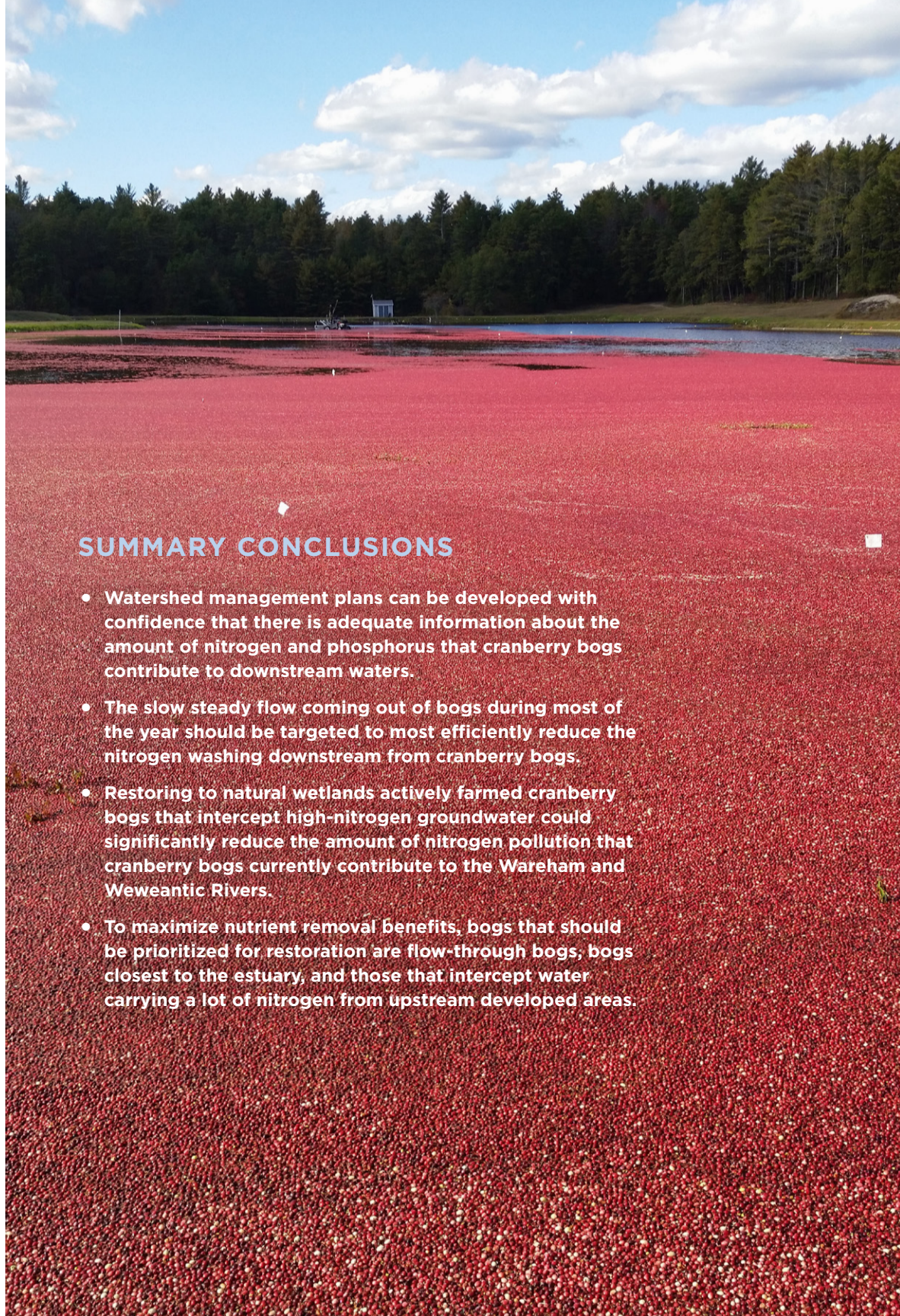


# **CRANBERRY** **AGRICULTURE AND** **WATER QUALITY** **IN BUZZARDS BAY**

A Decade of Scientific Investigation

NOVEMBER 2023

## PROJECT PARTNERS



## SUMMARY CONCLUSIONS

- Watershed management plans can be developed with confidence that there is adequate information about the amount of nitrogen and phosphorus that cranberry bogs contribute to downstream waters.
- The slow steady flow coming out of bogs during most of the year should be targeted to most efficiently reduce the nitrogen washing downstream from cranberry bogs.
- Restoring to natural wetlands actively farmed cranberry bogs that intercept high-nitrogen groundwater could significantly reduce the amount of nitrogen pollution that cranberry bogs currently contribute to the Wareham and Weweantic Rivers.
- To maximize nutrient removal benefits, bogs that should be prioritized for restoration are flow-through bogs, bogs closest to the estuary, and those that intercept water carrying a lot of nitrogen from upstream developed areas.

## ABOUT THIS REPORT

Discharge of nitrogen and phosphorus pollutes freshwater ponds, streams, and rivers and the saltwater bays and harbors of Buzzards Bay. In fresh waters, phosphorus, or phosphorus in combination with nitrogen, triggers excess algae growth. In salt waters, nitrogen leads to an overabundance