Nitrogen Fertilizer Application to Virginia's Eastern Shore: Refining Land Use and Fertilizer Estimates for the Seaward Side

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Abstract

Reactive nitrogen (N_r) inputs to the seaward side of Virginia's Eastern Shore from agricultural fertilizer were estimated with a high-resolution GIS data layer in which active agricultural fields were represented as individual polygons. Fields within the watersheds that feed the seaside lagoons were identified from the most recent high-quality air photos from the Virginia Base Mapping Program (VBMP) and manually digitized. Identification of fields under active cultivation was based on the presence of crops or tilling patterns and the absence of large areas of standing water, woody vegetation, livestock, or suburban development in the photos. A total of 2038 individual fields were identified and outlined, and each field was assigned a crop rotation based on CropScape data [USDA, 2017] from 2013 through 2016. 84% of fields were identified as growing a corn, wheat, and soybeans rotation. N_r application was assigned to each field based on the recommendations of the Virginia Cooperative Extension. Based on this data layer, the total mass of N_r applied as fertilizer to the seaward side was estimated to be 2.02×10^6 kg per year. The average fertilizer application rate was estimated to be 123 kg of N_r per year per hectare of cropland.

This data layer is being used to help estimate of agricultural N_r inputs to the seaside lagoons for the entirety of the Virginia Eastern shore, but it can also be used on a watershed or sub-watershed scale to estimate N_r inputs to individual streams or bays. This tool will be useful in estimating agricultural N_r inputs upstream of water sampling locations, which can help researchers estimate N_r removal by biological processes in various soils, aquifers, and creeks. This data layer yields less spatial error than CropScape alone, which has lower resolution and often falsely categorizes abandoned fields or meadows as active cropland in the study area.

Introduction

The purpose of this thesis is to estimate the amounts of reactive nitrogen applied as agricultural fertilizer to cropped fields on the seaward side of the Virginia Eastern Shore. Reactive nitrogen (N_r) refers to the biologically active forms of nitrogen (N) which are necessary for life [*Galloway and Cowling,* 2002]. The species of N_r include all forms of N except unreactive dinitrogen gas (N_2). Nitrogen compounds can be assimilated into biomass or exist as free molecules in the environment. Inorganic N_r is cycled through the environment via a series of the microbially-mediated oxidation and reduction reactions including nitrification and denitrification, respectively. The process of nitrification refers to the oxidation of ammonia (NH_3), first to nitrite (NO_2^-) and then to nitrate (NO_3^-) (Equation 1), whereas the process of denitrification is the process where nitrate is reduced sequentially to nitrite (NO_2^-), nitric oxide (NO), nitrous oxide (N_2O), and finally to unreactive dinitrogen gas (N_2) (Equation 2) by the oxidation of organic carbon. Nitrogen fixation is the process by which dinitrogen gas (N_2) is converted to ammonia (NH_3) (Equation 3). Nitrogen can be fixed through natural processes or synthetically though man-made processes.

$$\mathbf{NH_3 \rightarrow NO_2^- \rightarrow NO_3^-} \qquad \text{Equation 1}$$

$$\mathbf{NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2} \qquad \text{Equation 2}$$

$$\mathbf{N_2 \rightarrow NH_3} \qquad \text{Equation 3}$$

Although there are other oxidation and reduction reactions involving N, nitrification and denitrification dominate in most systems, and are the dominant reactions globally [*Mills,* 2017].

Availability of N_r is a predominant limiting factor when it comes to agricultural food production, and modern agriculture relies heavily on synthetically fixed nitrogen fertilizer to meet the demands of the growing global population [*Gruber and Galloway*, 2008]. The advent of the Haber-Bosch process of industrial synthetic nitrogen fixation has led to a drastic increase in nitrogen fertilizer availability and usage that, when coupled with advances in genetic crop modification, has led to a great increase in crop yields [*Erisman et al.,* 2008]; however, it has also led to an increase of N_r in environmental reservoirs [*Galloway et al.,* 2003], particularly in the groundwater underlying and adjacent to agricultural areas [*McMahon et al.,* 2008*; Howarth,* 2008*; Denver,* 1989]. This accumulation has occurred because, although methods have been developed to fix N_2 into N_r synthetically, there is no widely-used industrial means of returning excess N_r to its unreactive state, and the amount of N_r being added to ecosystems often substantially exceeds the ability of the existing microbial communities to return the N_r to its unreactive state through denitrification.

Common nitrogen fertilizers include ammonium nitrate (NH_4NO_3), ammonium sulfate ($(NH_4)_2SO_4$), diammonium phosphate ($(NH_4)_2HPO_4$), and urea ammonium nitrate (UAM, a mixture of urea ($CO(NH_2)_2$), ammonium nitrate, and water) [*Maguire et al.,* 2009]. Losses of N_r from soil due to volatilization, denitrification, and leaching are often unavoidable; while a field with poorly-drained soil may be prone to high soil denitrification, a well-drained field may be at higher risk for leaching [*Spalding and Exner,* 1993*; Bouwman et al.,* 2002*; Hofstra and Bouwman*, 2005]. In aerobic soils, the reduced nitrogen in these fertilizers will undergo nitrification, and, because it is a mobile anion, nitrate that isn't taken up by crops can quickly leach into the groundwater. N_r often exists in high concentrations in groundwater under and adjacent to regions of intense agricultural activity, [*McMahon et al.,* 2008*; Howarth,* 2008*; Denver,* 1989]. Indeed, nitrate is the most ubiquitous contaminant of groundwater in the US

[*Canter,* 1997]. In high enough concentrations, N_r, along with other limiting nutrients like phosphorus, can cause eutrophication and harmful algal blooms [*Boesch et al.,* 2001*; Heisler et al.,* 2008].

Coastal lagoons with high residence times, such as the mid-Atlantic lagoons, are particularly susceptible to algal blooms caused by nutrient enrichment [*Bricker et al.,* 2008], and the Chesapeake Bay has been under extreme eutrophication pressure for many years. The coastal marshes and lagoons of the Virginia Coast Reserve are, therefore, at risk due to extensive fertilization of farms along the Delmarva Peninsula. However, the seaside lagoons of the Eastern Shore of Virginia do not seem to have experienced the same magnitude of eutrophication as the Chesapeake Bay [*Cole,* 2011]. Certainly the high ratio of water to land plays a role, as does the continual flushing of the lagoons with oceanic water, but biological processes in stream sediments have also been credited with reducing NO_3^- discharge to streams from groundwater [*Mills et al.,* 2011*; Gu et al*., 2007; *Gu et al*., 2008]. Continuation of the quality of water in the seaside lagoons of the Eastern Shore is therefore dependent in part upon agricultural inputs of N_r not exceeding the capacity of streambed denitrifying bacterial communities to remove these contaminants in the watersheds where this process occurs at a substantial level.

Virginia's Eastern Shore comprises Accomack and Northampton counties that cover the southern portion of the Delmarva Peninsula. The geology of both counties consists mainly of unconsolidated, fossiliferous upper Pleistocene-era sand, gravel, silt, and clay deposits, known as the Columbia group, overlying Miocene-era sand and clay layers [*Sinnott and Tibbitts,* 1954; *Mixon*, 1985]. Together, they make up 5452 km^2 of sandy peninsula. According to the USDA's

2012 census of Agriculture [*USDA NASS,* 2014], 22.3 % of Accomack county and 31.6 % of Northampton county is cropland, for a total of 4.33 x 10^4 hectares of cropland across both counties. Overall, 25.3% of Virginia's Eastern Shore is cropland. The distribution of this agricultural land over the peninsula is variable (Figure 1).

