



Delaware Wetlands:

Status and Trends from 2007-2017

DELAWARE DEPARTMENT OF
NATURAL RESOURCES AND
ENVIRONMENTAL CONTROL

Delaware Wetlands: Status and Trends from 2007 to 2017

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Acronyms

Below is a list of acronyms that are found throughout the document. Acronyms are listed in alphabetical order.

Acronym	Description
DELSC	Delaware Living Shorelines Committee
DEM	Digital Elevation Model
DNREC	Delaware Department of Natural Resources and Environmental Control
EPA	U. S. Environmental Protection Agency
GIS	Geographc Information System
HGM	Hydrogeomorphic
HOA	Homeowners Association
LiDAR	Light Detection and Ranging
LLWW	Landscape, Landform, Waterbody, Water Flow Path
MHW	Mean High Water
NHD	National Hydrography Dataset
NWI	National Wetlands Inventory
QA/QC	Quality Assurance/Quality Control
WMAP	Wetland Monitoring and Assessment Program

Executive Summary

Positioned almost entirely on the Coastal Plain, Delaware is relatively flat in elevation, creating a wet, poorly drained landscape in many areas. Wetlands make up nearly a quarter of the state, ranging in type and location from coastal salt marshes to freshwater forests at the upper reaches of watersheds. Wetlands are integral parts of the natural system and provide valuable benefits to people, including flood reduction, carbon sequestration, erosion control, reduction of damage from severe storms, water quality improvement, recharge of groundwater aquifers, provision of recreation opportunities, and provision of habitat for important plants and animals. As important as they are, less than half the extent of wetlands is present than what existed historically. Changes, losses, and gains of wetlands over time can occur due to natural and human-induced actions, and those same forces exist today.

Delaware is a small state, which enables the ability to conduct wetland inventory statewide using landscape-level mapping with techniques that have improved over time. The most current assessment of wetlands, presented here, used aerial imagery from 2017 and compared the current data with similar wetlands inventory data from 2007. Previous wetland mapping in Delaware was conducted by the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) in 1982, by NWI and Delaware's Department of Natural Resources and Environmental Control (DNREC) in 1992 and 2007, and by Virginia Tech and DNREC in 2017. Each of these efforts produced a status assessment for 1982-1992 (Tiner 2001), for 1992-2007 (Tiner et al. 2011), and this report for 2007-2017.

This inventory classified wetlands in two ways (formerly known as NWIPlus classification). The first was by ecological type, which classified wetlands using biological, physical, and chemical properties. The second used abiotic features to classify wetlands such as landscape position, landform, water flow path, and water body type. New to the 2017 mapping effort was the use of the recently developed NWI Version 2.0. Version 2.0 mapped wetlands using the standard classification (Cowardin et al. 1979), but also combined other surface water data such as rivers, streams, and ditches into polygonal form using the National Hydrography Dataset (NHD). This created a comprehensive characterization of surface water on the landscape, and the combined information greatly enhanced the ability of users to trace the potential movement of water, and all that it carries, as it moves between wetlands and other aquatic ecosystems.

Wetland mapping using the 2017 imagery identified 296,351 acres of wetlands across Delaware. Palustrine forested wetlands comprised about 50% of the state's wetland total acreage. Estuarine emergent wetlands comprised 24% of the state's wetlands. New Castle County contained the fewest wetlands at 44,925 acres (15%), followed by Kent County, which contained 110,472 acres (37%). Sussex County contained the most wetlands with 140,954 acres (48%). By major drainage basin, the Piedmont Basin had only 7,510 acres (2%), the Delaware Bay Basin had 130,260 acres (44%), the Chesapeake Basin had 99,674 acres (34%), and the Inland Bays Basin had 58,907 acres (20%).

The abiotic classification enabled DNREC scientists to complete a landscape-level assessment to predict the ability of Delaware's wetlands to potentially perform 10 functions. Nearly two-thirds or more of the state's wetlands were identified as having the potential to perform the following functions at high or moderate levels: nutrient transformation, carbon sequestration, bank and shoreline stabilization, and provision of habitat for other wildlife. Other functions predicted to be provided by more than 45% of the state's wetlands were surface water detention, sediment retention, and provision of habitat for fish and aquatic species. About one-third of the wetlands were predicted to be important for coastal storm surge detention, streamflow maintenance, stream shading, and waterfowl or waterbird habitat.

The acreage trends of wetlands identified in this report compared aerial imagery from 2007 and 2017, and the derived wetland data from each of those years. Using the NWI Version 2.0 method created challenges in comparing the 2017 data with the 2007 data. This was largely due to areas mapped as large wetland polygons in 2007 being depicted as wetland polygons with water feature (e.g., streams) polygons in 2017. Technique changes such as these made it difficult to directly compare both acreages and types from 2007 to 2017. Generally, the status and trends evaluation identified 3,012 acres of vegetated wetland loss due to conversion to another land use. There were also 375 acres of gained vegetated wetlands, resulting in a net loss of 2,636 acres of vegetated wetlands statewide. Most of the wetland loss was of palustrine forested wetlands and was due to clearing, development, agriculture, and transportation projects. Estuarine wetland losses were attributed mostly to environmental causes, development, and transportation/utilities. Environmental causes, such as erosion or sea-level rise, converted vegetated marshes to estuarine open water or intertidal shores.

The overall net loss of wetland acreage between 2007 and 2017 meant there was also an inherent loss of the beneficial functions that wetlands provide. Natural causes of loss are currently increasing for coastal wetlands due to sea-level rise and erosion. Delaware's freshwater wetlands continue to see the most impact, and with reduced jurisdiction incorporated at the federal level, there is increased need for a state freshwater program to protect wetlands. This study verifies the same trends of wetland loss and diminishing function that has occurred for the past 35 years. These trends will continue without intervention, leading to even further reduced natural beneficial services that wetlands provide to Delaware citizens.

To help prevent future tidal wetland losses, nature-based shoreline stabilization techniques should be used along coastlines, and tidal wetland restoration should occur that aims to resemble natural, vegetated tidal wetland characteristics and functions. Undeveloped tracts of land should be preserved adjacent to current tidal wetlands to allow them to migrate inland as sea-level rises. In addition, invasive *Phragmites australis* should be treated wherever possible to discourage the plant from spreading and to restore native high marsh habitat. To prevent future non-tidal wetland losses, a comprehensive state regulatory program needs to be created, and regulations should be strongly enforced. Non-tidal wetland restoration should occur that styles projects after natural, vegetated non-tidal wetland characteristics and functions. Finally, clear cutting in non-tidal wetlands should be avoided, and areas that were previously clear-cut should be restored as soon as possible.

Introduction

Wetlands are extremely valuable natural features, as they provide many beneficial functions. Wetlands provide habitat for numerous wildlife and plant species, many of which live only in wetlands. They also help to reduce flooding and storm damage by storing and slowly releasing water and by absorbing and reducing destructive wave energy. Additionally, wetlands can help clean water by filtering out excess sediments and pollutants before water reaches streams, rivers, and bays. Wetlands also filter groundwater as it seeps down to recharge drinking water aquifers. Wetlands are the focus of many recreational activities such as kayaking, birding, and fishing. Roughly 75% of commercially harvestable fish and shellfish use wetlands as protective nursery grounds and thus support Delaware's robust fishing and crabbing industry and income. Lastly, wetlands of all types provide unparalleled beauty and serve as a hallmark feature on Delaware's landscape.

Wetlands comprise nearly 25% of Delaware's land area in a variety of types and forms. The majority of Delaware's wetlands are non-tidal freshwater, mostly in the form of forested wetlands. Headwater forested wetlands are relatively flat but perform critical groundwater filtration and serve to funnel surface water gently as headwater streams take form. These unassuming wetlands can appear dry during late summer and fall months and are highly vulnerable to loss. Moving down through the watershed, riverine floodplain wetlands line freshwater streams and rivers, providing stormwater overflow storage, critical wildlife corridor habitat, and filtration of pollutants coming from uplands. These picturesque, mucky wetlands are often thick with skunk cabbage, briars, and crayfish chimneys. Spotted among forested areas are isolated depression ponds which may be dry in late summer or several feet deep in later winter and spring. Depressions, including Coastal Plain ponds, are critical habitat for many amphibians, including many salamander and frog species. Delaware's iconic salt marshes found along the coast have simple grassy and shrubby plant communities and range from expansive fields bordering the Delaware Bay and Inland Bays to fringing strips along tidally influenced creeks and rivers throughout the state.

As such a prominent part of the state's landscape, wetlands have significant potential to provide these valuable ecosystem services to people and wildlife alike. However, it is estimated that Delaware has already lost approximately half of its wetlands since early human settlement, mostly from conversion to agriculture or development. A wetland mapping analysis spanning 1981-1992 reported a loss of nearly 2,000 acres of vegetated wetlands due to conversion to agriculture, development, and construction of roads/highways and ponds (Tiner 2001). Since then, the rate of loss of vegetated wetlands has increased by 9%. From 1992 to 2007, state wetland mapping analysis showed that Delaware experienced a net loss of 3,126 acres of vegetated wetlands. Forested freshwater wetlands accounted for the majority of those losses. While some acreage increases were documented from 1992 to 2007, most wetland gains were the result of non-vegetated wetlands, such as stormwater ponds, being installed. Such non-vegetated wetlands do not perform beneficial functions to the same degree as vegetated wetlands (Tiner et al. 2011).

Consistent with several past decades, more recent losses of statewide wetlands have largely been caused by conversion of forested freshwater wetlands to agricultural lands, residential or commercial development, or roads. Weak wetland regulations on the state and federal level have long been blamed for loss of wetland acreage. The state of Delaware does regulate activities in tidal wetlands, which greatly reduces anthropogenic losses. However, the Delaware Department of Natural Resources and Environmental Control (DNREC) does not have the authority to regulate activities in non-tidal wetlands unless they are over 400 acres in contiguous size. Most non-tidal wetlands in Delaware are not that large. Freshwater wetland regulation on the federal level in Delaware is overseen by the U. S. Army Corps of Engineers and their strict delineation criteria. Recent rollback of authority over headwater and isolated wetlands, and lack of enforcement on the ground, have allowed wetland impacts to cumulatively build up over the past 30 years as Delaware has experienced intense population growth and development pressure.

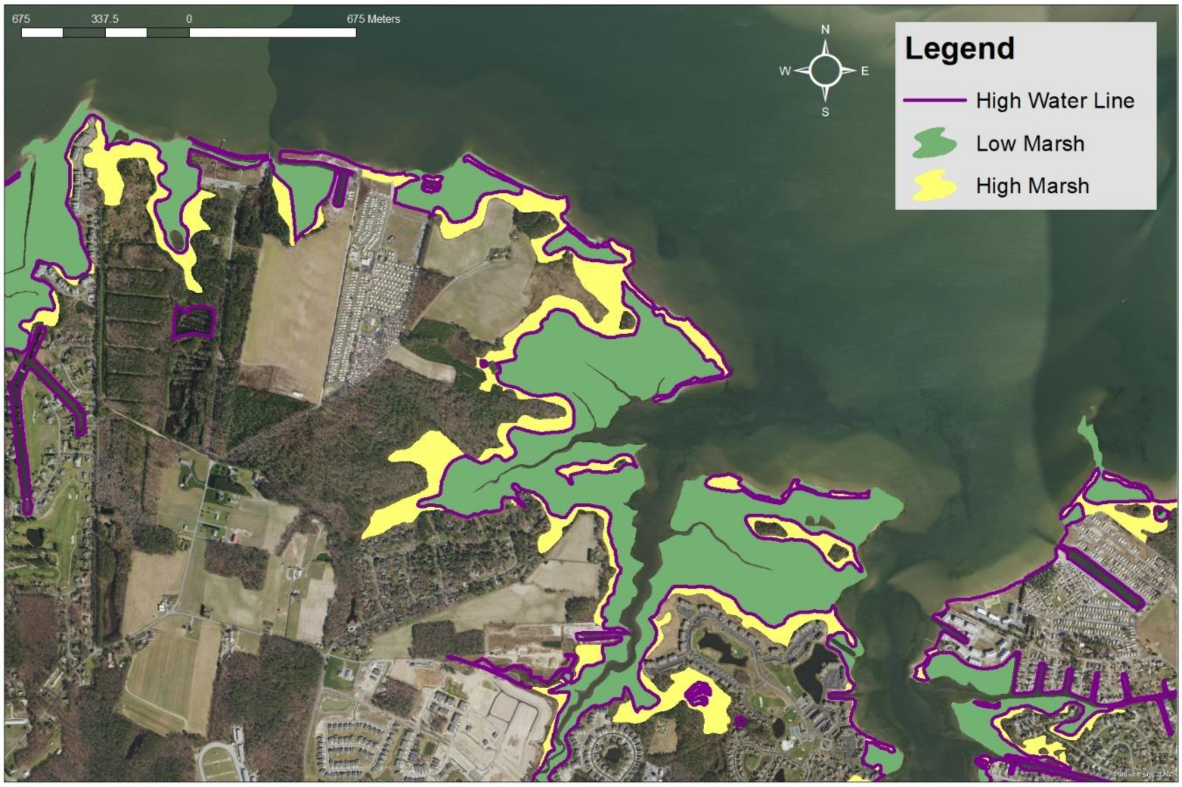
Given the consistent trend over time of wetland loss, and the need for stronger regulation and conservation programs in Delaware, it is important to track and report wetland acreage changes coupled with targeted management recommendations that can help curb wetland loss. DNREC's Wetland Monitoring and Assessment Program (WMAP) has documented this in the past and continues to do so. This report by WMAP details wetland acreage status and trends for the state of Delaware from 2007 to 2017. The report also describes how wetland acreage losses, gains, and changes will affect wetland functions. Management recommendations are provided to address how to combat the most pervasive wetland issues and prevent future wetland losses and impacts.