of algae. Most of the nitrogen pollution that reaches Buzzards Bay comes from septic systems, wastewater treatment plants, and road runoff. However, in parts of the watershed where there are dense concentrations of cranberry bogs, bogs can contribute significant amounts of nutrients.

This report describes work by the Buzzards Bay Coalition and partner organizations committed to protecting water quality in Buzzards Bay. The work was supported by a series of grants over 10 years. The goal was to improve understanding of how cranberry bogs contribute to nutrient pollution of coastal watersheds and to use this understanding to inform management actions that minimize nutrient discharges and maximize nutrient removal.

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## BACKGROUND

Cranberries are wetland plants that have been harvested for food, medicine, and dyes dating to before Europeans colonized North America. Cranberry bogs have historically been an important part of the landscape, heritage, and local economy of southeastern Massachusetts.

Approximately 20% of the nation's cranberry crop is produced within Massachusetts and much of that occurs within the watershed of Buzzards Bay (51%).

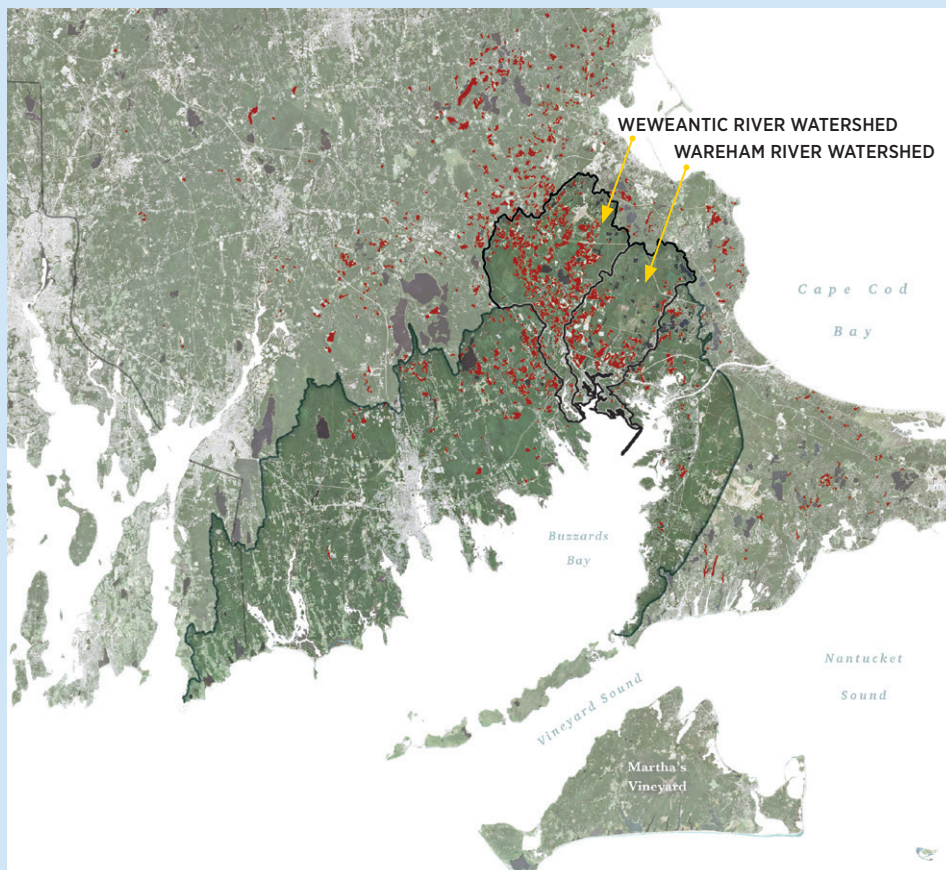
Cranberry agriculture is intimately connected to natural waterways. Growers use ponds and rivers as