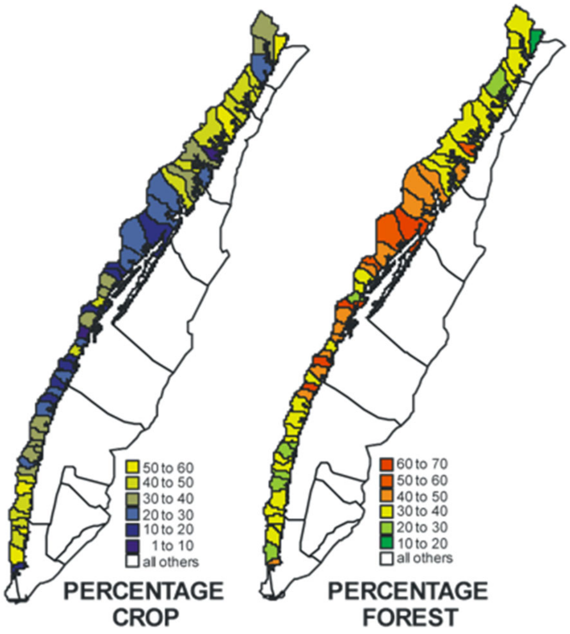


Figure 1. Map of the Virginia Eastern Shore's seaside watersheds showing how estimated percentage of cropland (left) and forest (right) vary spatially. Maps generated by [*Mills et al.,* 2011] from data by [*Hayden and Porter*, 2001]

The Eastern Shore's upland soils are predominantly members of the Bojac series (Coarse-Loamy, Mixed, Semiactive, Thermic Typic Hapludult), which covers about 40% of Northampton county [*Norris et al.,* 1989] and about 22% of Accomack county [*Norris et al.,* 1994]. These well-drained, sandy soils have a relatively high hydraulic conductivity, about 0.4 × 10^{-2} cm/sec to 1 × 10^{-2} cm/sec [*Gallagher et al*., 1996], therefore the potential for rainwater to leach reactive nitrogen from the surface of farm fields and quickly transport it to the underlying water table is high. The Eastern Shore's unconfined aquifer comprises predominantly unconsolidated fine- to medium-grain sand, gravel, and shells, early to mid-Pliocene in age [*Mixon,* 1985]. Such aquifers are often low in organic carbon, and therefore have limited potential for denitrification [*Hiscock et al.*, 1991]. Once reactive nitrogen reaches the groundwater as nitrate, it remains unchanged quantitatively or qualitatively until it reaches a location where biological activity can occur [*Denver et al.*, 2004; *Mills et al.,* 2011].

Understanding how N_r moves through the ecosystem requires a good estimate of both nitrate inputs and outputs (Figure 2). N_r outputs for sixteen seaside streams on the Eastern Shore of Virginia have been monitored since 2001 (Bundick Creek, Parker Creek, Ross Branch Creek, Frogstool Branch, Pungo Creek, Coal Kiln Creek, Green's Creek, Phillip's Creek, Red Bank Creek, Mill Creek North, Holt Creek, Taylor Creek, Cobb Mill Creek, Narrow Channel Branch, Mill Creek South, and Tommy's Ditch) [*Chauhan et al.*, 2003; *Mills et al.,* 2003; *Olson et al.,* 2006; *Mills et al.,* 2011], which has led to several estimates of nitrogen loading from the uplands to the seaside lagoons (Table 1). Stream discharge for the 16 streams was related to watershed area [*Hayden and Porter*, 2001] in order to construct a discharge-to-watershed-area relationship. This relationship was used to predict discharge in the 38 unmonitored seaside watersheds. Likewise, nitrogen concentrations were recorded in the 16 streams in order to construct a relationship between N concentration and agricultural intensity in the specific watershed. This relationship was used to predict N concentrations in the unmonitored streams.

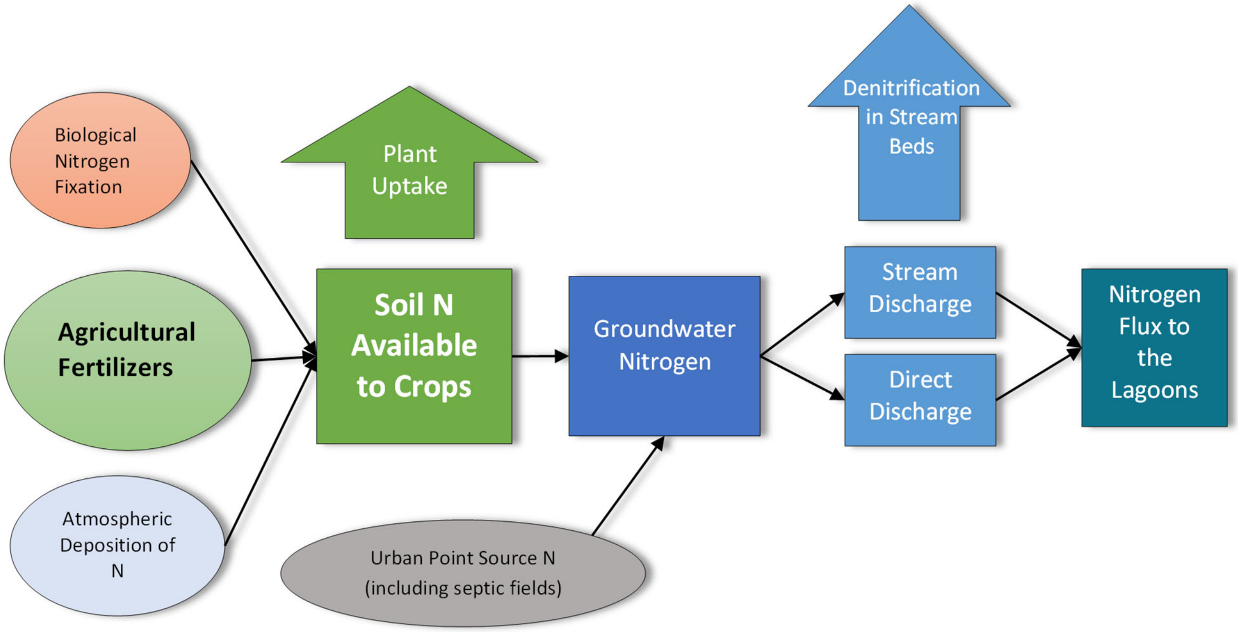


Figure 2. A mass balance diagram depicting the flow of reactive nitrogen through the Eastern Shore ecosystem.

Predicted N concentration and predicted discharge in the 54 seaside watersheds was used to estimate N loading to the seaside lagoons [Chauhan et al., 2003; Mills et al., 2003; Olson et al., 2006; Mills et al., 2011].

Table 1. Five Estimates of Annual N (as NO_3^-) Loading to the Seaside Lagoons of Virginia's Eastern Shore.
Table from (*Mills et al.,* 2011)

Estimated Load (kg NO_3^--N)	**Reference**
1.4-2.5 x 10^5	*Chauhan et al.*, 2002
3.8 x 10^5	*Mills et al.,* 2003
2.6 x 10^5	*Olson et al.,* 2006
7 x 10^4	*Cole*, 2011*
1.8 x 10^5	*Mills et al.,* 2011

*Estimate is for 6 small and 9 large watersheds

Though the above method is useful in estimating N_r output, N_r inputs are still largely unknown. Factors such as distribution of different crops and their differing fertilizer application rates are not taken into account, which is a source of potential error as agriculture is the most significant terrestrial source of reactive nitrogen to the groundwater [*Cole,* 2011]. In order to begin to estimate overall N_r inputs, the distribution and intensity of these inputs must be known.