Methods

Mapping

Previously, wetland maps were created for Delaware based on 2007 aerial imagery. New maps were created and finalized in 2020 for the state based on 2017 imagery. To do so, wetlands were classified and mapped by Virginia Polytechnic Institute and State University (Virginia Tech) according to specific wetland classification and mapping standards (FGDC 2013, Dahl et al. 2020). Mapping was done using 2017 leaf-off aerial imagery from the state of Delaware. Wetland classification was done according to both the Cowardin system (Cowardin et al. 1979) and by hydrogeomorphic (HGM) characteristics (Tiner 2011). The HGM classification system incorporated landscape, landform, waterbody type, and water flow path (LLWW). Wetland features were mapped as polygons, with a minimum mapping unit of 0.25 acres (with some mapped smaller), using the North American Datum of 1983 and the Delaware State Plane coordinate system. Polygons were mapped at a feature accuracy of 95% and attribute accuracy of 85%. Quality assurance and quality control (QA/QC) of data was performed by WMAP and Virginia Tech in several stages by reviewing initial mapped blocks and performing field visits to mapped sites and providing feedback. Once the 2017 wetland mapping was complete, Virginia Tech used 2017 and 2007 wetland maps to create a Delaware wetland loss, gain, and change summary for that 10-year span.

Three additional shapefiles were also created, including high marsh, low marsh, and ordinary high-water line (Map 1). The high marsh file isolated all mapped intertidal estuarine polygons that were coded as irregularly flooded (i.e., P water regime). This layer was designed to quickly identify high marsh habitat that is only flooded one or two times per month under normal conditions. The low marsh file isolated all mapped intertidal estuarine polygons that were coded as regularly flooded (i.e., N water regime) and was designed to quickly identify *Spartina alterniflora* marsh that is flooded at least once daily. Lastly, the ordinary high-water line file, also known as mean high water (MHW), was developed by tracing the boundaries between wetland polygons that were coded as regularly and irregularly flooded in tidal locations. Elevation was also considered when drawing the line in some areas. This was done simply to provide a desktop estimate of the ordinary high-water line under normal conditions. No calculations were performed using the high-water line layer; therefore, nothing is reported for the high-water line in the results of this report.



Map 1. An example of the high marsh, low marsh, and high-water line map layers overlaying 2017 imagery of Delaware.

Statewide status and trends were analyzed and compiled for all three counties (New Castle, Kent, and Sussex) and the state's four major drainage basins (Piedmont, Delaware Bay, Chesapeake Bay, and Inland Bays/Atlantic Ocean). Wetland status and trends are also reported by wetland type, including tidal and non-tidal wetlands, and vegetated and non-vegetated wetlands.

Changes from Previous Mapping and Trends Report

Wetland acreages based on remote sensing and other methods often produce different results. This is especially true given differences in image quality, scale, and resolution. Aerial imagery is just a snapshot in time when the image is taken, and the ground can range from very wet to very dry condition. This often leads to different results when mapping at intervals over time (e.g., every five or 10 years). The promising fact is that technology, data, and expertise improve over time and the intent is always to advance the accuracy of wetland mapping data. As such, there were differences in wetland mapping between the previous effort in 2007 and the most recent effort in 2017, as well as differences in how results from data analyses were reported. These differences are detailed below and are summarized in Table 1.

National Wetland Inventory (NWI) Version 2.0

One of the most prominent changes in the 2017 mapping effort since 2007 was the incorporation of the U.S. Fish and Wildlife Service National Wetland Inventory (NWI) Version 2.0 methodology (USFWS 2020). Version 2.0 used the existing Cowardin et al. (1979) classification to map wetlands and deep-water habitats using ecological descriptors. It also incorporated the National Hydrographic Dataset (NHD) for stream segments, which augmented the wetlands data for more complete and accurate representation of surface water features. This allowed the user to clearly consider the connection and interaction of wetlands and streams in a watershed.

The new stream data created a much larger number of riverine polygons in 2017 compared with 2007. Some of these polygons may have been formerly included as part of a wetland polygon in 2007, while others were new riverine polygon features not previously mapped. The expansion of the riverine category effectively reduced the size of the palustrine wetland category overall. This created challenges in determining status and trends and comparing to previous mapping efforts.

Inclusion of LiDAR

For mapping wetlands, additional spatial data were used to assist in determination of wetland location such as soil type, land use, and elevation differences. New digital elevation modeling (DEMs) using Light Detection and Ranging (LiDAR) was completed for Delaware in 2014. These data were more refined than previous versions and measured ground surface differences in inches rather than feet. This elevation dataset identified wetlands where they were missed in prior mapping and helped to confirm where wetlands were mistakenly mapped in the past that were not truly wetlands. This greatly improved the accuracy of the 2017 mapping while creating sweeping changes to the mapping in some locations. It also created additional challenges for status and trends analysis when comparing 2017 data with 2007 data. LiDAR, in combination with clearer aerial imagery, improved identification of wetlands that were dominated by *Phragmites australis* (i.e., '5' modifier in Cowardin classification) in the 2017 mapping effort as well.

Different Wet Signatures in Aerial Imagery

As mentioned above, aerial imagery can vary in multiple ways, such as revealing differences in ground-level wetness from one year to another. Although both 2007 and 2017 were average precipitation years, it was evident that 2007 was wetter at the time of image capture than 2017. This varied slightly across the state. The drier 2017 imagery revealed fewer dark imagery signatures on the ground, and those signatures were used to help identify the location of wet soils and determine wetland locations and boundaries. Fewer dark imagery signatures in 2017 resulted in reduced mapped acreage statewide compared with 2007. Some polygons mapped in 2007 and no longer mapped in 2017 because of wet signature differences may have represented actual wetland losses, while others were not true wetland losses, but rather simply technique changes based on conditions of aerial imagery. This presented some challenges when analyzing the wetland trends layer, particularly in terms of losses. Instances that were found not to represent true wetland losses were not included in trends analyses.

H-Wetlands No Longer Mapped

In the previous mapping effort and report from 2007, "H-wetlands", or hydric wetlands, were included in the survey. H-wetlands were defined as hydric soil map units exhibiting natural vegetation but lacking a photo-interpretable wet signature, representing "potential" wetlands that should be further verified at the site location. However, field observations since 2007 showed that many H-wetlands did not turn out to be actual wetlands. These observations suggest that the statewide wetland acreage total reported in 2007, which included H-wetlands, was likely an overestimation. H-wetlands were therefore not mapped in 2017 and were not included in this report to avoid overestimation of acreage totals.

Instead, polygons that were H-wetlands in 2007 (62,290.2 acres) were reexamined using improved mapping techniques and were either mapped as true wetlands or were dropped from the 2017 dataset. Polygons that were mapped as H-wetlands in 2007 and were retained in 2017 (4,039.4 acres; 6.5% of H-wetlands) still had natural vegetation but also had a photo-interpretable wet signature in 2017 imagery. Such polygons were no longer classified as H-wetlands but instead received typical Cowardin and LLWW classifications, and they were included in acreage calculations in this report. H-wetland polygons from 2007 that were removed from the mapped dataset for 2017 (58,250.8 acres; 93.5% of H-wetlands) included those hydric soil map units with natural vegetation that still lacked a photo-interpretable wet signature in 2017 imagery. The fact that so many H-wetlands from 2007 were not included in the 2017 dataset helps to explain why total statewide wetland acreage is significantly lower in 2017 compared with 2007.

The discontinuation of H-wetland mapping also had implications for the 2017 wetland trends layer. The trends layer compiled wetland polygon gains, losses, and type changes from 2007 to 2017. Because H-wetlands were mapped in 2007 but not in 2017, there were challenges in comparing the two datasets to create an accurate trends layer. For example, some polygons that were mapped as H-wetlands in 2007 and were mapped as true wetlands in 2017 were originally counted in the wetland gains category, and some polygons that were mapped as H-wetlands in 2007 and were not mapped as wetlands at all in 2017 were originally counted in the wetland losses category. Such instances were not true gains or losses because no actual wetland gains or losses occurred on the ground; they instead represented refinement of mapping techniques. Therefore, those instances were not included in trend calculations.

Technique Improvements in Wetland Trends

Computer-based, landscape-level mapping capabilities and procedures are constantly evolving. Between 2007 and 2017, many advances in mapping techniques were made which had important implications for the wetland trends layer. For example, an area of tree shading that was incorrectly identified as a wet signature and subsequently made into a wetland polygon in 2007 may be correctly omitted from the 2017 mapping effort because the new mapping techniques corrected shading errors. Upon extensive polygon inspection throughout the QA/QC process, it was determined that many wetland polygons included in the original 2017 trends layer that were marked as gains or losses were instead the result of the technique improvements. Within the loss category, 913.7 acres of tidal wetlands and 14,807.5 acres of non-tidal wetlands were not true losses, as no change in land use type was seen in aerial imagery between 2007 and 2017 (see example in Map 2). Within the gain category, 1,634.0 acres of tidal wetlands and 5,873.0 acres of non-tidal wetlands were not true gains, as no change in land use type was seen in aerial imagery between 2007 and 2017. These updates due to technique improvements were not included in wetland loss or gain analyses because they did not represent actual loss or gain of wetlands.

Map 2. An example of a polygon (outlined in pink) that was not altered between 2007 (left) and 2017 (right) but was included in the trends layer as a ‘loss’ because of computer mapping technique changes. Such cases are not included in loss calculations.

Similarly, many polygons in the wetland changes from 2007 to 2017 layer noted a shift in wetland classification yet did not show any real land use change based on aerial imagery. Such changes did not represent true changes to wetland type, but rather corrections to the 2007 classifications based on mapping technique improvements and were therefore not included in trends analyses. For example, some 2007 tidal wetland polygons that did not change over time in aerial imagery but were corrected in terms of classification in 2017 (6,944.8 acres) were correctly reclassified as riverine polygons. Non-tidal wetland polygons that were corrected (7,092.8 acres) included those wetlands that were correctly reclassified to riverine polygons (i.e., surface water polygons cutting through wetland polygons), riverine polygons that were correctly changed from one riverine to another riverine type, farmed wetland polygons (i.e., Pfs) that were correctly reclassified as palustrine emergent or unconsolidated bottom wetlands, and palustrine polygons that were correctly changed to lacustrine polygons.

Table 1. Summary of updates to wetland mapping in 2017, the effects of those updates on mapping accuracy and mapped acreage, and effects of those updates on the 2007-2017 trends layer.

