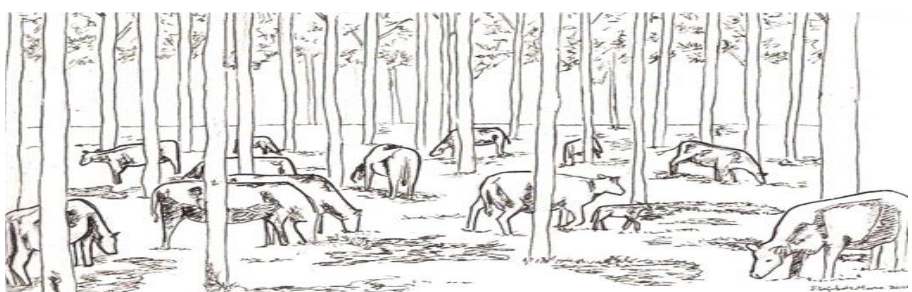
Third Picture – Growing crops in between rows of crop trees **(Please circle only one number)**

Second Picture – Growing crop trees where livestock graze **(Please circle only one number)**

I am not interested ——————————→ I am very interested

Interest level increases from left to right

1 **2** **3** **4** **5**



Second

I am not interested ——————————→ I am very interested

Interest level increases from left to right

1 **2** **3** **4** **5**

Third Picture

4. Do you raise crops to sell, if so, what do you grow? ____

If not, ☐ I raise crops **but not to** sell *or* ☐ I **do not** raise crops

5. Do you raise livestock to sell, if so which animals? ____

If not, ☐ I raise livestock **but not to** sell *or* ☐ I **do not** raise livestock

6. If you raise crops and/or livestock *for sale*, to whom do you sell your goods? **If not**, skip to next question.

☐ Crop aggregator	☐ Feed company	☐ Agricultural corporation
☐ Grocery store	☐ Roadside stand visitor	☐ Farmers market patron
☐ Specialty food store	☐ Restaurant	☐ Community Supported Agriculture members

☐ Someone or somewhere else? ____

7. Have you ever planted trees in fields, pastures, or creek sides? (**Please check only one)**

☐ **YES** or ☐ **NO**

8. Please indicate how important these potential benefits are to you when making land management decisions. **(Please write in one importance level for each potential benefit)**

1 → **2** → **3** → **4**

Not at all important **Somewhat important** **Important** **Very important**

____ Crop production	____ Water quality	____ Livestock	____ Wildlife habitat
____ Soil conservation	____ Income	____ Beautification	____ Resale

9. Planting trees on farms is… **(Please circle only one number)**

A terrible idea → An ok idea → A great idea

1 **2** **3** **4** **5**

10. I could profitably sell fruit and nuts produced on my property **(Please circle only one number)**

Strongly disagree ← Don't know → Strongly agree

1 **2** **3** **4** **5**

11. I could profitably sell merchantable timber grown on my property **(Please circle only one number)**

Strongly disagree ← Don't know → Strongly agree

1 **2** **3** **4** **5**

12. Are there any of the following value-added opportunities near your property? **(Please check all that apply)**

☐ Growers groups ☐ Food hubs ☐ Distribution centers ☐ Canneries

Next to last page! Thanks for your patience

☐ Tool/equipment-shares ☐ Certified kitchens ☐ Agri-tourism ☐ Don't know

13. Please circle **only one number** to indicate the **balance for you** between the two “end-point” options that finish each statement. “**3**” = a perfect mixture of the two, and “**1**” and “**5**” = completely one or the other.

When it comes to projects on my land…

I do all the work ←		**perfectly balanced**	→ I don’t do any of the work	
1	**2**	**3**	**4**	**5**
I never seek advice		**perfectly balanced**	I always seek advice	
1	**2**	**3**	**4**	**5**
I do a lot of them		**perfectly balanced**	I don’t do any	
1	**2**	**3**	**4**	**5**
I own all the equipment		**perfectly balanced**	I don’t own any equipment	
1	**2**	**3**	**4**	**5**