sources of water to irrigate bogs, protect cranberry plants from frost, and flood the bogs for harvest. Water that leaves cranberry bogs may carry with it nitrogen and phosphorus that come in part from fertilizer that is applied to bogs to help cranberries grow. Nutrients released from cranberry bogs then travel in groundwater, streams, and rivers to Buzzards Bay.

The Weweantic River and Wareham River Watersheds contain more than 9,000 acres of cranberry bogs. In total, cranberry bogs are estimated to account for roughly 30% of the

nitrogen pollution to the Weweantic River and 20% to the Wareham River (residential septic systems are the major source of nitrogen to both rivers). Nitrogen pollution has plagued these estuaries for years. In the Wareham River, the Massachusetts Estuaries Project determined that close to 40% of the total nitrogen load to the river needs to be reduced to restore clean water (Howes et al., 2014).

New technology and cranberry cultivars have led to the recent, rapid expansion of the cranberry industry in other parts of North America. Massachusetts cranberry farmers face poor fruit prices that are not keeping up with increasing costs, and generally low yields from bogs still planted with native cranberry cultivars. Farmers have to decide whether it makes sense to invest in renovating bogs with updated technology and hybrid cultivars that bring higher yields, produce high-value berries, and require less water. Less productive bogs have the potential to be retired and restored to natural wetlands where they could serve as sinks that absorb and remove nutrients. Retired bogs are those where farming no longer occurs. Restored bogs are those where additional steps are taken to return the bog to a natural wetland.





## THE RESEARCH

Beginning in 2011, the Buzzards Bay Coalition, U.S. Department of Agriculture Agricultural Research Service (USDA), Woodwell Climate Research Center, University of Massachusetts (UMass) Cranberry Station, Cape Cod Cranberry Growers' Association, Marine Biological Laboratory, Southeastern Regional Planning & Economic Development District, and the Town of Carver began collaborating to quantify how cranberry agriculture affects downstream waters. The work involved both field sampling and improving watershed models. Local farmers facilitated sampling on their farms.

**Research Summary** – Our studies covered three main research areas: **1) Measuring nutrient releases from cranberry bogs, 2) Modeling how cranberry bogs impact overall watershed nutrients, and 3) Potential water quality benefits of restoring natural wetlands at current cranberry bogs.**

**1) Measuring nutrient releases from cranberry bogs** – We used field studies of water, nitrogen, and phosphorus movement on multiple cranberry farms to quantify the magnitude of nutrient inputs and outputs and nutrient movement in different phases of cranberry crop management.

**2) Modeling how cranberry bogs impact watershed nutrients** – Using watershed models we estimated the amount of nitrogen from all watershed sources, including cranberry bogs, in the Wareham River watershed. We used models to estimate nitrogen that reaches Buzzards Bay from bogs in different places in the watershed as the water moves through creeks and streams on its way to the estuary.

**3) Potential water quality benefits of restoring natural wetlands at current cranberry bogs** – We used models to estimate the potential nitrogen removal that might be achieved by restoring some cranberry bogs to natural wetlands, which are excellent at retaining nutrients.