New to Wetland Maps in 2017	Effect Relative to 2007 Maps	Effect on 2007-2017 Trends Layer	Explanation
Use of NWI Version 2.0 (Incorporated NHD)	--Increased riverine acreage --Decreased palustrine wetland acreage	--Artificial inflation of gain and change categories	--Added some new riverine polygons --Updated some polygon classifications from palustrine to riverine
Inclusion of LiDAR	--Increased wetland mapping accuracy	--Artificial inflation of gain and loss categories	--Identified wetlands where missed in 2007 --Omitted polygons mistakenly mapped in 2007
Presence of Different Wet Signatures	--Decreased overall wetland acreage	--Artificial inflation of loss category	--2017 drier than 2007 at time of image capture
Disinclusion of H-Wetlands	--Decreased overall wetland acreage	--Artificial inflation of loss and gain categories	--6.5% of 2007 H-wetlands retained in 2017 as actual wetlands --93.5% of 2007 H-wetlands dropped in 2017
Use of Other Technique Improvements (e.g., correction of tree shading)	--Increased wetland mapping accuracy	--Artifical inflation of gain, loss, and change categories	--Corrected mistakes found in 2007 wetland classifications --Identified wetlands where missed in 2007 --Omitted polygons mistakenly mapped in 2007

Reporting

The way in which wetlands are presented in this report is different from previous reports. In previous reports (Tiner 2001, Tiner et al. 2011), wetland results were organized according to their ecological system classification (i.e., palustrine or estuarine), whereas in this report, wetland results are organized according to tidal regime (i.e., tidal or non-tidal). A portion of palustrine wetlands are tidal and are thus included in the tidal sections in 2017. This decision was made to align wetland results more closely with

Delaware's wetland regulatory framework, as the state of Delaware regulates wetlands based on their tidal regime. However, this does make direct numeric comparisons across reports more challenging.

Trends Analyses

All calculations from the trends layer (i.e., gains, losses, and changes) only included polygons that were ≥ 0.25 acres in size. This was because most wetland polygons that were <0.25 acres were very small slivers that only represented tiny adjustments in polygon boundaries and did not represent meaningful changes on the ground. Wetland losses and gains were examined in concert with Delaware land use data from 2017 to attribute losses and gains to specific land uses. All land use categories were spot-checked using aerial imagery to affirm accuracy. Land-use categories that were found to be frequently inaccurate upon spot-checking (e.g., forested gains) were examined on a polygon-by-polygon basis.

Wetland loss polygons were sorted into tidal and non-tidal wetlands and were then placed in six categories that described reasons for losses: clearing, development, agriculture, transportation/utilities, environmental impacts, and technique improvements. Cleared wetlands were those wetlands that were completely cleared of trees or emergent vegetation from 2007 to 2017 as seen in aerial imagery. Wetlands lost to development were those that were clearly wetlands in 2007 imagery and were built upon by residential housing or industrial buildings by 2017. Polygons were categorized as lost to agriculture if they were clearly wetlands in 2007 and were converted to agricultural uses, such as row crops, livestock, or poultry, by 2017. Those categorized as lost to transportation/utilities were noted as being converted from wetland to roads or utility areas. Wetlands lost to environmental impacts were those that were not noticeably destroyed by human activity in imagery but were rather destroyed by processes such as erosion and sea-level rise, particularly along the coast. The technique improvement category included polygons where there was no visible change in imagery from 2007 to 2017, but improvement to mapping techniques caused those polygons to be correctly removed from the dataset. As mentioned above, technique improvements were excluded from loss calculations (see 'Changes from Previous Trends Report' section above). Only losses of vegetated wetlands are presented in this report because losses of vegetated wetlands translate into much greater losses of functional potential compared with losses of non-vegetated wetlands.

Wetland gains were grouped into six categories for reporting that described reasons for gains: agriculture, residential development, industrial operations, migration, restoration, and technique improvement. All of the above categories were true gains in wetlands except the technique improvement category, which was instead due to better mapping layers and technology from 2007 to 2017. These wetlands consisted of some H-wetlands from the 2007 layer (see 'H Wetlands No Longer Mapped' section above), refinement of polygon shapes and edges, and the addition of polygons that were not labeled in the 2007 layer. As mentioned above, technique improvements were excluded from gain calculations. The agriculture category consisted of any agricultural creation of a wetland to remove water from crop fields or other farming activities. The development category consisted of open water wetlands that were created as stormwater ponds around residential developments. The industrial operations category included wetlands that were created in an industrial setting, such as for mining extraction or refinery cooling. The migration category captured the migration, or natural movement, of wetlands (mainly tidal) inland from existing wetlands into uplands. The last category was restoration, which was any area that was non-wetland in 2007 but became a vegetated or semi-vegetated wetland by 2017 with obvious signs of restoration or habitat creation. Both vegetated and non-vegetated wetland gains are presented in this report to get a clear picture of what most gains represented in terms of wetland type and functional potential.

Similarly, wetland change polygons were sorted into tidal and non-tidal wetlands and were then characterized based on change type. Change types included wetlands that were vegetated in 2007 and were then non-vegetated in 2017, wetlands that were non-vegetated in 2007 and vegetated in 2017, and wetlands that changed vegetation type between 2007 and 2017, such as scrub shrub to forested. All change types were spot-checked using aerial imagery to affirm accuracy during the QA/QC process. Change types that were found to be frequently inaccurate upon spot-checking were examined on a polygon-by-polygon basis. Some polygons could fit in multiple categories, but for simplicity, all polygons were only placed in one category. When considering what category to place a polygon in, changes in tidal regime (e.g., non-tidal to tidal) were accounted for first, followed by changes in salt content (e.g., tidal palustrine to estuarine), and lastly by changes in vegetation type (e.g., succession). For example, a wetland that was classified as PUBVx in 2007 and as E2EM1N in 2017 could technically be placed in a saltwater intrusion category (i.e., freshwater to saltwater change) or in a succession category (i.e., vegetation growth), but for the sake of this analysis, it was placed in the saltwater intrusion category because change in salt content was a deciding factor over change in vegetation. Polygons in the change layer that did not represent actual wetland type changes, but rather corrected classifications because of technique improvements, were not included in analyses. Wetlands that changed from one non-vegetated type to another non-vegetated type (e.g., PUB to PUS) were also omitted from analyses because such shifts do not suggest significant functional changes.

Functional Analysis

Until recently, wetland status and trend analyses typically involved only tracking losses, gains, and changes to wetland acreage and type. Functional analysis on a landscape-scale is now also possible by using the abiotic classification (Tiner 2003b) and the Cowardin et al. (1979) classification. Functional classification uses features like vegetation type, hydrology, landscape position, landform, and connectivity (linkage to other wetlands and waters) that provide individual wetlands with certain opportunities to perform different functions. Among wetland types, not all provide the same level of function. Thus, wetland functional analysis is based on the idea that certain wetland types are more likely to provide certain functions. While tracking changes in wetland acreage is important, it can be argued that tracking functional change is more appropriate in addressing the benefits that wetlands provide. Changes to the landscape over time can lead to a change in functional performance. Field-based functional assessments are more accurate but having the ability to do a functional prediction statewide based on landscape-level assessments is invaluable. It is important to note that landscape-scale functional analysis does not assess wetland quality or condition. DNREC's WMAP offers reports on their website on wetland condition by watershed based on field-level data (DNREC 2021).

For this report, the functional classification (Tiner, 2003b) and the standard Cowardin et al. (1979) classification were both used to predict the potential of wetland types to perform a set of 10 wetland functions. Predicted wetland functions included: surface water detention; coastal storm surge detention; streamflow maintenance; nutrient transformation; carbon sequestration; sediment and other particulates retention; bank and shoreline stabilization; fish and aquatic invertebrate habitat; waterfowl and waterbird habitat; and other wildlife habitat. Two other habitat-related functions, stream shading and wood duck habitat, were assessed and recorded as sub-functions under fish and aquatic invertebrate habitat and waterfowl and waterbird habitat, respectively. From these functional ratings, the sum and percentage of wetland acres in 2017 that were predicted to provide moderate to high levels of each of the 10 functions were calculated. Farmed wetlands were excluded from these analyses.

Similar to the assessment of status and trends of acreage and type, changes to Delaware's wetlands regarding functional potential were difficult to assess in comparing 2007 and 2017. For example, the significant increase in riverine wetlands stemming from the addition of the NHD required in NWI Version 2.0 resulted in a larger lotic stream category and reduced the terrene category of abiotic features compared with the 2007 data. In addition, the improvement in mapping technology removed some wetlands mapped in 2007, but also added some wetlands in 2017, some of which were and remain in natural condition. Because of the many mapping technique changes, comparisons between 2007 and 2017 functional analysis were limited, and conclusions must be drawn with caution.

Results

Current Status: 2017

A total of 296,351.1 acres of wetlands were mapped using 2017 imagery, including vegetated and non-vegetated wetlands (Figure 1, Table 2). Over half (56.4%) of all wetlands in Delaware were palustrine wetlands, including 167,020.7 wetland acres, and a large majority of those wetlands were forested. Most palustrine wetlands were non-tidal (154,011.5 acres; 92.2% of palustrine wetlands), while a much smaller portion were tidal (13,009.2 acres; 7.8%). There were 113,250.7 acres of mapped estuarine wetlands, which made up 38.2% of the state's wetlands. Most mapped estuarine wetlands were either emergent or unconsolidated bottom, with 71,342.6 acres (63.0% of estuarine wetlands) being vegetated and the other 37.0% (41,908.1 acres) being non-vegetated. Less common mapped wetland types included marine (907.0 acres; 0.3% of state wetlands), tidal and non-tidal riverine (9,479.3 acres; 3.2%), and tidal and non-tidal lacustrine wetlands (5,693.4 acres; 1.9%).

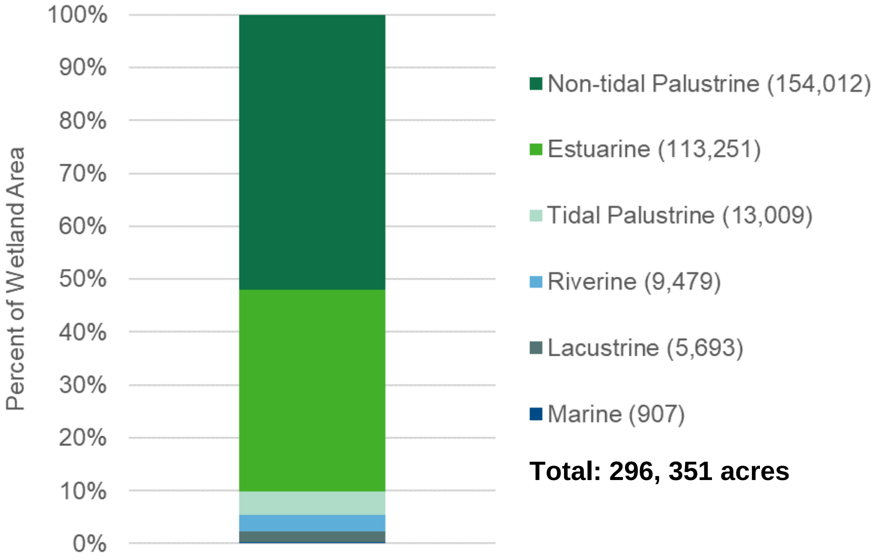
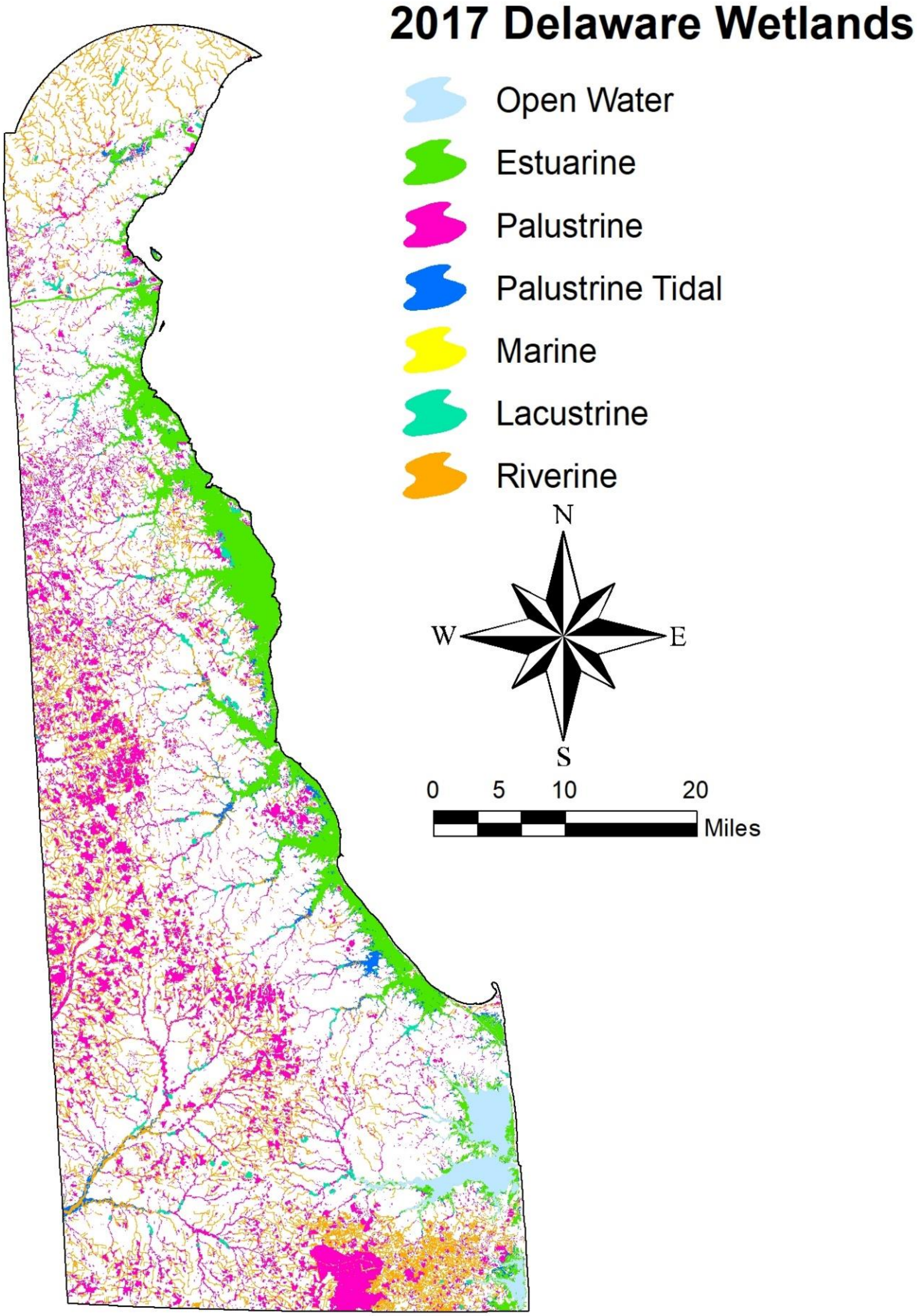