When it comes to outdoor recreation…

I prefer intense activities ←		**perfectly balanced**	→ I prefer leisurely activities	
1	**2**	**3**	**4**	**5**
I organize a lot of activities		**perfectly balanced**	I never organize activities	
1	**2**	**3**	**4**	**5**
I own lots of recreational equipment		**perfectly balanced**	I own no recreational equipment	
1	**2**	**3**	**4**	**5**
I am very interested		**perfectly balanced**	I am generally not interested	
1	**2**	**3**	**4**	**5**

When it comes to issues in my community…

I always share my opinions ←		**perfectly balanced**	→ I let others speak for me	
1	**2**	**3**	**4**	**5**
I am always interested		**perfectly balanced**	I don’t care all that much	
1	**2**	**3**	**4**	**5**
It is my duty to speak out		**perfectly balanced**	Public debate is not my obligation	
1	**2**	**3**	**4**	**5**
I am very active		**perfectly balanced**	I rarely get involved	
1	**2**	**3**	**4**	**5**

We would like to stay in touch if you are interested in learning more about or participating in workshops or tours focused on planting and managing crop trees in fields, pastures or on your creek sides. If so, please provide your name and the best way to contact you (ex., email or phone number)

____

Below are a few demographic questions – please recall our mandate to protect your confidentiality but we understand if you are not comfortable answering one or more of them

14. What year were you born? __________ ***and*** are you? ☐ **Male or** ☐ **Female**

15. What is the highest level of education you have completed? **(Please check only one box)**

☐ Some high school ☐ High school / GED ☐ Associates degree ☐ Bachelor's degree ☐ Graduate degree

16. What was your approximate 2013 household income before taxes? **(Please check only one box)**

☐ Less than $24,999	☐ $25,000 to $49,999	☐ $50,000 to $99,999
☐ $100,000 to $149,999	☐ $150,000 to $200,000	☐ More than $200,000

Do you have any final thoughts or reactions that you would like to share?

____

____

Many thanks for your time and effort!

7.2 ANOVA of Agroforestry Interest by ten-year age cohort

Table 7.2.1: Results of one-way ANOVA of Agroforestry Interest by ten-year birth cohort.
H_0 = Agroforestry interest does not vary by ten-year birth cohort.
*, **, and *** indicate H_0 is rejected at α=0.05, α=0.01, and α=0.001 levels of significance, respectively.

Ten-year birth cohort***				
1 1910-1919	3	0.5%	2.11	1.39
2 1920-1929	20	4.0%	1.76	0.89
3 1930-1939	73	12.7%	1.81	0.91
4 1940-1949	171	29.64%	2.3	1.05
5 1950-1959	188	32.6%	2.6	1.09
6 1960-1969	86	14.9%	2.94	1.05
7 1970-1979	27	4.7%	2.7	1.14
8 1980-1989	9	1.6%	2.67	1.22

Table 7.2.2: Results of Bonferroni multiple comparison tests following one-way ANOVA of Agroforestry Interest by ten-year birth cohort.
H_0 = Agroforestry interest does not vary by ten-year birth cohort
, **, and * indicate H_0 is rejected at α=0.05, α=0.01, and α=0.001 levels of significance, respectively.*

Cohort (a)	Cohort (b)	Mean difference (a-b)	P
1910-1919	1920-1929	0.35	1.000
	1930-1939	0.30	1.000
	1940-1949	-0.19	1.000
	1950-1959	-0.49	1.000
	1960-1969	-0.83	1.000
	1970-1979	-0.59	1.000
	1980-1989	-0.56	1.000
1920-1929	1930-1939	-0.05	1.000
	1940-1948	-0.54	1.000
	1950-1959	-0.84	0.078
	1960-1969	***-1.18	0.002
	1970-1979	-0.94	0.147
	1980-1989	-0.91	1.000
1930-1939	1940-1949	*-0.49	0.037
	1950-1959	***-0.79	0.000
	1960-1969	***-1.13	0.000
	1970-1979	**-0.89	0.006
	1980-1989	-0.86	0.814
1940-1949	1950-1959	-0.30	0.230
	1960-1969	***-0.64	0.000
	1970-1979	-0.40	1.000
	1980-1989	-0.37	1.000
1950-1959	1960-1969	-0.34	0.437
	1970-1979	-0.10	1.000
	1980-1989	-0.07	1.000
1960-1969	1970-1979	0.24	1.000
	1980-1989	0.27	1.000
1970-1979	1980-1989	0.03	1.000