## RESEARCH AREA 1

# Measuring Nutrient Releases from Cranberry Bogs

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### Background

Prior to our work, only two studies had estimated how much nitrogen or phosphorus is released from cranberry bogs (DeMoranville and Howes, 2005; Howes and Teal, 1995). One study focused on a flow-through bog, which is a type of bog where a river channel flows through the bog. Flow-through bogs represent only about 20% of the bogs in Massachusetts (Hoekstra et al., 2019). The other study looked at six traditional wetland-type bogs. Wetland-type bogs, rather than lining a river channel, are set in areas that were former wetlands, often on the edges of forest or near ponds and are connected to streams by ditches or channels. These studies showed losses of nitrogen and phosphorus were higher for the flow-through bogs than traditional wetland bogs. However, there was a wide range of outputs across bogs that made it hard to develop bog management strategies to reduce watershed nutrient pollution.

### Methods

We monitored nitrogen and phosphorus inputs and outputs in traditional wetland bogs that all had similar fertilizer amounts applied. In an initial study, we monitored six bogs for one-and-a-half years with surface water samples collected by hand from the bog inlets and outlets. Because previous research suggested that flood events accounted for most of the annual nutrient loss, the initial study focused on flood events.

To get a more complete understanding of the nutrient losses over the whole year, we then carefully tracked the amount of water moving into and out of three bogs and the nitrogen and phosphorus concentrations of that water. We instrumented these bogs with automated samplers that collected water more frequently than was possible by hand. For one year, the samplers collected water during flood releases and during low flows between floods. The samplers were set to collect samples daily during most of

the year when the bogs were not flooded. During fall harvest floods and winter freeze protection floods, we programmed samplers to collect frequently (every 20 minutes) when water volumes were changing fast and less frequently (every several hours) when less water was moving.

The volumes of water that moved during floods were estimated with water level and flow recorders. We paired the water flow data with measured nutrient concentrations to calculate how much nitrogen and phosphorus moved downstream during floods and during the rest of the year.

### Results

By comparing six bogs, we found that the variation in nitrogen concentrations leaving the bogs was influenced more by nitrogen sources in the watershed and how much water flows through a bog than by cranberry management. Although there was variability among bogs, the nitrogen exiting the six bogs was close to that estimated for wetland bogs from other studies (Town of Carver, 2015). The more detailed sampling of three bogs showed similar variability (Neill et al., 2017). Net stream transport of nitrogen averaged 3.1 lb/ac (range of -0.1 to 11.3 lb/ac). This provided greater certainty about nutrient loading rates that should be used in watershed planning. We found a smaller range of phosphorus concentrations among the bogs than for nitrogen concentrations. The amount of phosphorus washing downstream from the bogs (1.9 to 4.0 lb/ac, average of 2.7 lb/ac) was similar to or slightly higher than measured in previous studies. The amount of nitrogen fertilizer applied is well-balanced with the amount of nitrogen in the crop harvest.

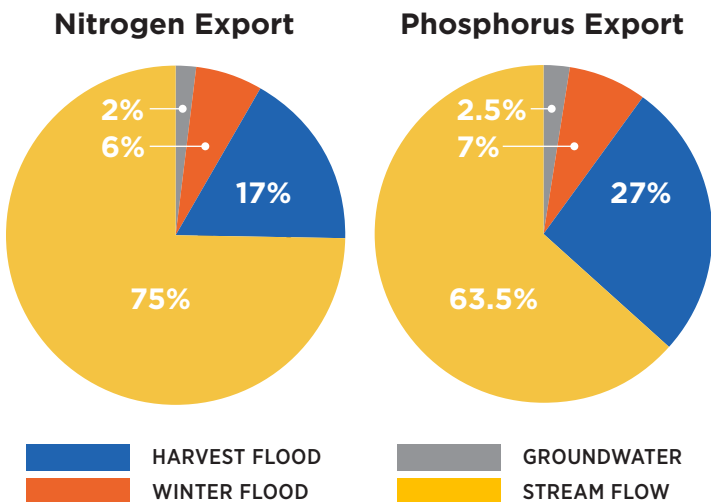
The automated samplers deployed at three bogs revealed how much nitrogen and phosphorus was leaving the bogs during different times of year. The small, steady trickle of water that left the bogs during non-flooding times accounted for the majority of the water flowing downstream.