Agricultural inputs can be divided into fertilizer applied to cropland, and nitrogen-rich waste associated with livestock production. Other, relatively smaller sources of N_r include atmospheric deposition of reactive nitrogen, biological nitrogen fixation, and urban point sources (Figure 2). Urban point source nitrogen might include residential use of fertilizers and septic system effluent. According to the National Atmospheric Deposition Program [*National Atmospheric Deposition Program*, 2017], 1.5 kg/ha of NH_4^+-N and 1.4 kg/ha of NO_3^--N were deposited in the Chesapeake Bay region from atmospheric wet ion deposition in the year 2015

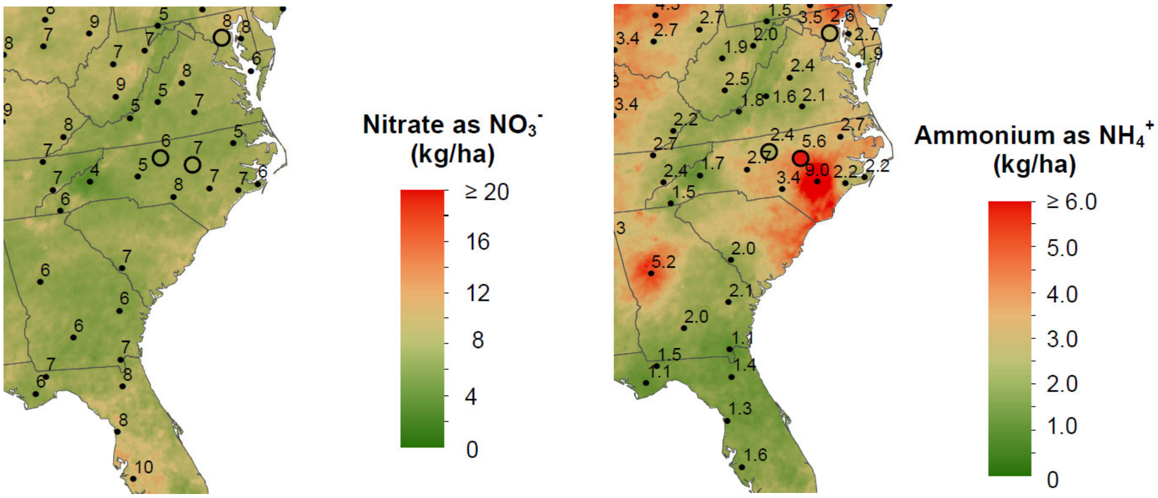


Figure 3. Maps of wet ion deposition of NO_3^- (left) and NH_4^+ (right) in kg/ha for the year 2015 [*National Atmospheric Deposition Program,* 2017]

(Figure 3). Biological nitrogen fixation can potentially contribute anywhere from 0.5 - 100 kg of N_r per hectare per crop rotation depending on the type of legume grown [*Maguire and Heckendorn*, 2017]. On the Eastern Shore, however, soybeans are the only widely grown nitrogen-fixing crop [*USDA NASS*, 2014], and they contribute roughly 0.5 kg of N_r per hectare after harvest [*Maguire and Heckendorn*, 2015]. Contribution of N_r from soybeans grown on the Eastern Shore is so low because the majority of the plant's nitrogen is stored in its seed pods, which are carried away during harvest. The 0.5 kg of N_r per hectare contributed to the soil represents the plant's below- ground biomass, including its nodulated roots, left behind after harvest. On average, growing soybeans does not result in a net input of N_r to the ecosystem if the beans are harvested, particularly if high yield cultivars are being grown [*Salvagiotti et al.*, 2008]; therefore a 0.5 kg per hectare contribution of N_r is reasonable in this instance.

Previous estimates of N_r applied to cropped fields on the Eastern Shore were made at the county level [*Mills*, 2015] (Table 2). Average fertilizer application rates for both Accomack and Northampton counties were multiplied by the total amount of fertilized cropland to find total annual application for each county. To estimate total application in the seaside watersheds, the fraction of the total two county area which comprised the seaward watersheds was multiplied by the total fertilizer applied. This method assumed that application rates were uniform across the entire Eastern Shore, but because farming intensity is variable along the length of the peninsula (Figure 1), it should follow that fertilizer application is not uniform either. Though the assumption of uniform application rate might be reasonable for a county-wide estimate, the smaller and more specific an area for which fertilizer application estimates are attempted, the more likely it is that these estimates will be less accurate. For higher granularity estimates of fertilizer application, a different approach is required.

Table 2. Estimated Fertilizer-N Inputs to Virginia's Eastern Shore [*Mills* 2015]

County	Fertilized Cropland (ha)	Annual Application Rate (kg/ha)	Total Annual Application (kg)
Accomack	21,174	100	2,112,265
Northampton	20,924	89	1,852,751
Eastern Shore (both counties)	42,098	94	3,963,612
			Total Fertilizer Input to Seaside (kg)
			1.01 x 10^6 kg

The objective of this project was to develop a reasonable, high resolution estimate for reactive nitrogen applied as fertilizer to cropland within the seaside watersheds on Virginia's Eastern Shore. No recent land use map exists of the seaward side of Accomack and Northampton counties with suitably high resolution and accuracy; therefore, an updated, high-resolution data layer covering the seaward side of the Eastern Shore that accounts for cropped area, including the crops grown, was created in order to estimate fertilizer N_r inputs to the seaside watersheds.

Research Approach

Using the most recent high resolution air photos (taken in Spring 2013-2015) collected by the Virginia Base Mapping Program [*VBMP,* 2015], farm fields under active cultivation were identified and hand-digitized for the entirety of the seaward side of the Virginia Eastern Shore using ArcMap 10.1 (ESRI). A polygon was drawn around the borders of each field identified as cropland. Fields were outlined as precisely as possible, creating a single-feature layer of polygons, with each polygon representing an individual field (Figure 4). When multiple fields were adjacent to one another, or when different crops were being grown on different parts of a field, care was taken to subdivide the field polygons so that, as much as possible, each polygon encompassed a single field growing a single crop. Visual cues were used to identify fields that are most likely currently under cultivation because of the visual similarities between agricultural fields and vacant lots in the airphotos. These visual cures were the presence of tilling or planting patterns, the lack of standing water, absence of livestock, absence of signs of suburban development such as paved roads, and a lack of successional vegetation such as woody shrubs. Where available, street-view photography was used to verify the field classification [*Google, 2014*]. The street view photos used were taken between the months of June and November, 2014.

Next, each individual farm field polygon was assigned a crop or crop rotation that was predominantly farmed on that field. CropScape (https://nassgeodata.gmu.edu/CropScape/) data for the years 2013-2016 were downloaded for Northampton and Accomack Counties, VA. Four years of data were used to increase the probability of observing less commonly planted