Figure 1. Acreage composition of wetland types in Delaware based on 2017 maps and ecological characteristics.

Table 2. 2017 acreage of wetlands in Delaware classified by ecological characteristics.

System		Sub-System	Class	Acreage
Estuarine	Tidal	Vegetated	Aquatic Bed	75.1
			Forested	110.4
			Scrub-Shrub	339.0
			Emergent	70,818.1
		Non-Vegetated	Rocky Shore	1.5
			Unconsolidated Shore	5,296.3
			Unconsolidated Bottom	36,610.3
		Total Estuarine		**113,250.7**
Palustrine	Tidal	Vegetated	Aquatic Bed	3.0
			Emergent	1,742.9
			Scrub-Shrub	2,364.3
			Forested	8,680.6
		Non-Vegetated	Unconsolidated Shore	0.6
			Unconsolidated Bottom	217.8
		Total Palustrine Tidal		13,009.2
Palustrine	Non-Tidal	Vegetated	Aquatic Bed	41.9
			Farmed	321.0
			Scrub-Shrub	5,891.0
			Emergent	6,734.6
			Forested	134,855.9
		Non-Vegetated	Unconsolidated Shore	24.7
			Unconsolidated Bottom	6,142.4
		Total Palustrine Non-Tidal		154,011.5
		Total Palustrine		**167,020.7**
Marine	Tidal	Non-Vegetated	Rocky Shore	10.0
			Unconsolidated Shore	897.0
		Total Marine		**907.0**
Riverine	Tidal	Vegetated	Emergent	670.9
		Non-Vegetated	Unconsolidated Shore	62.5
			Unconsolidated Bottom	1,827.9
		Total Riverine Tidal		2,561.3
	Non-Tidal	Non-Vegetated	Unconsolidated Shore	0.7
			Unconsolidated Bottom	708.2
			Stream Bed	6,209.1
		Total Riverine Non-Tidal		6,918.0
		Total Riverine		**9,479.3**
Lacustrine	Tidal	Non-Vegetated	Unconsolidated Bottom	26.4
		Total Lacustrine Tidal		26.4
	Non-Tidal	Vegetated	Aquatic Bed	19.1
			Emergent	255.0
		Non-Vegetated	Unconsolidated Shore	50.4
			Unconsolidated Bottom	5,342.5
		Total Lacustrine Non-Tidal		5,667.0
		Total Lacustrine		**5,693.4**
TOTAL MAPPED				**296,351.1**



Map 3. 2017 wetland type distribution across the state of Delaware. Wetlands are classified based on ecological characteristics.

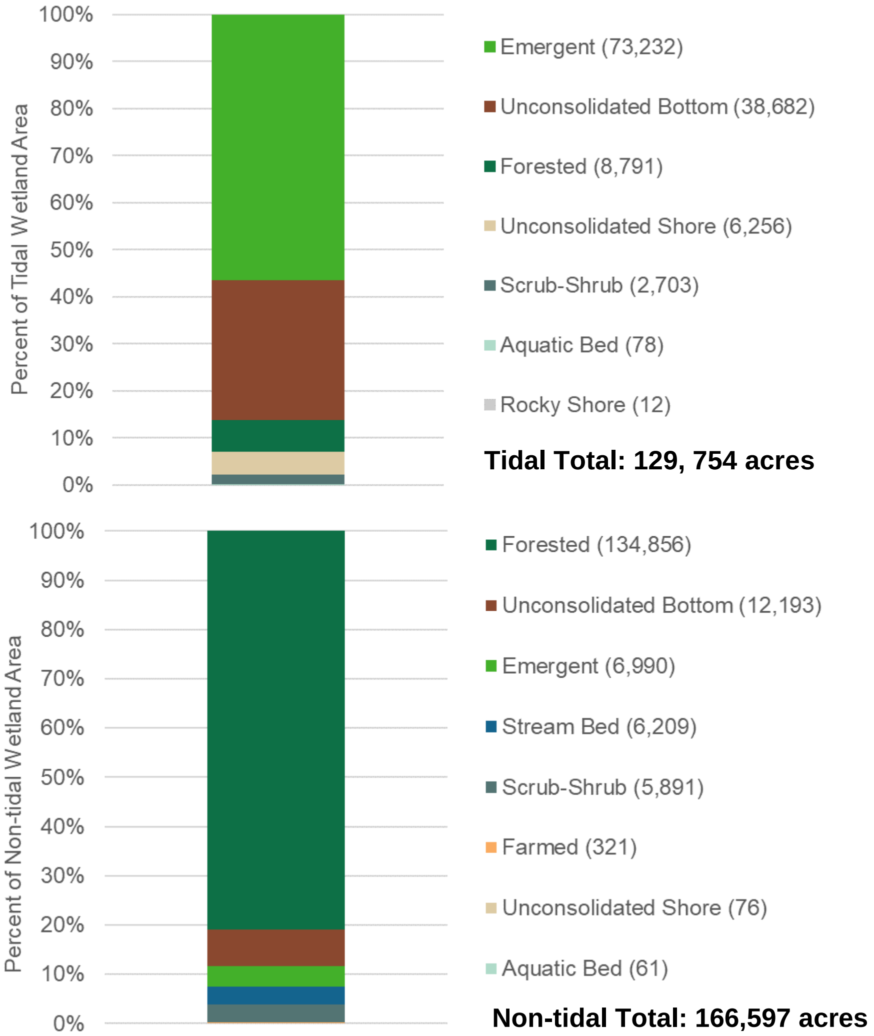


Figure 2. Statewide acreage of tidal (top) and non-tidal (bottom) wetland types in Delaware based on 2017 maps.

Estuarine wetlands were located along the Delaware Bay and throughout the Inland Bays, and non-tidal palustrine wetlands were scattered throughout the state. Tidal palustrine wetlands occurred in small areas throughout the state between estuarine and non-tidal palustrine wetlands. Riverine wetlands were scattered throughout the state but were particularly concentrated along the southern border of the state, the northern border of the state, and headwater areas along the western border of the state. Lacustrine wetlands were present throughout the state, but in much smaller quantities than other wetland types. Marine wetlands were present in relatively small quantities along the coast (Map 3).

Most tidal wetlands were either emergent (73,232.0 acres; 56.4% of tidal wetlands) or unconsolidated bottom (38,682.1 acres; 29.8%). Other tidal wetlands included forest (8,791.0 acres; 6.8%), unconsolidated shore (6,255.9 acres; 4.8%), and scrub-shrub (2,703.3 acres; 2.1%). Aquatic bed (78.1 acres) and rocky shore (11.6 acres) comprised very small proportions of tidal wetlands (<0.1%). In contrast, most non-tidal wetlands in Delaware were forested (134,855.9 acres; 80.9% of non-tidal wetlands). Other non-tidal wetlands included unconsolidated bottom (12,193.4 acres; 7.3%), emergent (6,989.7 acres; 4.2%), stream bed (6,209.0 acres; 3.7%), scrub-shrub (5,891.0 acres; 3.5%). Very few non-tidal wetlands were farmed (321.0 acres; 0.2%), unconsolidated shore (75.7 acres; 0.1%), or aquatic bed (60.9 acres; 0.1%; Figure 2).

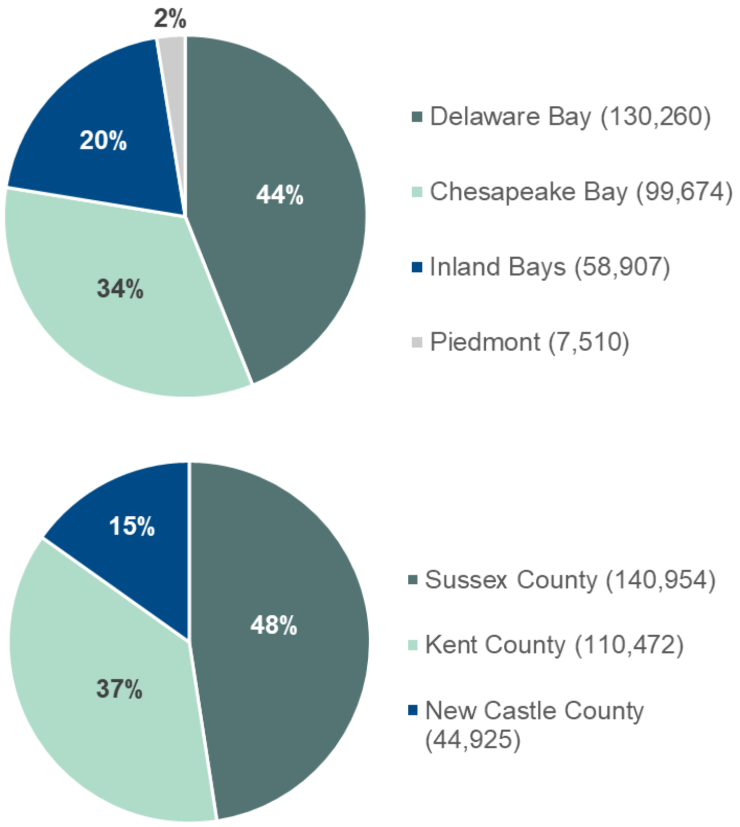


Figure 3. Delaware wetland acreage by drainage basin (top) and by county (bottom) based on 2017 wetland maps.

By drainage basin, the highest proportion of wetlands were within the Delaware Bay drainage basin (130,259.9 acres; 44.0%), followed by the Chesapeake Bay (99,673.9 acres; 33.7%) and Inland Bays (58,907.4 acres; 19.9%). A small portion of Delaware's wetlands were within the Piedmont drainage basin (7,510.0 acres; 2.4%; Figure 3). Most of the vegetated wetlands in the Piedmont, Chesapeake Bay, and Inland Bays drainage basins were palustrine forested wetlands. Emergent estuarine wetlands dominated the Delaware Bay drainage basin. By county, nearly half (140,954.1 acres; 47.6%) of Delaware's wetlands were in Sussex County. A significant portion were also in Kent County (110,472.0 acres; 37.3%) and the smallest portion were in New Castle County (44,925.0 acres; 15.1%; Figure 3).

High and Low Marsh

As of 2017, there was an estimated total of 18,630.9 acres of estuarine high marsh habitat. Most of this (17,933.3 acres; 96.3% of high marsh) was emergent vegetation. Other vegetated high marsh areas were much less common and included scrub-shrub (339.0 acres; 1.8%) and forest (110.4 acres; 0.6%). Non-vegetated areas were also relatively uncommon and included unconsolidated shore (246.5 acres; 1.3%) and rocky shore (1.7 acres; <1.0%; Table 3). Notably, over half (9,799.9 acres; 52.6%) of mapped high marsh areas were composed entirely or partially of invasive *P. australis*, as shown in the example in Map 4.