Though the concentrations of nitrogen and phosphorus in this trickle were generally low, because the amount of water added up over the course of the year, the steady trickle made up the largest fraction of both nitrogen and phosphorus released downstream.

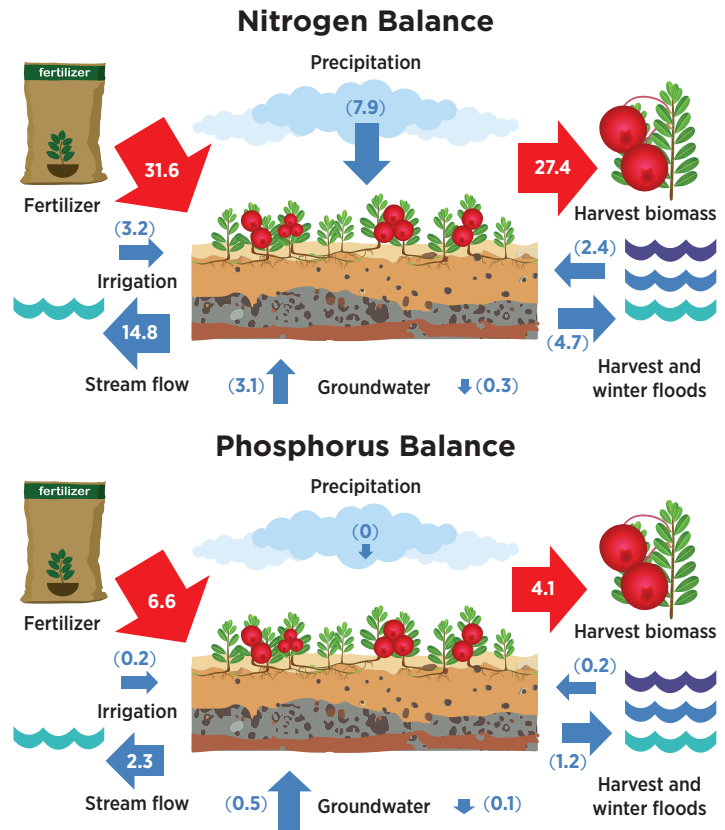
The amount of nitrogen and phosphorus released in the steady trickle of water leaving the bogs is linked to how much water the steady trickle represented, which was influenced by where a bog sits in the landscape. Some bogs were very wet and water flowed through their ditches constantly. Others bogs had ditches that were mostly dry or with water that was not flowing. Two of the bogs studied had groundwater springs that brought water into the bogs over the course of a year, while the third bog did not. The difference in the amount of nutrients washed downstream between bogs was primarily related to how much water moved through the bog systems rather than specific farming practices. One bog was fed with a particularly large amount of natural groundwater input from springs. The larger amount of water flow resulted in higher overall amounts of nutrients washing downstream from this bog.

### Management Implications

This work improved our estimates of how much nitrogen and phosphorus are released from cranberry bogs. This provides confidence that the estimates can be used for effectively developing nitrogen reduction management plans such as Total Maximum Daily Loads (TMDLs) required by the Clean Water Act.



Because most of the annual nitrogen and phosphorus losses occurred during non-flooding times, management measures aimed at nutrient removal from the small but steady outflows during non-flood periods could be beneficial. Such management might include additional storage time in ponds or increased naturalization of stream channels to enhance nitrogen uptake and denitrification. Bogs discharging higher amounts of flow are good targets for nutrient removal measures because larger amounts of nitrogen and phosphorus are passing through them.



*above* Diagrams show the annual movement of nitrogen (top) and phosphorus (bottom) through cranberry bogs. Numbers are the average of three bogs in pounds nitrogen or phosphorus per acre. Nitrogen and phosphorus are deposited on bogs through application of fertilizer, precipitation, water pumped onto the bogs through irrigation and during harvest and winter floods, and from groundwater flowing into the bogs. Nitrogen and phosphorus flow out of bogs by removal of berries and leaves during harvest, when flood waters are released, and when water on the bog soaks into the groundwater or flows from the ditches into streams.