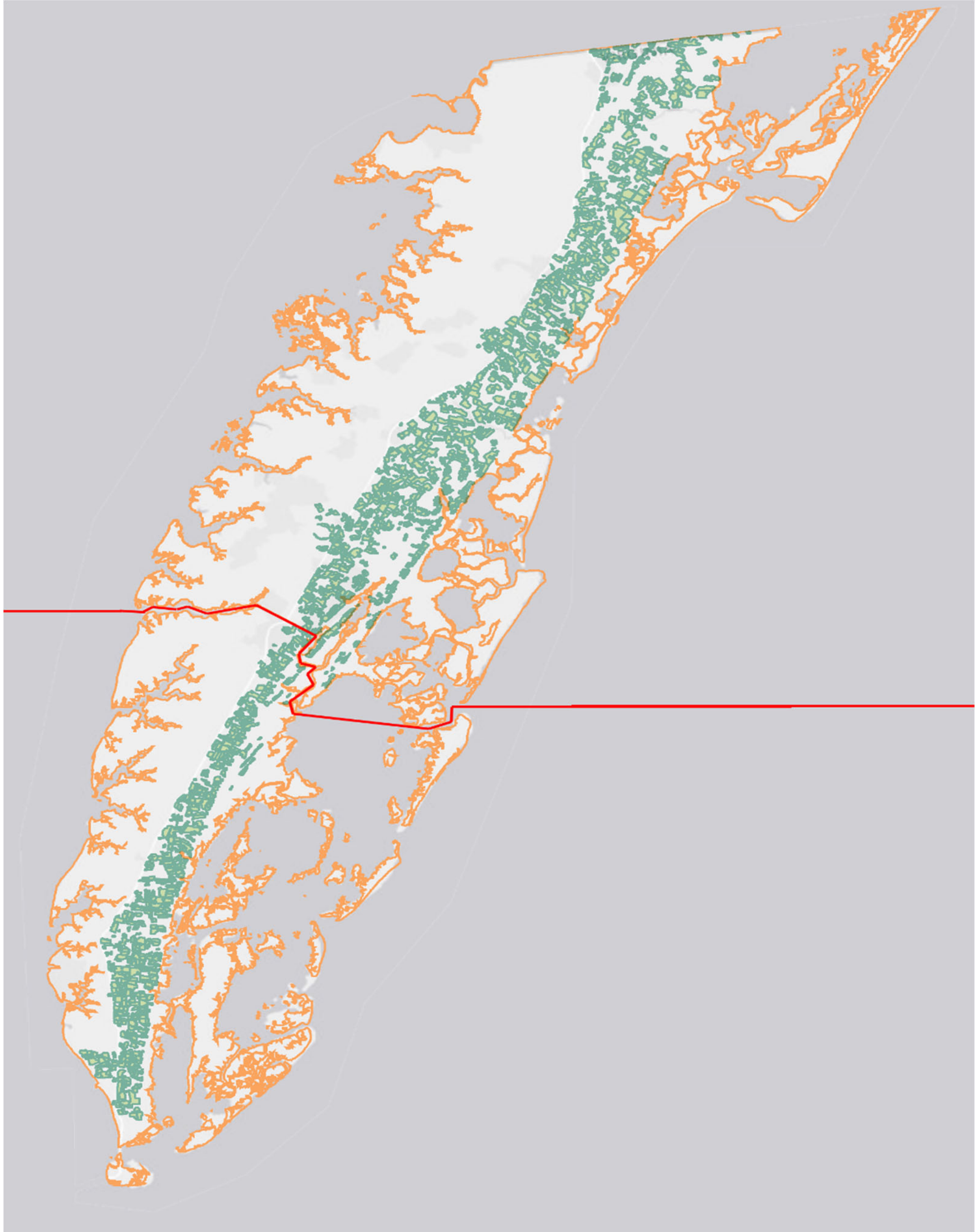


Figure 4. GIS map of Virginia's Eastern Shore showing agricultural fields within the seaside watersheds in green. The red line shows the boundary between Accomack county (north) and Northampton county (south).

crops and to permit some level of averaging of interannual variation to allow the results to be generalized. The CropScape data layers exist as raster files that do not include data for tomato fields [*Brush et al.,* 2015]. Therefore, all tomato fields within the area of interest were identified manually using air photos. The rows of dark plastic liners typically used in tomato "plasticulture" were distinctive in the air photos (Figure 5), making remote identification possible. Any air photos taken during the growing season would show all of the active tomato fields for that year because tomatoes are typically not rotated in sequence with other harvested on the Eastern Shore [*Theresa Pittman, Accomack County Cooperative Extension, personal communication,* 2017].

Once the tomato fields were identified, the CropScape data layers were analyzed. CropScape uses numerical data to indicate which crops are grown where. For example, a

Figure 5. An Eastern Shore air photo showing a tomato field (outlined in red) adjacent to several non-tomato fields. Note the darker striations in the tomato fields.

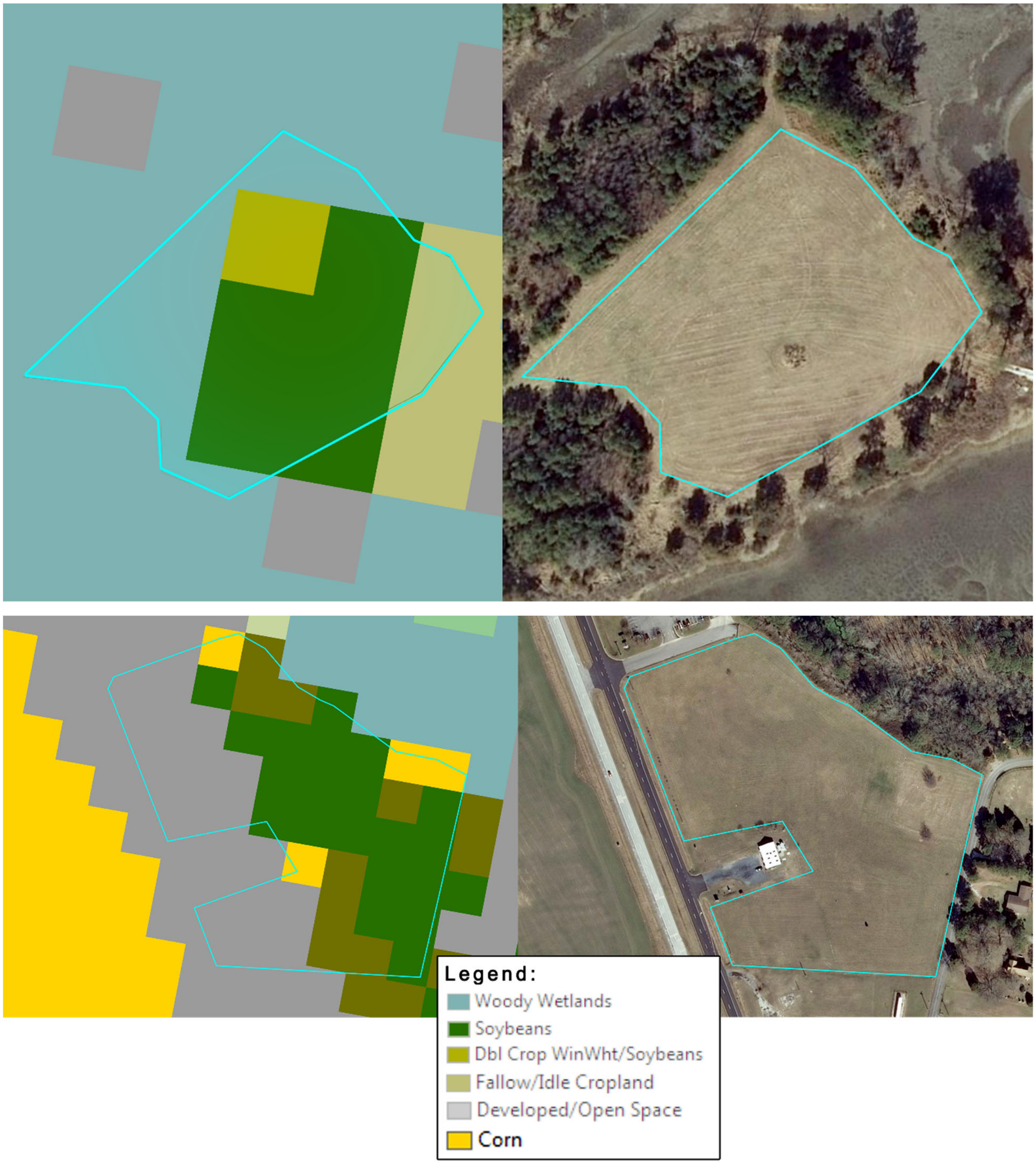


Figure 6. Two fields which were inaccurately categorized as 'Woody Wetlands' (top) and 'Developed/Open Space' (bottom) by ArcMap. Due to Cropscape's large pixel size, pixels from adjacent non-agricultural land can bleed over into fields. Smaller fields with higher perimeter-to-area ratios are most susceptible to this problem. Both fields above had to be manually labeled as 'Soybeans'. These figures illustrate the potential inaccuracy of CropScape over very small areas.