There was a total estimated 57,883.2 acres of estuarine low marsh habitat in 2017, meaning that there was much more low marsh habitat in Delaware than high marsh habitat. Most low marsh was emergent vegetation (52,983.3 acres; 91.5% of low marsh habitat), which likely corresponded to *S. alterniflora* marsh. The remainder of mapped low marsh was composed of non-vegetated unconsolidated shore (4,899.9 acres; 8.5%; Table 3).

Table 3. High marsh and low marsh acreage in Delaware based on the 2017 high marsh and low marsh wetland maps.

Marsh type	Subsystem	Class	Total Acreage
High marsh	Intertidal		
	Vegetated	Emergent	17,933.3
		Scrub-shrub	339.0
		Forested	110.4
	Nonvegetated	Unconsolidated shore	246.5
		Rocky shore	1.7
	Total Mapped		**18,630.9**
Low marsh	Intertidal		
	Vegetated	Emergent	52,983.3
	Nonvegetated	Unconsolidated shore	4,899.9
	Total Mapped		**57,883.2**

Map 4. High marsh habitat that was dominated by *P. australis* as of 2017 is outlined here in pink.

Losses: 2007-2017

Between 2007 and 2017, Delaware lost 238.5 acres of vegetated tidal wetlands and 2,773.0 acres of vegetated non-tidal wetlands. Most of the vegetated tidal wetland losses (157.8 acres; 66.3% of losses) were because of environmental impacts such as erosion or rising sea level. Other causes of tidal loss were development (31.2 acres;

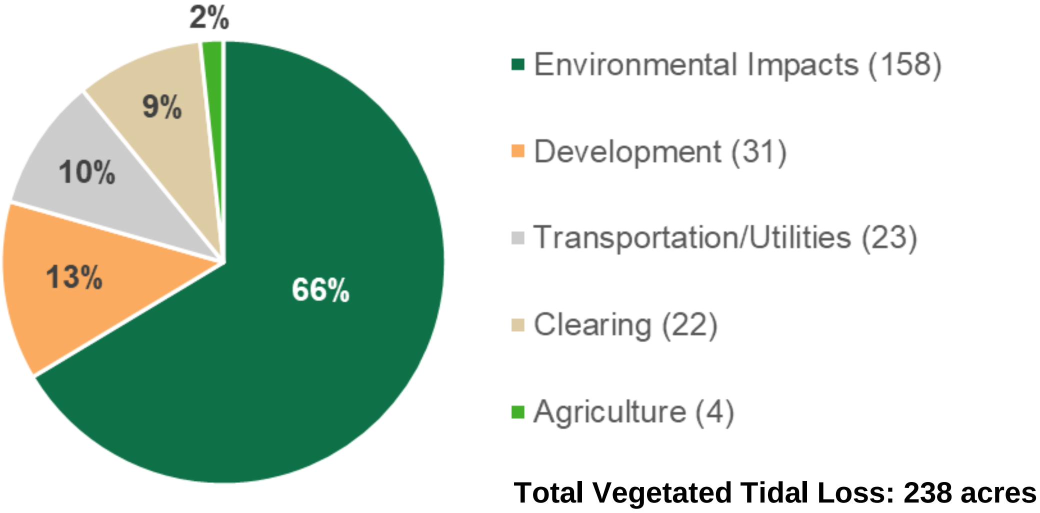


Figure 4. Proportions of vegetated tidal wetland losses from different causes between 2007 and 2017. Only losses ≥ 0.25 acres in size are included in calculations of proportions.

13.1%), transportation and utilities (23.1 acres; 9.7%), land mowing or clearing (21.7 acres; 9.1%), and agriculture (4.2 acres; 1.8%; Figure 4, Map 5). In contrast, most of the vegetated non-tidal losses were caused by clearing (1,508.1 acres; 54.4% of losses). Development (654.7 acres; 23.6%) and agriculture (533.5 acres; 19.2%) were also significant causes of non-tidal wetland loss between 2007 and 2017. Fewer losses were caused by transportation or utilities (74.8 acres; 2.8%), and hardly any were caused by environmental impacts (2.0 acres; <1.0%; Figure 5, Map 6).

Map 5. Pictured is an example of tidal emergent wetland in 2007 (left) that is lost to open water by 2017 (right).

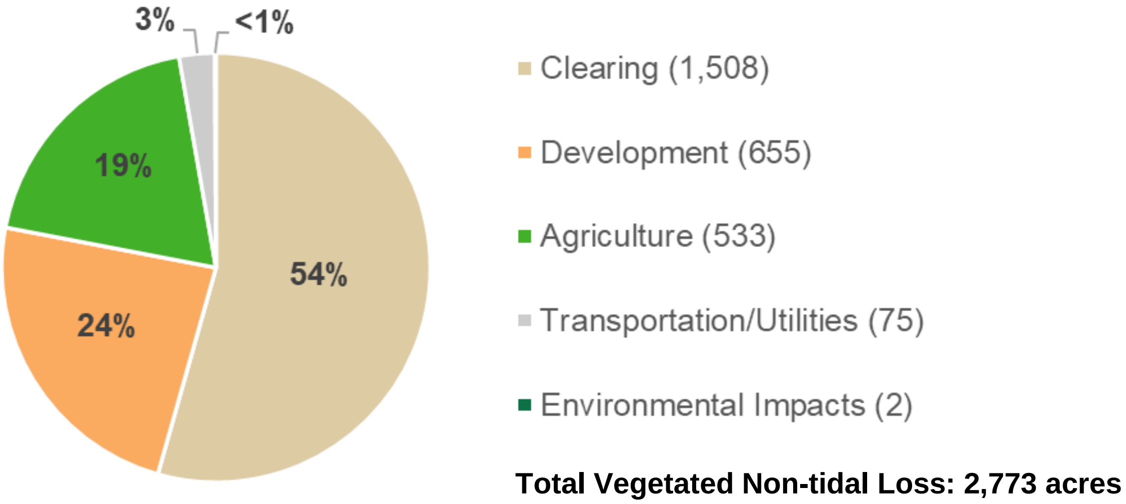


Figure 5. Proportions of vegetated non-tidal wetland losses from different causes between 2007 and 2017. Only losses ≥ 0.25 acres in size are included in calculations of proportions.

Map 6. Outlined in orange is an example of a non-tidal forested wetland in 2007 (left) that was lost to agriculture by 2017 (right).

Sussex County sustained the worst vegetated wetland losses in terms of acreage, having lost 2,000.4 acres of wetlands (66.5% of losses) between 2007 and 2017. Kent County lost a total of 717.9 acres (23.8%), while New Castle County lost 293.2 acres (9.7%). Tidal wetland loss was concentrated largely in Kent and New Castle Counties, while most non-tidal wetland loss occurred in Sussex County (Table 4).

In terms of drainage basin, the Chesapeake Bay watershed lost the most vegetated wetlands (1,884.1 acres; 62.6% of losses), followed by the Delaware Bay watershed (565.6 acres; 18.8%), the Inland Bays/Atlantic Ocean watershed (501.5 acres; 16.6%), and the Piedmont watershed (60.2 acres; 2.0%). Tidal wetland loss was concentrated largely in the Delaware Bay watershed and non-tidal wetland loss was the most extreme in the Chesapeake Bay watershed (Table 4).

Table 4. Vegetated wetland losses by county and wetland type between 2007 and 2017. Included are all losses ≥ 0.25 acres.

Geographic Area	Wetland Type	Loss (-)
New Castle County	Tidal	99.2
	Non-tidal	194.0
	Acreage Lost	293.2
Kent County	Tidal	110.6
	Non-tidal	607.3
	Acreage Lost	717.9
Sussex County	Tidal	28.7
	Non-tidal	1,971.7
	Acreage Lost	2,000.4
State of Delaware Loss (by county)		**3,011.5**
Piedmont Watershed	Tidal	18.8
	Non-tidal	41.3
	Acreage Lost	60.2
Delaware Bay Watershed	Tidal	208.5
	Non-tidal	357.1
	Acreage Lost	565.6
Chesapeake Bay Watershed	Tidal	1.1
	Non-tidal	1,883.0
	Acreage Lost	1,884.1
Inland Bays/Atlantic Ocean Watershed	Tidal	10
	Non-tidal	491.5
	Acreage Lost	501.5
State of Delaware Loss (by watershed)		**3,011.5**

Gains: 2007-2017

Between 2007 and 2017, Delaware gained 1,406.0 acres of wetlands, including 375.3 acres of vegetated wetlands (26.7% of total gains) and 1,030.7 acres of non-vegetated wetlands (73.3%). The state gained 136.1 acres of vegetated tidal wetlands. Most of those gains were due to wetland migration inland (124.0 acres; 91.1% of vegetated tidal gains), while much smaller proportions of vegetated tidal gains were from restoration (5.7 acres; 4.2%), agriculture (3.8 acres; 2.8%), and development (2.6 acres; 1.9%; Figure 6). Delaware gained very few non-vegetated tidal wetlands (8.9 acres) between 2007 and 2017, and those gains were from wetland migration inland (5.8 acres; 65.2% of non-vegetated tidal gains), agriculture (1.9 acres; 21.3%), and development (1.2 acres; 13.5%; Figure 6).

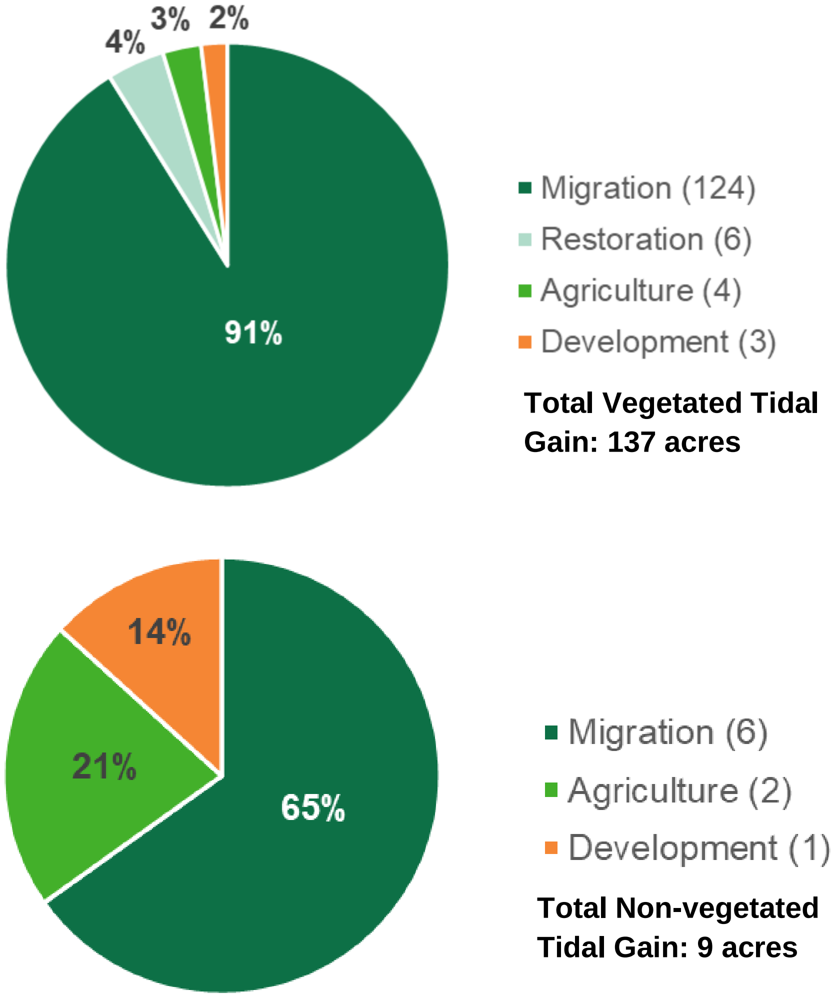


Figure 6. Sources of tidal vegetated (top) and non-vegetated (bottom) wetland gains between 2007 and 2017. This includes only gains ≥ 0.25 acres.

In that same time, Delaware gained 239.2 acres of vegetated non-tidal wetlands. Most of those gains were due to agriculture (102.8 acres; 43.0%), followed by development (46.4 acres; 19.5%), restoration (44.1 acres; 18.4%), industrial operations (35.5 acres; 14.8%), and wetland migration inland (10.4 acres; 4.3%; Figure 7). The state gained far more non-vegetated wetlands than vegetated wetlands, amounting to 1,021.8 acres. Most non-vegetated non-tidal gains were because of development (439.9 acres; 43.0%) or industrial operations (417.0 acres; 40.8%), followed by agriculture (151.0 acres; 14.8%) and restoration (13.9 acres; 1.4%; Figure 7).