## RESEARCH AREA 2

# Modeling How Cranberry Bogs Impact Watershed Nutrients

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### Background

Nitrogen pollution comes from a number of sources. To understand the importance of any nutrients coming from cranberry bogs, it is necessary to compare them with other nutrient sources in the watershed. Models are effective tools for estimating the amount of nutrients different sources contribute to a waterbody. The Wareham and Weweantic River watersheds are the two watersheds in Southeastern Massachusetts that have the most cranberry farm acreage. We used the Wareham River as a case study to model how nutrients that enter the watershed from cranberry agriculture contribute to nutrient pollution downstream in the estuary.

### Methods

We used a well-established model called the Nutrient Loading Model (NLM), to estimate how much nitrogen reaches waterbodies (Valiela et al., 1997). Nitrogen loads are based on detailed information about the watershed and studies of how much nitrogen comes from different features in the landscape (e.g., residential areas, sewage treatment plants, the atmosphere, natural areas, and agriculture). The NLM model has been regularly used in Southeastern Massachusetts over the last 20 years. For this study, new data were collected on the concentration of nitrogen coming from rain. Recent reports (2016-2018) were obtained on how much nitrogen is released from the Wareham Pollution Control Facility. Cranberry fertilizer rates were estimated based on a survey of cranberry growers in the watershed.

The NLM model estimates how much nitrogen reaches surface waters. We paired the NLM with a stream channel model (Wollheim et al., 2006) to see what happens to the nitrogen once it reaches the water and moves downstream through progressively larger streams to the Bay. The stream channel model uses information about the size of different stream and river stretches to estimate how much nitrogen will be taken up by plants and microbes as the water moves in stream channels filled with plants and organic matter.

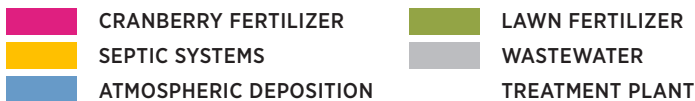
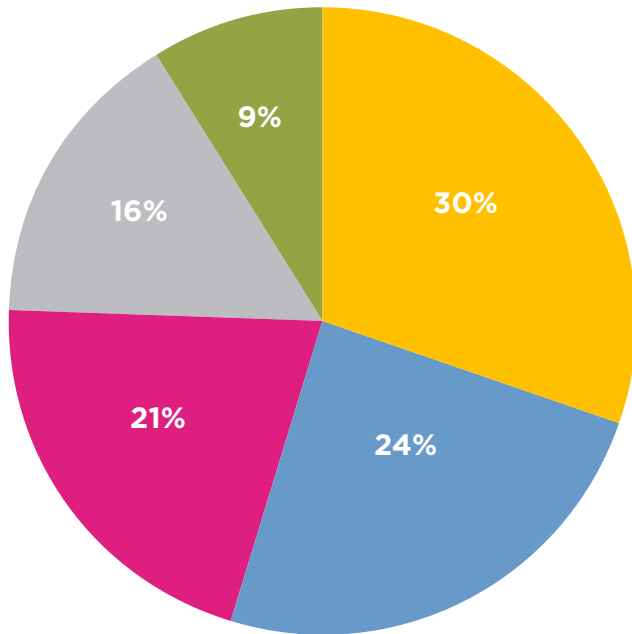
Both of these models estimate the nitrogen moving through the system but not phosphorus. Phosphorus sticks to soils and sediments so it does not travel as easily downstream as nitrogen. As a result, phosphorus is not as large a problem as nitrogen at the watershed scale, and there are currently no plans to create watershed scale management plans for phosphorus. We therefore focused only on nitrogen since it poses the most concern at the watershed scale.



**above** UMass Cranberry Station scientists collect groundwater samples near a bog.



## Nitrogen Sources to the Wareham River



### Results

The updated NLM modeling showed that cranberry bogs accounted for about 20% of the nitrogen flowing into the Wareham River (Kennedy et al., 2023), which is similar to previous estimates (Howes et al., 2014; Williamson et al., 2017). However, not all bogs contributed equal amounts of nitrogen. Flow-through type bogs that line river channels release more nitrogen than wetland bogs that connect to water bodies through streams or ditches. As water travels from bogs to small streams that connect with larger streams and eventually the Wareham River, some of the nitrogen from the bogs is used by aquatic plants and bacteria. This uptake by plants and bacteria helps to reduce the impact of nitrogen from cranberry bogs. We estimated that currently, two-thirds of the nitrogen leaving the bogs in the Wareham River watershed is removed by uptake by plants and bacteria as the water moves through natural streams and wetlands (Neill et al., 2021).