CropScape pixel with the value 1 represents corn, while 5 represents soybeans, etc. Using the zonal statistics tool in ArcMap, the CropScape value corresponding to the crop type covering the majority of the field in question was determined for each field. This process yielded four years of crop data, from 2013 to 2016. The field attribute data and CropScape key were exported as spreadsheets which were then loaded into MATLAB. In MATLAB, each field's majority crop value was converted into the corresponding crop name from the CropScape key, resulting in an output spreadsheet which contained names of the majority crop types for each field. Additionally, the original CropScape data in each field that had been manually identified as tomato fields was overwritten so they were correctly categorized as tomato fields.

Small fields adjacent to non-agricultural areas were sometimes erroneously categorized by CropScape, due to both the pixel size of the Cropscape data and minor differences between where Cropscape defined field boundaries and where the fields boundaries appeared in air photos (Figure 6). Fields categorized as 'Deciduous Forest', 'Developed/Low Intensity', 'Developed/Open Space', 'Developed/High Intensity', 'Shrubland', or 'Woody Wetlands' were reviewed individually and, when appropriate, manually corrected.

The resulting data table consisted of crop type organized by field ID and by year. Looking at data the four years of data, one of five crop rotations was assigned to each field (Table 3). These five rotations are the most commonly practiced commercial rotations on Virginia's Eastern Shore [*Theresa Pittman, Accomack County Cooperative Extension, personal communication,* 2017]. Fields with only soybeans, corn, winter wheat and/or cover crops grown over the past four years were assigned the rotation of corn, wheat, soybeans (rotation 1), the

Table 3. The five most common crop rotations seen on the Eastern Shore.

Rotation ID	Crop Rotation	Length of Rotation (years)
1	Corn, Wheat, Soybean	2
2	Cotton, Potatoes, Corn, Wheat, Soybeans	4
3	Potatoes, Corn, Wheat, Soybeans	3
4	Sorghum, Corn, Wheat, Soybeans	3
5	Tomato	1

most common rotation on the Eastern Shore. For fields with other crops reported in addition to corn, soybeans, and wheat, these distinguishing crops were reported in a separate column for ease of identification. Common miscellaneous crops included cotton, potatoes, barley, and sorghum. Barley is not a cash crop on the Eastern Shore, and is instead used as an unfertilized cover crop, so it was disregarded. Other less common miscellaneous crops included alfalfa, dry beans, and rye, but these occurred in fewer than ten fields each over the course of the entire four-year observation period, so they were classified as outliers and those fields were assigned the corn, wheat, soybeans rotation (rotation 1) (Table 4). Fields that grew cotton at any point over the four-year study period were assigned the cotton, potatoes, corn, wheat, soybeans rotation (rotation 2). Fields that crew potatoes and did not grow either cotton or sorghum were assigned the potatoes, corn, wheat, soybeans rotation (rotation 3). Fields that grew sorghum were assigned the sorghum, corn, wheat, soybeans rotation (rotation 4). The Eastern Shore fields identified as growing tomatoes were classified as tomato-only fields (rotation 5), as tomatoes are not rotated with any other non-cover crops on the Eastern Shore of Virginia.

Table 4. Tally of fields with crops other than just corn, wheat, and soybeans reported as majority crops within their boundaries over the four-year study period (2013-2016) and the rotation ID those fields were assigned.

Crop Type	Field Count	Rotation ID Assigned*
Alfalfa	8	1
Barley	180	1
Dry Beans	5	1
Rye	1	1
Cotton	48	2
Cotton/Potatoes	3	2
Barley/Potatoes	9	3
Potatoes	113	3
Barley/sorghum	2	4
Dry Beans/ Sorghum	1	4
Potatoes/Sorghum	2	4
Sorghum	108	4
Tomato	25	5

*For an explanation of which crop rotations are associated with which Rotation IDs, see Table 3

Any fields that were categorized consistently as "woody wetlands," “herbaceous wetlands,” “developed/low intensity,” or “developed/open space” by CropScape were removed. Fields that were only intermittently categorized as one of the aforementioned categories and which were accessible from public roads were visited to provide ground-truthing. Fields were ground-truthed based on their expected rotation. For example, a field with a predicted rotation of corn, wheat, and soybeans was considered verified if any of the crops in the expected rotation were present. Fields that were intermittently categorized as non-cropland by CropScape were checked for signs of active cultivation, such as the presence of crops or evidence of recent tillage.

Each crop was then assigned an N_r input rate (kg/ha/year) was based on either fertilizer recommendations for individual fields based on soil test data provided by the Accomack County Cooperative Extension Office [*Theresa Pittman, Accomack County Cooperative Extension, personal communication,* 2017] in the case of corn, sorghum and soybeans (Table 5), or the fertilizer recommendations for farming in the state of Virginia compiled and published by the Virginia Cooperative Extension Service [*Maguire and Heckendorn*, 2015] for wheat, cotton, potatoes, and plasticulture tomatoes (Table 6).

Table 5. Nitrogen fertilizer application recommendations from soil test data for Accomack County fields provided by the Accomack County Extension Service

Crop	Fertilizer N Recommendation (kg/ha)	Average N (kg/ha)
Soybeans	0 0 0 0	0
Sorghum	123	123
Corn	135 157	146

[*Theresa Pittman, Accomack County Cooperative Extension, personal communication*, 2017]

Table 6. General nitrogen application recommendations from the Virginia Cooperative Extension

Crop	Recommended N Application
Wheat	Variable*
Cotton	22.7 kg/bale of expected yield**
Potato	140-168 kg/ha
Tomato	235 kg/ha***

[*Maguire and Heckendorn*, 2015]
*Wheat is fertilized in 3 stages. See table 7.
**For our estimate of average bales of cotton harvested, see table 8.
***This recommendation is for plasticulture, or polyurethane mulched, tomatoes

It is recommended that wheat be fertilized in three stages: first at planting (usually sometime after October), again in December or January, and finally in Febuary or March. The recommended fertilizer amounts vary depending on soil conditions; therefore, a midpoint value was chosen for each fertilization stage and summed for the total wheat application estimate (Table 7).

Table 7. Recommended nitrogen application for wheat at three different points in its growth cycle.

	At Planting	Dec-Jan	Feb-Mar
Minimum N applied (kg/ha)	0	0	39.2
Maximum N applied (kg/ha)	25.2	33.6	90.0
Midpoint (kg/ha)	12.6	16.8	64.6
Total of midpoints (kg/ha)			94.0

The recommendation for cotton is reported in weight of N per bale of expected yield. In order to obtain estimates in kilograms per hectare, data on the average yields for cotton were obtained from the USDA's census of Agriculture [*USDA NASS,* 2014] (Table 8).

Table 8. Average bales of cotton harvested per hectare in Northampton and Accomack county.

Location and year*	Bales Harvested	Hectares Planted	Bales per Hectare
Northampton 2007	1753	291	6.02
Accomack 2002	1405	556	2.53
Northampton 2002	2551	1008	2.53
Accomack 1997	924	322	2.87
Northampton 1997	3336	874	3.82
	Average yield (bales/ha)		3.55
	Recommended N (kg/bale)		22.7
	Average N (kg/ha)		80.6

[*USDA NASS*, 2014]

*Data for Accomack county in 2007 and both counties in 2012 was unavailable

The resulting nitrogen fertilizer application estimates for each of our nine crops over the course of a single growing season are reported in Table 9. The total recommended fertilizer for each crop of interest as reported in Table 9 was then summed, resulting in the total fertilizer applied to a field over the course of a full rotation. This value was then divided by the length of said rotation in years, resulting in an average annual application in kg N/ha/year (Table 10).

Once each field had been assigned an N_r input rate in Kg N/ha/year, that rate was then multiplied by the area of each field to produce a total N_r input for each field in kg N/year.