By county, Sussex County gained the most wetlands between 2007 and 2017 (726.6 acres; 51.7% of total gains). Most of those gains were non-vegetated (587.5 acres; 80.9% of Sussex gains), and only 19.1% (139.1 acres) in the county were vegetated wetland gains. In terms of tidal regime, Sussex County gained 84.0 acres of tidal wetlands (11.5% of Sussex gains), most of which were vegetated, and gained 642.6 acres of non-tidal wetlands (88.5%), most of which were non-vegetated. Kent County gained the next largest amount of wetland acreage between 2007 and 2017 (392.0 acres; 27.9% of total gains). Nearly three-quarters (284.1 acres; 72.5% of Kent gains) of those gains were non-vegetated, with the other 27.5% (107.9 acres) being vegetated. Kent County gained more non-tidal wetlands (356.8 acres; 91.0% of Kent gains) than tidal wetlands (35.2 acres; 9.0%). Most non-tidal gains in the county were non-vegetated, while most tidal gains were vegetated. New Castle County gained the smallest amount of wetland acreage during the same time (287.4 acres; 20.4% of total gains). Of those wetlands, 159.1 acres were non-vegetated (55.4% of New Castle gains) and 128.3 acres were vegetated (44.6%). Most gains in New Castle County were non-tidal wetlands (261.6 acres; 91.0% of New Castle gains), over half of which were non-vegetated. The county gained far fewer tidal wetlands (25.8 acres; 9.0%), though all were vegetated (Table 5).

The Delaware Bay watershed gained the most of any other basin in Delaware between 2007 and 2017 (676.2 acres; 48.1% of total gains). Almost two-thirds (417.7 acres; 61.8% of Delaware Bay gains) of those wetlands were non-vegetated, and the remaining 38.2% (258.5 acres) were vegetated. In terms of tidal regime, most gained wetlands in the Delaware Bay were non-tidal (575.4 acres; 85.1% of Delaware Bay gains), most of which were non-vegetated. Delaware Bay also gained 100.8 acres (14.9%) of tidal wetlands, and nearly all of those were vegetated. The Inland Bays/Atlantic Ocean watershed gained the next largest amount of wetland acreage out of the four major basins in the state (383.6 acres; 27.3% of total gains). The vast majority of those gains were non-vegetated wetlands (335.1 acres; 87.4% of Inland Bays/Atlantic Ocean gains), with far fewer gains being vegetated (48.5 acres; 12.6%). The southern Delaware watershed gained 340.6 acres (88.8% of Inland Bays/Atlantic Ocean gains) of non-tidal wetlands, mostly non-vegetated, and 43.0 acres (11.2%) of tidal wetlands, mostly vegetated (Table 5).

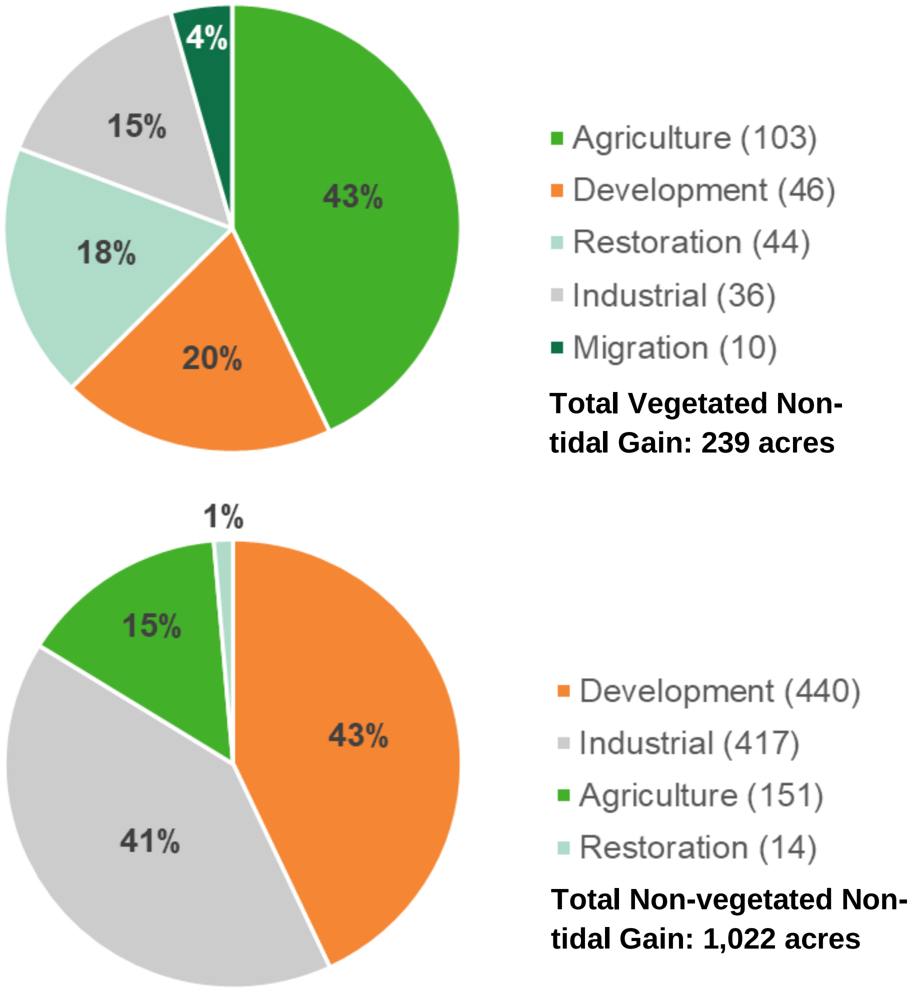


Figure 7. Sources of non-tidal vegetated (top) and non-vegetated (bottom) wetland gains between 2007 and 2017. This includes only gains ≥ 0.25 acres.

The Chesapeake Bay watershed gained 294.6 acres of wetlands between 2007 and 2017 (21.0% of total gains). Most gains in that basin were non-vegetated (251.8 acres; 85.5% of Chesapeake Bay gains), with only 14.5% (42.8 acres) being vegetated. All gains in the Chesapeake Bay watershed were non-tidal. Lastly, the Piedmont watershed, the smallest major basin in the state, gained the smallest amount of wetland acreage (51.6 acres; 3.6 % of total gains). Approximately half of those gains were non-vegetated (26.1 acres; 50.6% of Piedmont gains) and the other half were vegetated (25.5 acres; 49.4%). Almost all wetland gains in the Piedmont watershed were non-tidal (50.4 acres; 97.7% of Piedmont gains), and those were nearly evenly split between vegetated and non-vegetated. Only 1.2 acres of gained wetlands in the Piedmont were tidal (2.3%), and those wetlands were vegetated (Table 5). Examples of different types of wetland gains throughout the state can be seen in Map 7.

Table 5. Gains by county and by watershed between 2007 and 2017. Included are all gains ≥ 0.25 acres.

Geographic Area	Wetland Type	Sub-system	Acreage
New Castle County	Tidal	Vegetated	25.8
		Non-vegetated	0.0
	Non-tidal	Vegetated	102.5
		Non-vegetated	159.1
	Acreage Gained		287.4
Kent County	Tidal	Vegetated	34.5
		Non-vegetated	0.7
	Non-tidal	Vegetated	73.4
		Non-vegetated	283.4
	Acreage Gained		392.0
Sussex County	Tidal	Vegetated	75.8
		Non-vegetated	8.2
	Non-tidal	Vegetated	63.3
		Non-vegetated	579.3
	Acreage Gained		726.6
Total Vegetated Gain			**375.3**
Total Non-vegetated Gain			**1,030.7**
State of Delaware Total Gain (by county)			**1,406.0**
Piedmont Watershed	Tidal	Vegetated	1.2
		Non-vegetated	0.0
	Non-tidal	Vegetated	24.3
		Non-vegetated	26.1
	Acreage Gained		51.6
Delaware Bay Watershed	Tidal	Vegetated	97.5
		Non-vegetated	3.3
	Non-tidal	Vegetated	161.0
		Non-vegetated	414.4
	Acreage Gained		676.2
Chesapeake Bay Watershed	Tidal	Vegetated	0.0
		Non-vegetated	0.0
	Non-tidal	Vegetated	42.8
		Non-vegetated	251.8
	Acreage Gained		294.6
Inland Bays/Atlantic Ocean Watershed	Tidal	Vegetated	37.4
		Non-vegetated	5.6
	Non-tidal	Vegetated	11.1
		Non-vegetated	329.5
	Acreage Gained		383.6
Total Vegetated Gain			**375.3**
Total Non-vegetated Gain			**1,030.7**
State of Delaware Total Gain (by watershed)			**1,406.0**

Map 7. Examples of wetland gains. Example a) shows a gained agricultural wetland in 2017; b) shows gained residential stormwater ponds in 2017; c) shows a wetland gained from restoration in 2017; d) shows a gained industrial pond in 2017; e) and f) show how tidal marsh was gained from an upland forest through the process of marsh migration from 2007 (e) to 2017 (f).

When combined with the statewide losses of vegetated wetlands, Delaware had a net loss of 102.4 acres of vegetated tidal wetlands and a net loss of 2,533.9 acres of vegetated non-tidal wetlands between 2007 and 2017 (Figure 8). Together, this meant that Delaware experienced a total net loss of 2,636.3 acres of vegetated wetlands.

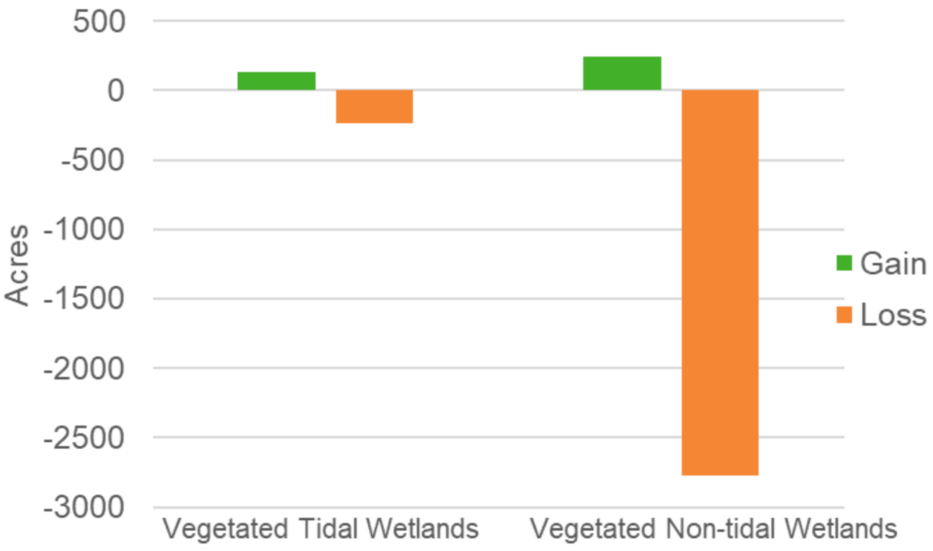


Figure 8. Statewide gains and losses of vegetated tidal and non-tidal wetlands between 2007 and 2017 based on wetland maps.

Wetland Type Changes: 2007-2017

A total of 6,169.7 acres of tidal wetlands and 7,652.5 acres of non-tidal wetlands changed from one wetland type to another from 2007 to 2017 statewide (see examples in Map 8). Some tidal wetlands (919.3 acres; 14.9% of tidal changes) changed from tidal palustrine to estuarine, suggesting that saltwater intrusion or rising sea levels may have converted tidal freshwater wetlands to brackish wetlands. Many tidal wetlands changed from vegetated wetland types in 2007 to non-vegetated wetland types in 2017 (64.5% of tidal changes), such as intertidal unconsolidated or rocky shore (2,562.0 acres), estuarine unconsolidated bottom (1,411.1 acres), or tidal freshwater lakes or ponds (5.9 acres). Fewer tidal wetlands changed from non-vegetated types to vegetated types (667.2 acres; 10.8% of tidal changes). Other tidal wetlands were vegetated in both 2007 and 2017 but experienced changes in dominant vegetation cover type (9.8% of tidal changes). For example, successional changes (172.8 acres) were observed in some tidal wetlands, such as changes from emergent to scrub-shrub vegetation. Changes due to increased flooding (431.4 acres) were also seen (Table 6). Evidence of increased flooding included dead or downed trees in areas that were forest bordering marsh in 2007 and were converting to emergent marsh by 2017.