### Management Implications

Cranberry bogs are an important source of nitrogen to the Wareham River. As watershed management plans are developed to reduce nitrogen, the impact of cranberry agriculture should be considered. This could include encouraging or incentivizing best practices that prevent nitrogen from washing downstream from bogs such as creating storage ponds, naturalizing stream channels, or avoiding fertilizer application prior to predicted rain. Our work focused on cranberry varieties that have been most abundant in Southeastern Massachusetts. However, the industry is beginning to transition bogs to newer varieties that yield more fruit. Researchers at the UMass Cranberry Station/USDA are studying the potential impact of these newer varieties.



**above** Water samples collected from a bog are filtered prior to laboratory analysis for nitrogen and phosphorus.

## RESEARCH AREA 3

# Potential Water Quality Benefits Of Restoring Natural Wetlands At Current Cranberry Bogs

### Background

The evolving economics of cranberry agriculture is leading some growers to retire a portion of their bogs currently in production that are more difficult to farm or less profitable in order to modernize farm operations, invest in new, high-yield cranberry cultivars, and prioritize higher-performing bogs. At the same time, the Massachusetts Division of Ecological Restoration has developed techniques for restoring retired cranberry bogs to naturalized wetlands. Wetland restoration provides ecological benefits including nutrient removal, improved habitat for birds, fish, amphibians and reptiles, greater natural floodwater storage, and locations for recreation and access to nature.

State and federal programs currently provide funding to retire farmland and restore some retired bogs to natural wetlands. At the same time, towns are under pressure to reduce nitrogen pollution to estuaries. We wanted to understand how much nitrogen could be reduced by restoring bogs to natural wetlands in the Wareham River watershed. How retirement and restoration of cranberry bogs may influence phosphorus in the watershed was not studied since there are currently no management plans targeting phosphorus reduction at the watershed scale.

### Methods

We classified all the bogs in the Wareham River watershed using aerial photographs to determine whether they were flow-through, traditional non-flow-through, or newly renovated or newly constructed non-flow-through. They were also classified based on what size stream they connected to. The amount of nitrogen released downstream from all the bogs was calculated based on the total area of each type of bog and whether the water traveled through natural streams and wetlands.

We then developed scenarios to test how retiring or restoring bogs would impact the amount of nitrogen flowing to the Wareham River estuary. When a cranberry bog is retired from active farming, fertilizer is no longer applied, which reduces nitrogen inputs, though the amount of nitrogen leaving the system as harvested cranberries is also reduced. Wetlands have the potential to remove substantial amounts of nitrogen, but even bogs that were originally built in wetlands do not necessarily revert to wetlands when farming stops. Because cranberry farming involves adding layers of sand to bogs, which raises the height of bogs over time, many retired bogs naturally turn into forest or shrubland rather than wetlands. Active restoration of cranberry bogs aims to disturb the top soil layer, exposing the organic material below and create more natural stream channels to encourage retired bogs to become wetlands.