Table 9. Fertilizer application per crop in kg/ha for the seven predominant crops grown within the study area.

Crop	N (kg/ha)
Corn	146
Wheat	94
Soybeans	0
Cotton	80.6
Potatoes	154
Sorghum	123
Tomatoes	235

Table 10. The five most common crop rotations practiced commercially on the Eastern Shore and the N_r fertilizer inputs associated with each rotation.

Rotation ID	Crop Rotation	Length of Crop Rotation (years)	Total N_r Fertilizer in kg per full Rotation*	Average applied N_r in kg/ha/year**
1	Corn, Wheat, Soybean	2	240	120
2	Cotton, Potatoes, Corn, Wheat, Soybeans	4	474	119
3	Potatoes, Corn, Wheat, Soybeans	3	394	131
4	Sorghum, Corn, Wheat, Soybeans	3	363	121
5	Tomato	1	235	235

*Determined by summing the fertilizer recommendations for each component crop.

**Determined by dividing the total kg of N_r applied per rotation by the length of the rotation in years.

Results & Discussion

A total of 2038 individual cropped fields were identified on the seaward side of Virginia's Eastern Shore. The total area of those fields was 1.65 x 10^4 hectares. In 2012, the USDA reported that between Accomack and Northampton counties there was a total of 4.29 x 10^4 ha of harvested cropland [*USDA NASS,* 2014]. The fields within our study area, the seaward side, therefore represent 38.5% of total cropland, with the other 61.5% of cropland located on the bayside. 84% of the fields within our study area (1718 fields total) were categorized as growing a corn, wheat, and soybean rotation (rotation 1). A comparatively small number of fields were growing other crops. 3% of the fields (52 fields total) were growing cotton and potato in addition to corn, wheat, and soybeans (rotation 2). 6% of the fields (127 fields total) were growing just potato in addition to corn, wheat, and soybean (rotation 3), and an

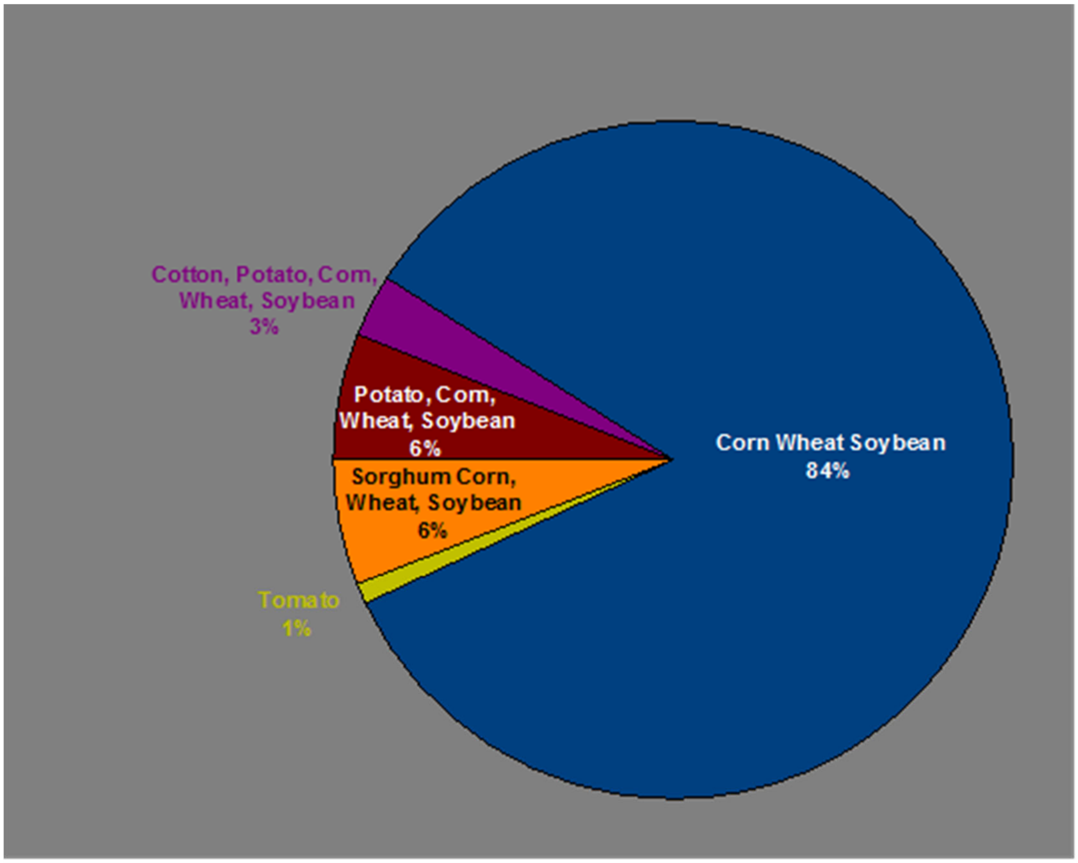


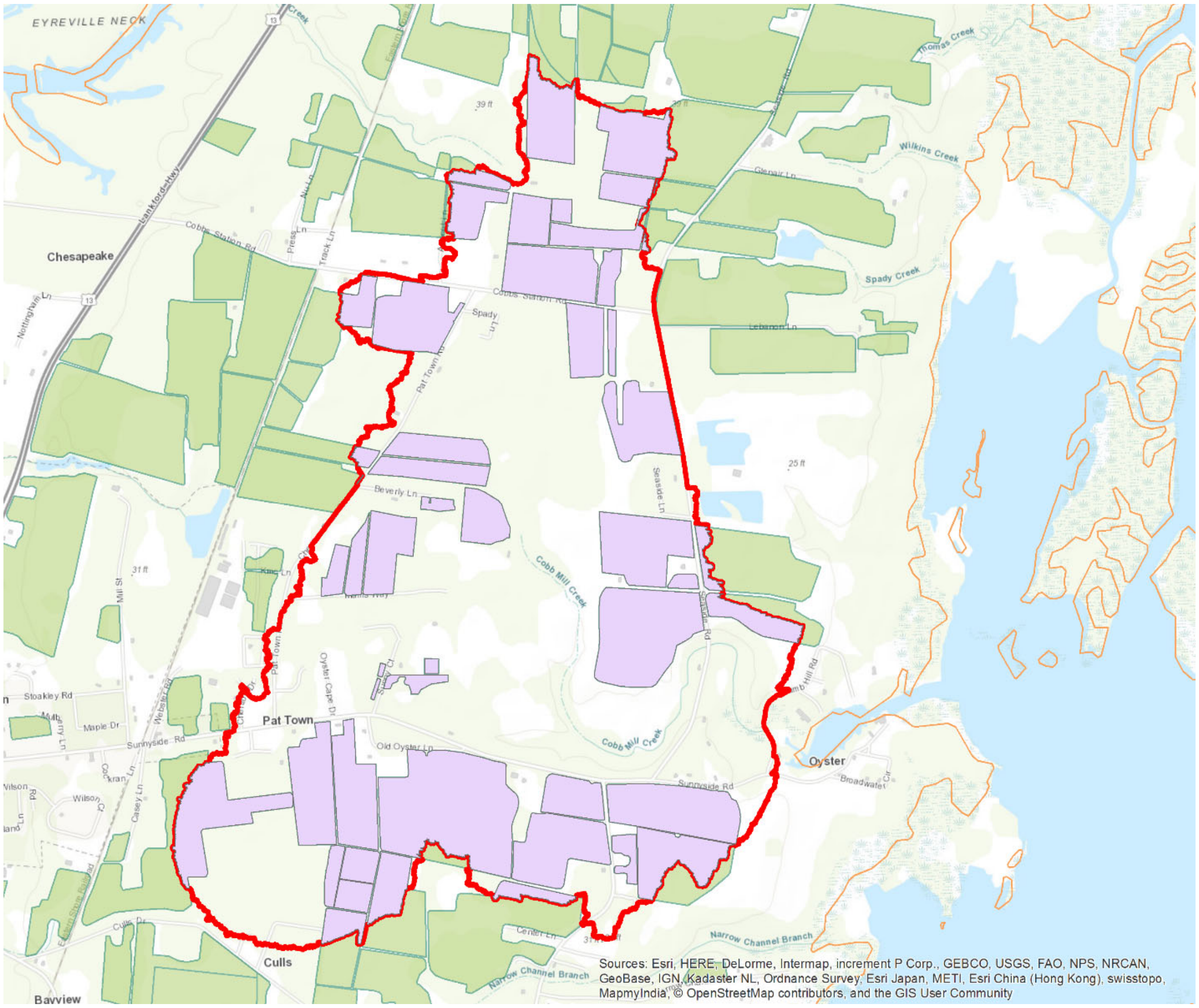
Figure 7. The five most common crop rotations grown on the seaward side of Virginia's Eastern Shore expressed as percentages of total fields.