Map 8. Pictured are examples of wetland type changes outlined in yellow from 2007 to 2017. On the top row is a non-tidal wetland that was forested in 2007 (a), was deforested between 2007 and 2017, and started recovering to scrub-shrub habitat by 2017 (b). On the bottom row is a tidal wetland that was emergent in 2007 (c) and was unconsolidated bottom in 2017 (d).

A significant amount of wetland acreage changed from being non-tidal to tidal wetlands between 2007 and 2017 (1,181.3 acres; 15.4% of non-tidal changes). It may be that rising sea level pushed the head of tide further inland during that 10-year period. A relatively small proportion of non-tidal wetlands changed from vegetated wetland types in 2007 to non-vegetated freshwater lakes or ponds in 2017 (266.6 acres; 3.5% of non-tidal changes). Other non-tidal wetlands changed from non-vegetated freshwater ponds or lakes to vegetated wetland types (729.8 acres; 9.5% of non-tidal changes).

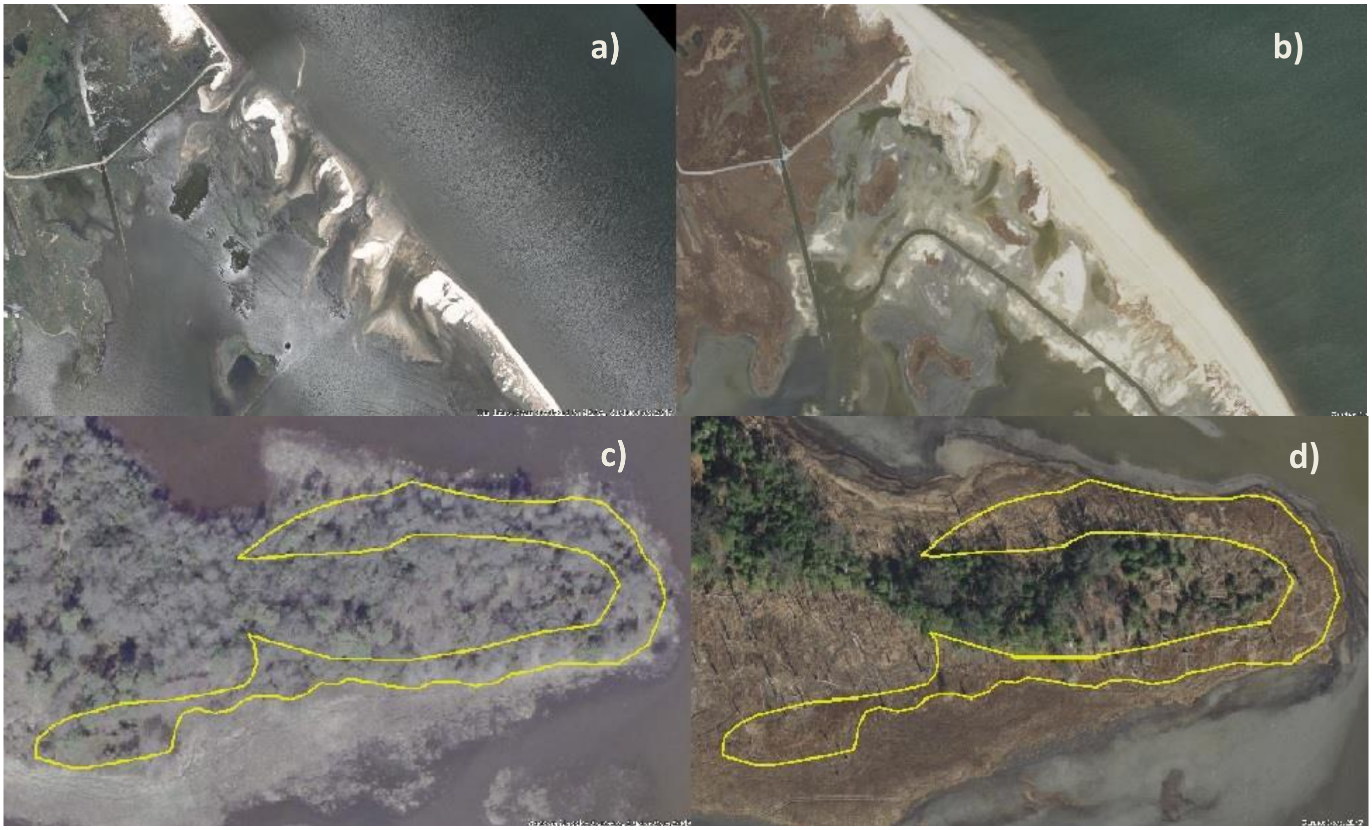
However, most non-tidal changes were from one non-tidal vegetated wetland type to another vegetated wetland type (71.5% of non-tidal changes). Some changes were because of succession (2,772.6 acres), such as changes from non-tidal scrub-shrub to forest. Other non-tidal wetlands experienced vegetation type changes because of increased flooding (314.3 acres). These cases were often in forested areas where floodplains expanded. Numerous non-tidal wetlands also experienced vegetation changes because of deforestation (2,387.9 acres; Table 6). These areas were forested in 2007 and were logged and cleared sometime between 2007 and 2017. Some areas started to regrow by 2017 and had some scrub-shrub vegetation, while others did not show any regrowth of woody vegetation by 2017 and were classified as emergent.

One area that experienced many wetland changes from both natural causes and human intervention between 2007 and 2017 was Prime Hook National Wildlife Refuge in Sussex County. A total of 2,915.0 acres of tidal wetlands changed within the refuge during that time, accounting for 47.2% of all tidal wetland changes across the state. Beaches and barrier dunes in the refuge were being eroded by coastal storms and were finally breached by Hurricane Sandy in 2012 (Map 9a). After this, a large-scale restoration project began at Prime Hook that restored beach and dune habitat (Map 9b), restored historic channels to promote tidal flow in marsh areas, and recreated new marsh habitat with dredged material from channel construction. Because of the storm breaches and the restoration project, many emergent tidal wetlands changed to unconsolidated bottom or

Table 6. Acres of tidal and non-tidal wetland type changes from 2007 to 2017. Included are changes ≥ 0.25 acres.

Wetland Type	Change Type (2007-2017)	Change Description	Acres
Tidal	Saltwater intrusion:	Tidal palustrine to estuarine	919.3
	Vegetation growth from:	Estuarine unconsolidated bottom	559.2
		Intertidal unconsolidated shore	93.2
		Tidal freshwater ponds/lakes	14.8
	Vegetation loss to:	Intertidal unconsolidated or rocky shore	2,562.0
		Estuarine unconsolidated bottom	1,411.1
		Tidal freshwater ponds/lakes	5.9
	Vegetation changes:	Succession	172.8
		Increased flooding	431.4
	Total Tidal Changes		**6,169.7**
Non-tidal	Tidal regime:	Non-tidal to tidal	1,181.3
	Vegetation growth from:	Non-tidal freshwater ponds/lakes	729.8
	Vegetation loss to:	Freshwater ponds/lakes	266.6
	Vegetation changes:	Succession	2,772.6
		Increased flooding	314.3
		Deforestation	2,387.9
	Total Non-tidal Changes		**7,652.5**

shore, and vice versa. Some coastal forested wetland areas experienced tree die-off and converted to emergent wetlands because of flooding and saltwater inundation associated with the storms and breaches (Map 9c, d).



Map 9. Shown are the Prime Hook beach and dune breaches following Hurricane Sandy in 2012 (a) and the restoration of those areas by 2017 (b). Also shown is a coastal forest outlined in yellow within Prime Hook intact in 2007 (c) and severely damaged and converted to emergent marsh by 2017 (d).

Wetland Function

Analysis of wetland function in 2017 for 10 different functions revealed nearly two-thirds or more of the state's wetlands had the potential to perform the following functions at high or moderate levels: nutrient transformation, carbon sequestration, bank and shoreline stabilization, and provision of habitat for other wildlife. Other functions predicted to be provided by more than 45% of the state's wetlands were surface water detention, retention of sediments and other particulates, and provision of habitat for fish and aquatic species. About one-third of the wetlands were considered important for coastal storm surge detention, streamflow maintenance, stream shading, and waterfowl or waterbird habitat. Less than 10% of wetlands were predicted to provide wood duck habitat (Table 7).

Table 7. Acreage and percent of 2017 wetlands (including ponds) predicted to perform each wetland function at high or moderate levels, and the wetland acreage in 2007. Farmed wetlands are not included.

Wetland Function	2017 Acreage	% of DE's Wetlands likely performing at moderate to high levels	2007 Acreage
1. Surface Water Detention (This function is limited to freshwater wetlands; the role of coastal wetlands in water storage is handled by the Coastal Storm Surge Detention Function.)	150, 203	50.7	171,045
2. Coastal Storm Surge Detention (This function includes tidal wetlands plus contiguous non-tidal wetlands subject to flooding during storm surges.)	94, 096	31.8	85,523
3. Streamflow Maintenance (These wetlands are sources of streams or along first order perennial streams or above.)	112,825	38.1	134,620
4. Nutrient Transformation	261,078	88.1	246,847
5. Carbon Sequestration	256,802	86.7	249,012
6. Sediment and Other Particulates Retention	149,215	50.4	156,756
7. Bank and Shoreline Stabilization	203,469	68.7	182,105
8. Fish and Aquatic Invertebrate Habitat	136,087	45.9	78,230
Stream Shading	106,349	35.9	36,935
9. Waterfowl and Waterbird Habitat	85,691	28.9	80,920
Wood Duck	24,423	8.2	25,691
10. Other Wildlife Habitat	230,112	77.6	248,090

The acreage of wetlands providing certain functions at moderate or high levels appeared to increase from 2007 to 2017, including coastal storm surge detention, nutrient transformation, carbon sequestration, bank and shoreline stabilization, fish and aquatic invertebrate habitat, stream shading, and waterfowl and waterbird habitat. For other functions, the acreage of wetlands providing them at moderate or high levels appeared to decrease from 2007 to 2017, including surface water detention, streamflow maintenance, retention of sediment and other particulates, wood duck habitat, and other wildlife habitat (Table 7). While some of those functional differences could have been a result of wetland gains, losses, or changes from 2007 to 2017, many of the observed differences in predicted functions between 2007 and 2017 were caused by differences in mapping techniques (see 'Functional Analysis' in Methods section).

Discussion

Tidal Wetlands

There was a net loss of 102.4 acres of vegetated tidal wetlands from 2007 to 2017. Most tidal wetland loss (66.3%) was due to environmental impacts such as erosion and sea-level rise and was largely concentrated in the Delaware Bay watershed. Environmental impacts were also the most significant sources of estuarine wetland loss from 1992 to 2007 (Tiner et al. 2011). Some of the wetland type changes that occurred between 2007 and 2017 showed that environmental impacts were strong drivers of tidal wetland alteration as well as loss. Changes from tidal palustrine to estuarine and from coastal forest to estuarine marsh all suggest that sea level has continued to rise and push saltwater and the head of tide further inland. Similarly, most tidal wetland gains were because of marsh migration inland.

The Mid-Atlantic region, including Delaware, is a sea level rise hotspot (Sallenger et al. 2012), and sea-level rise is predicted to continue. Past and more recent tidal wetland trends, in combination with future sea-level rise predictions, together highlight the importance of using nature-based shoreline stabilization strategies, such as living shorelines, to help curb erosion problems where appropriate to prevent further wetland loss. These trends also suggest that tidal wetland restoration, such as through the beneficial use of dredge material, is needed to counteract losses. It is crucial to leave tracts of natural land undeveloped adjacent to current marshes for marsh migration to occur as well. As sea level rises, tidal marshes have the ability to migrate inland and maintain their acreage and function. However, if the areas landward of tidal marshes are developed, the marshes will have nowhere to migrate, which will translate into further losses of tidal marsh acreage and function.

Over half of tidal wetland changes that occurred (64.5%) were from vegetated to non-vegetated tidal wetlands. Such changes have implications for tidal wetland functions. Non-vegetated wetlands do not usually perform certain functions, such as wave energy reduction, sediment retention, shoreline stabilization, and provision of wildlife habitat, at the same level as vegetated wetlands. Therefore, although those tidal wetlands were not entirely lost, their functional capacity was reduced. On the other hand, most tidal wetland gains were vegetated wetlands (93.9% of tidal gains), so many tidal gains likely perform wetland functions adequately. When implementing shoreline stabilization or restoration projects, it is critical that native vegetation is included to ensure maximum functional capacity.