additional 6% (116 fields total) were growing sorghum along with corn, wheat, and soybean (rotation 4). Only 1% of fields (25 fields total) were growing tomato (rotation 5). Figure 7 illustrates the degree to which rotation 1 dominates on the seaward side of the Eastern Shore.

The total annual mass of N_r applied as fertilizer to the fields within our study area was 2.02×10^6 kg. The average fertilizer application rate for the fields studied was 123 kg of N per ha. Due to Rotation 1 being the predominant crop rotation on the Eastern Shore, the overall average application rate in our study area (123 kg N/ha) is only slightly greater than the Rotation 1 application rate (120 kg N/ha). If we assume that the entire study area is using the standard Rotation 1 application rate of 120 kg N/ha instead, the total mass of applied N would by 1.98×10^6 kg, representing a 2.1% discrepancy in total mass of applied N. Although this is a relatively small discrepancy, it may increase at finer scales.

Cobb Mill Creek Watershed

The Cobb Mill Creek Watershed as defined by the SWAT Model (Herman, J. S. and A. L. Mills, unpublished data) was intersected with the current fields layer to explore how these data layers could be used to estimate fertilizer application within a specific watershed (Figure 8). The result was 51 field polygons. Field area was recalculated to account for fields that were only partially within the watershed bounds. Two of these fields were rotation 3 (potato, corn, wheat, soybean), one was rotation 4 (Sorghum, corn, wheat, soybean), and the remaining 48 fields were rotation 1 (corn, wheat, soybean). Each field's total applied N_r per hectare per year based on its crop rotation was multiplied by each field's area to determine each field's total N_r



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

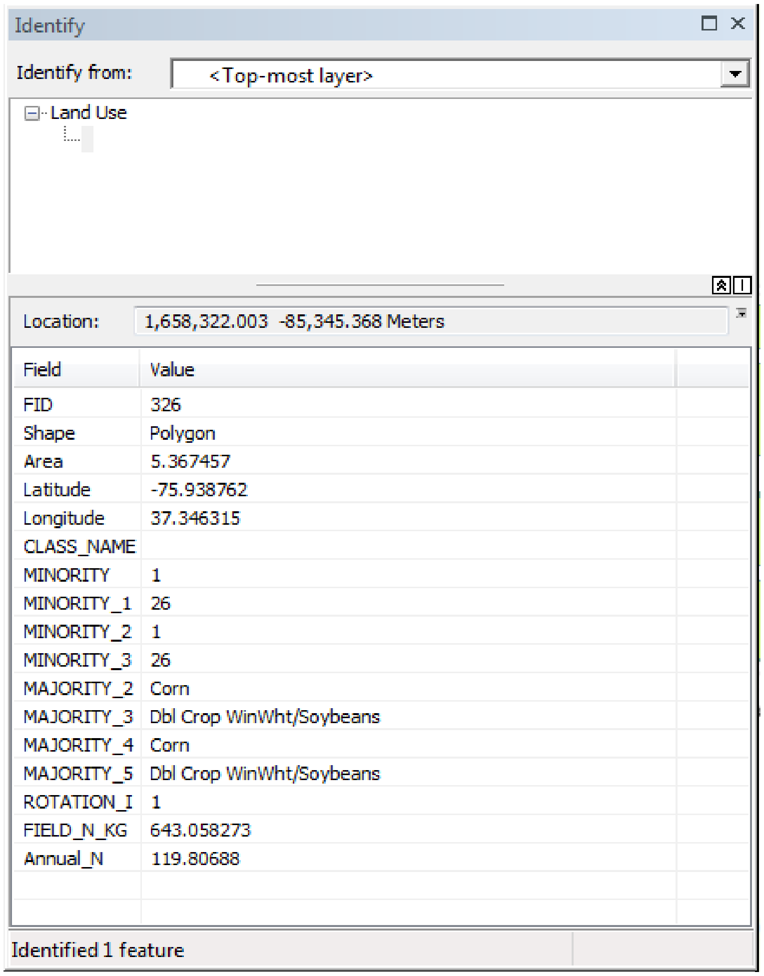
Figure 8. The Cobb Mill Creek watershed outlined in red with cropland within the watershed represented in pink and cropland outside the watershed represented in green.

applied. Using this method, within the Cobb Mill Creek Watershed, an average of 3.27 x 10^4 kg of N_r are applied as agricultural fertilizer each year. The total area under cultivation was found to be 231 hectares.

The Cobb Mill Creek watershed is 703 ha (Herman, J. S. and A. L. Mills, unpublished data); therefore, 33.9% of the Cobb Mill Creek watershed is under active cultivation. By comparison, 31.6 % of Northampton is cropland, meaning that Cobb Mill Creek has a slightly higher farming intensity that Northampton's county-wide average. The watershed as a whole was found to have an annual application of 46.5 kg of N_r per ha, and the average application of N_r to cropped fields within the Cobb Mill Creek watershed was 120 kg of N_r per ha per year.

Longevity and Updating

The strengths of this data layer lie in its precision, but to maintain its accuracy it will need to be updated periodically. Should fertilizer recommendations change in the future, the ANNUAL_N field (Figure 9) will need adjusting. If new crops are introduced widely within the study area in the future, it may be necessary to incorporate new CropScape layers and reevaluate the assigned crop rotation IDs for certain fields. For example, sorghum was not a widely grown crop on the Eastern Shore until 2013 and is now estimated to be grown in rotation in 6% of fields within the study area. If sorghum continues to grow in popularity, or conversely if it falls out of favor with local farmers, this percentage may change.



Location: 1,658,322.003 -85,345.368 Meters

Field	Value
FID	326
Shape	Polygon
Area	5.367457
Latitude	-75.938762
Longitude	37.346315
CLASS_NAME	
MINORITY	1
MINORITY_1	26
MINORITY_2	1
MINORITY_3	26
MAJORITY_2	Corn
MAJORITY_3	Dbl Crop WinWht/Soybeans
MAJORITY_4	Corn
MAJORITY_5	Dbl Crop WinWht/Soybeans
ROTATION_I	1
FIELD_N_KG	643.058273
Annual_N	119.80688

Identified 1 feature

Figure 9. Example data from a single field polygon. Fields of importance include Area (measured in ha), ROTATION_ID (the crop rotation, in this case Rotation 1: corn, wheat, and soybeans), FIELD_N_KG (the total amount of N_r applied to this field in kg/year) and Annual_N (the average N_r application rate in kg/ha/year for this field). Note that FIELD_N_KG is the product of Annual_N and Area.

New CropScape layers are released every year, but unless investigators suspect that significant change in the makeup of field crops has occurred, yearly updates to the data layer should be unnecessary. Both of the above updates may be performed on an exported attribute table. Modifications to the field polygons themselves may be necessary if either new fields which are obviously under production become visible in air photos, or if previously active fields begin to look abandoned.