It is worth noting that over half (52.6%) of mapped high marsh areas in tidal wetlands in 2017 were composed entirely or partially of invasive *P. australis.* Invasive species can rapidly displace the native species that characterize high-functioning high marsh habitat and that provide vital habitat for obligate wetland wildlife. It is also incredibly difficult to eradicate this species once established. Therefore, invasive *P. australis* should be removed or controlled as soon as possible both within and adjacent to tidal wetlands.

Non-Tidal Wetlands

From 2007 to 2017, there was a net loss of 2,533.9 acres of vegetated non-tidal wetlands. The Chesapeake Bay watershed endured the worst wetland losses of all of Delaware's drainage basins (62.6% of statewide losses) between 2007 and 2017, following the same trend that was seen between 1992 and 2007 (Tiner et al. 2011). If wetland losses in the headwaters of the Chesapeake Bay continue, there could be negative ramifications for downstream water quality.

Clearing (i.e., logging activities) accounted for a little over half of non-tidal wetland loss (54.4%). Development and agriculture were also significant sources of non-tidal wetland loss (23.6% and 19.2%, respectively), just as they were substantial sources of non-tidal wetland loss between 1992 and 2007 (Tiner et al. 2011). Lack of state regulation and recent weakened federal regulation leave these non-tidal wetlands very vulnerable to continued destruction. A state regulatory program for non-tidal wetlands that is properly enforced is needed in Delaware to curb the destruction of non-tidal wetlands across the state. Wetland restoration efforts are also needed to help counteract acreage losses. In addition, clear-cutting of forested wetlands should be avoided to further prevent non-tidal wetland losses.

Over three-quarters (81.0%) of non-tidal wetland gains were of non-vegetated wetlands, such as stormwater retention ponds around residential developments, ponds as part of industrial operations, or agricultural ponds. As stated previously, non-vegetated wetlands do not typically perform certain functions, such as wave energy reduction, sediment retention, shoreline stabilization, and provision of wildlife habitat, at the same level as vegetated wetlands, if at all. This means that although Delaware gained 1,261.0 acres of non-tidal wetlands, most of them had greatly reduced functional capacity. Any restoration efforts that seek to increase wetland acreage should therefore focus on creating habitats that resemble natural, vegetated wetlands.

Non-tidal wetlands that changed from vegetated to non-vegetated (3.5% of non-tidal wetland changes) likely experienced a decrease in functional capacity, whereas those that changed from non-vegetated to vegetated (9.5%) likely experienced an increase in functional capacity. Most changes to non-tidal wetlands were from one vegetated type to another (71.5%), and such changes have a variety of consequences. For example, different wildlife species are likely to inhabit wetlands with different vegetation communities.

Nearly one-third of changes seen in non-tidal wetlands (31.2%) were due to clearing. Such areas were forested in 2007 and were cleared of trees between 2007 and

2017. By 2017, these wetlands were in various stages of recovery; some had scrub-shrub vegetation, while others lacked woody vegetation. If the deforested wetlands can recover fully to their original state, they may regain all their functional capacity. However, if deforested wetlands are not allowed to recover, they will likely offer reduced or different functional capacity compared with natural forested wetlands. For example, dramatic changes in vegetation can strongly affect the wildlife that use wetlands, as different species specialize in forest versus emergent habitat. Large vehicles and equipment associated with clear-cutting may cause irreversible soil compaction and microtopography alterations, which could negatively affect plant regrowth, water filtration, and water pooling. As aforementioned, clear cutting in wetlands should be avoided wherever possible because of these potential consequences. Selective or partial clearing may reduce negative effects on wetland ecosystems in cases where impacts are inevitable.

Some wetlands that were non-tidal in 2007 were tidal by 2017 (15.4% of non-tidal wetland changes). If sea level continues to rise as predicted, non-tidal wetlands that are near the head of tide will continue to be converted to tidal wetlands as the head of tide moves further upstream. These changes may have implications for wildlife, as non-tidal and tidal wetlands are often inhabited by different plant and animal species.

Wetland Functions

During the 1992 to 2007 timeframe, most wetland gains were attributed to open water ponds (2,285.0 acres; Tiner et al. 2011). That same trend continued from 2007 to 2017, with gains of non-vegetated wetlands totaling 1,030.7 acres. Although this increase in wetland acreage from open water provided some functional benefit, such as fish and aquatic invertebrate habitat and waterfowl habitat, it should be noted that open water wetlands do not provide nearly the high and broad functions of natural, vegetated wetlands. The gain in open water function does little to address the range of functions lost from the widespread destruction of vegetated wetlands over these 10 years.

The observed decrease of the percent of wetlands performing certain functions was partially because of mapping technique changes between 2007 and 2017. However, wetland loss was also partially responsible for this decrease for many functions, including fish and aquatic invertebrate habitat (and stream shading), nutrient retention, surface water detention, bank and shoreline stabilization, and carbon sequestration. Any wetland restoration projects that occur should therefore resemble natural, vegetated wetlands as much as possible and aim to restore important functions that have been lost statewide.

Management Recommendations

The best way to prevent future wetland losses and improve or maintain current wetland habitat is to target specific issues that were found to be most prevalent in each wetland type. Below, management recommendations are detailed for tidal and non-tidal wetlands that relate to points emphasized above in the Discussion section. These recommendations specifically address the most severe causes of wetland acreage and functional losses between 2007 and 2017 according to wetland maps, and they are summarized in Table 8.

Tidal Wetlands

1. **Use nature-based shoreline stabilization techniques.** The main driver of tidal wetland loss from 2007 to 2017 was environmental impacts such as erosion and sea-level rise, and sea-level rise is predicted to continue at high rates in the Mid-Atlantic region (Sallenger et al. 2012). Therefore, nature-based shoreline techniques, such as living shorelines, should be used wherever possible to help curb tidal wetland erosion and make shorelines more resilient in the face of rising seas and coastal storms. Strengthening shorelines in this fashion would ensure that tidal wetlands and their beneficial functions, such as wave attenuation, storm protection, and provision of wildlife habitat, would be preserved. Living shoreline designs are site-specific and depend on many factors, such as wave energy, fetch, and slope, and they may range from traditional (i.e., only natural materials) in lower energy environments to hybrid (i.e., combination of natural materials and rocks or oyster castles) in medium energy environments (DELSC 2020). Natural resource professionals should continue to be trained on living shoreline techniques in Delaware, such as through the Introduction to Living Shorelines Training and the Site Evaluation Training held by the Delaware Living Shorelines Committee (DELSC; DELSC 2022). Project implementation and post-installation monitoring and adaptive management should also be priorities to ensure that projects are being installed and that they are successful.

2. **Preserve undeveloped tracts of land adjacent to tidal marshes to allow for marsh migration.** Preservation of land for marsh migration is another strategy to prevent further tidal wetland loss due to erosion and sea-level rise; if some inevitable losses are sustained along marsh edges, some of those losses may be offset if marshes are allowed to move inland. Evidence of marsh migration has been documented in Delaware, both in this report through aerial imagery (i.e., tidal wetland gains due to marsh migration inland, changes from coastal forest to estuarine marsh) and through field observations (Dorset and Rogerson 2018). Knowing that marsh migration is possible and is already occurring in some locations in Delaware, natural resources professionals, land managers, and decision makers should work together to support future marsh migration by preserving undeveloped tracts of land adjacent to current tidal marshes. Highly suitable lands for marsh migration,

such as those identified by DNREC's marsh migration model (Delaware Coastal Programs 2017), should be prioritized. Highly suitable lands include areas that are adjacent to current tidal marshes, have low slopes, are not currently developed, and have poorly drained soils. If marsh migration corridors are not preserved, marshes will have nowhere to go as sea level continues to rise, and tidal marshes will drown over time.

3. **Control and eradicate invasive *P. australis* wherever possible to prevent further spread and restore native high marsh.** The high prevalence of invasive *P. australis* noted in the 2017 mapping effort highlights the need for control and eradication of the species in tidal wetlands. Without treatment, *P. australis* will likely continue to spread, displacing native tidal wetland plant species and degrading wetland health. DNREC's Phragmites Control Program should continue to treat the invasive reed wherever possible throughout Delaware. In addition, natural resource professionals should educate landowners and homeowners associations (HOAs) about the negative effects of *P. australis*, how they can effectively treat it, and what beneficial native plant species they can plant in its place. They should also make landowners aware of the Phragmites Control Cost-Share Program.

4. **Restore tidal wetlands and model projects after natural, vegetated wetland characteristics and functions.** Vegetated tidal wetlands experienced a net acreage loss from 2007 to 2017. As such, tidal wetland restoration should be a priority. One way this can be achieved is through the beneficial use of dredge material, where dredged sediments can be placed in an area to increase the elevation of an existing marsh to improve its resiliency against rising sea-level (i.e., thin-layer placement), or in an area to restore a former marsh that has since drowned (i.e., thick-layer placement). The beneficial use of dredge material is still a relatively new technique in Delaware; however, a successful project was implemented by DNREC at Piney Point along Pepper Creek in 2013, and several new projects in the Inland Bays are being planned as of 2022. This restoration technique should be further explored, used, and refined to help restore tidal wetland acreage and function throughout the state. Importantly, such projects should always strive to resemble local natural tidal wetland conditions through characteristics such as native vegetation, elevation, and tidal regime.

Non-tidal Wetlands

1. **Create a more comprehensive state regulatory program that is enforced.** There was a net loss of vegetated non-tidal wetlands in Delaware from 2007 to 2017. A comprehensive state regulatory program that is properly enforced is needed to curb future losses. Currently, non-tidal wetlands are only regulated by the state if they are over 400 acres in contiguous size, meaning that most non-tidal wetlands are not regulated. Regulations should expand to include non-tidal wetlands of all sizes, including those that are geographically isolated or are in headwater regions.

Such regulations should be strongly and regularly enforced as well. This would help protect non-tidal wetlands and all the beneficial functions that they provide, including sediment and stormwater retention, water quality improvement, groundwater recharge, stream base flow, and provision of important wildlife habitat. Where unavoidable wetland losses are permitted, mitigation requirements should be strictly enforced.

2. **Restore non-tidal wetlands and model projects after natural, vegetated wetland characteristics and functions.** The net loss of vegetated non-tidal wetlands from 2007 to 2017 shows that, in concert with state regulations, non-tidal wetland restoration is needed to counteract losses and should be a priority. Restoration could include the rehabilitation of existing, degraded wetlands, the restoration of wetlands where they once existed, or creation of new wetlands. Restoration projects should take care to resemble natural wetland types (i.e., flat, riverine, or depression wetlands) and conditions (i.e., natural vegetation, hydric soil, and hydrology) to maximize functional potential. For example, projects should ideally include native vegetation rather than open water and should be placed in areas where hydric soils already exist. The same is true for mitigation wetlands, particularly because recent field assessments have shown that many mitigation wetlands in Delaware that are already in place do not resemble natural wetlands and are often open-water, non-vegetated habitats (Haywood et al. 2020).

3. **Avoid clear-cutting non-tidal wetlands and restore those that were previously clear-cut.** Clear-cutting was identified as a main source of vegetated non-tidal wetland loss from 2007 to 2017 based on wetland maps. This practice should be prevented to curb non-tidal wetland losses. Where logging must occur, selective cutting should be practiced instead to reduce negative impacts to non-tidal wetlands. Native vegetation should be replanted, and natural soil and hydrology conditions should be restored, as soon as possible in areas that were previously clear-cut so that some wetland characteristics and functions may be regained.

Table 8. Management recommendations to address issues that tidal and non-tidal wetlands experienced between 2007 and 2017 based on wetland maps.

Wetland Type	Management Recommendation	Major Issue(s) Addressed
Tidal	Use nature-based shoreline stabilization techniques	Erosion and sea-level rise
	Preserve undeveloped tracts of land adjacent to tidal marshes to allow for marsh migration	Sea-level rise
	Control and eradicate invasive *P. australis* wherever possible to prevent further spread and restore native high marsh	Invasive species
	Restore tidal wetlands and model projects after natural, vegetated wetland characteristics and functions	Vegetated wetland net loss
Non-tidal	Create a more comprehensive state regulatory program that is enforced	Vegetated wetland net loss
	Restore non-tidal wetlands and model projects after natural, vegetated wetland characteristics and functions	Vegetated wetland net loss
	Avoid clear-cutting non-tidal wetlands and restore those that were previously clear-cut	Clearing

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