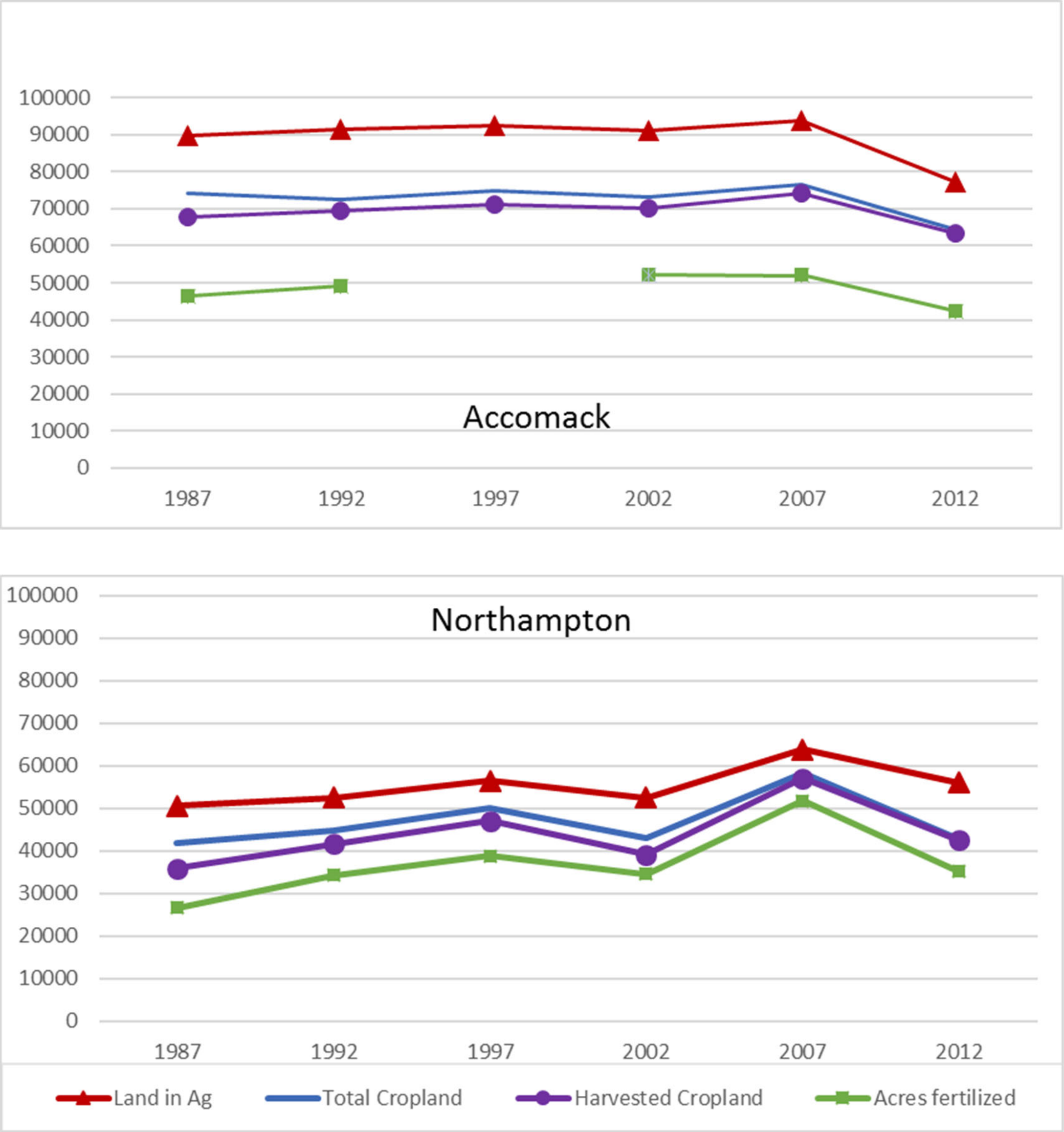


Figure 10. Changes in agricultural land use on Virginia's Eastern Shore from 1987 to 2012 in both Accomack (top) and Northampton (bottom) counties. Data taken from the 2012 USDA Census of Agriculture [*National Agricultural Statistics Service*, 2014]. Data for acres fertilized in Accomack County in 1997 was unavailable.

According to the USDA's National Agricultural Statistics Service, between the years of 2007 and 2012, there was a 19% decrease in harvested cropland on the Eastern Shore of Virginia, and a 25% decrease in total area fertilized [*National Agricultural Statistics Service*, 2014] (Figure 10). It is reasonable to assume that those numbers have continued to change in the years since the 2012 survey, possibly due to factors such as soil salinization, sea level rise, or economic changes. Since the USDA's National Agricultural Statistics Survey is released every five years, this data layer should at least be revisited just as often, so that changes in cropland can be taken into account.

Sources of Error

This data layer's field polygons were all delineated by hand using air photos. This was not due to lack of availability of up-to-date raster images. Indeed, several agencies generate up to date data on land cover across the entire Mid-Atlantic region, such as the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) [*NOAA,* 2013] or the Multi-Resolution Land Characteristics Consortium's (MRLC) National Land Cover Database (NLCD) [*Homer et al.,* 2015]. However, although these resources are quite valuable at the landscape level, each of these has major drawbacks when working at the scale of individual watersheds. When comparing the NLCD maps with recent air photos, it is clear that their map overestimates the amount of agricultural area. For example, forested areas adjacent to croplands are often categorized as cropped land. The NLCD datasets are also relatively low resolution, with a pixel size of 30 meters. Likewise, the C-CAP datasets have a pixel size of about 37 meters, and there are still issues with accuracy. For comparison, the VBMP air photos used to determine the boundaries of the field polygons have a pixel size of 0.3 meters.

The 2014 C-CAP Accuracy Report for the Mid-Atlantic region estimated that only 71.9% of the area categorized as 'Cultivated Crops' is actually such. Though such errors are often minimized by grouping similar land cover categories together, e.g., cultivated crops being grouped with pasture, grassland, and developed open space, that approach is only viable when looking at land cover as opposed to land use. CropScape is built upon the NLCD, and so has the same pixel size of 30 meters and suffers from the same issues with accuracy at very fine scales. These issues were mitigated by using hand-delineated field boundaries and only considering the CropScape data within each polygon. However, the process of examining air photos and deciding whether or not a field is under active cultivation can be subjective. During ground-truthing, we discovered that 13.3% of fields which appeared to be under cultivation were in fact not active cropland. These fields appeared to be former cropland that was no longer actively under cultivation. This could be due to a continued decrease in cropland since the air photos were taken. If that is the case, this data layer could still be overestimating the amount of cropland within the study area. It is also possible that some actively cropped fields were erroneously eliminated. These uncertainties must be considered when using this data layer. If total cropland on the Eastern Shore continues to decline and fields are not removed from this data layer accordingly, this error will increase over time.

In terms of the accuracy of CropScape to predict what crops are being grown within the delineated fields, we found that 96% of the time, when looking at fields which were confirmed as under active cultivation, the crops being grown during ground truthing fell within our predicted rotations from previous CropScape data. This does not include fields which were growing tomatoes, as CropScape cannot identify plasticulture tomatoes and those fields must therefore be identified manually from air photos. Since tomatoes have by far the highest N_r fertilizer recommendations as compared to the other four most common rotations, failing to identify tomato fields in air photos could lead to underestimates of fertilization intensity.

Conclusion

This data layer will allow future researchers to estimate reactive nitrogen application to cropland anywhere within the seaside lagoons' watersheds with both higher precision and accuracy than was previously possible. If coupled with N_r flux data from monitored streams, this data layer could help shed light on how much N_r is being removed through biological processes at the landscape scale. This data layer could also be used as a decision-making tool for future management of N_r inputs.

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