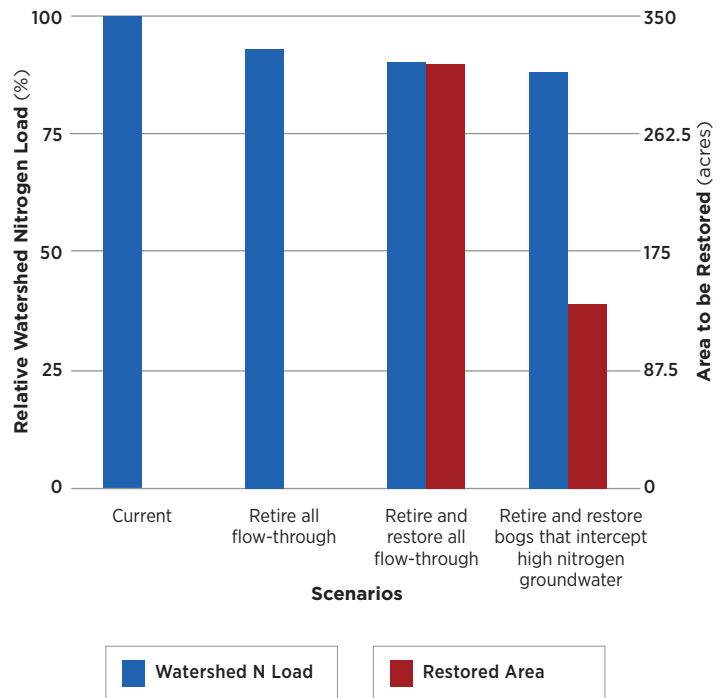
**above** Drone image of the Coonamessett River where former flow-through cranberry bogs have been restored to natural wetlands. Photo credit: Adam Soule

## Results

The location and type of bogs that are retired or restored had an important impact on the potential nitrogen benefit of retiring and restoring bogs. If all of the flow-through type bogs in the Wareham River watershed (which represent 19% of the total bog area) were restored, it would cut the amount of nitrogen from cranberry bogs making it to the Wareham River estuary by about 40%, which represents a reduction of overall nitrogen to the watershed of about 10% (Kennedy et al., 2023).

With wetland type non-flow-through bogs, targeting bogs in specific locations can greatly influence how much nitrogen makes it to the estuary. For example, restoration of randomly selected bogs or bogs that are high in the watershed that connect through many streams to the estuary will have only a small impact on the nitrogen reaching the Wareham River estuary. Restoring bogs close to the estuary will have a greater reduction in nitrogen pollution to the estuary than those farther away. More nitrogen makes it to the estuary from bogs close to the estuary because there is less time for the nitrogen from these bogs to be taken up by plants and bacteria in streams and channels (Neill et al., 2020).

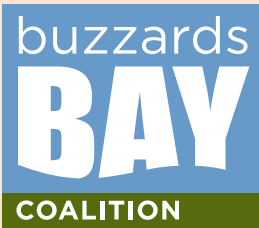
Restoration of wetlands on retired bogs has the potential to remove not just fertilizer from cranberry bogs, but any source of nitrogen that moves through wetlands as surface water and groundwater. Some cranberry bogs are in locations where they intercept surface and groundwater flowing from residential areas that contains high amounts of nitrogen. Restoring bogs that intercept high nitrogen groundwater would yield a high benefit relative to the area of cranberry bogs restored. By restoring less than half the acreage of flow-through bogs, restoring bogs that intercept high nitrogen groundwater would result in a slightly greater percentage of nitrogen reduction to the estuary (12%) than restoring all the flow-through bogs (Kennedy et al., 2023).



*above* The blue bars show model results for the nitrogen loading to the Wareham River under current conditions (100%) and under three scenarios for retiring and restoring bogs. The red bars indicate the acres of bogs that would be restored under each scenario.

## Management Implications

Retiring and restoring cranberry bogs could be a valuable part of the overall management plan for reducing nitrogen pollution to the Wareham River. A targeted strategy for restoration could reduce nitrogen to the Wareham River estuary by about 10%, which is one-quarter of the overall reduction needed to restore water quality. To maximize nutrient removal benefits, bogs that should be prioritized for restoration are flow-through bogs, bogs closest to the estuary, and those that intercept upstream water carrying high levels of nitrogen from developed areas.



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## SUMMARY CONCLUSIONS

- Watershed management plans can be developed with confidence that there is adequate information about the amount of nitrogen and phosphorus that cranberry bogs contribute to downstream waters.
- The slow steady flow coming out of bogs during most of the year should be targeted to most efficiently reduce the nitrogen washing downstream from cranberry bogs.
- Restoring to natural wetlands actively farmed cranberry bogs that intercept high-nitrogen groundwater could significantly reduce the amount of nitrogen pollution that cranberry bogs currently contribute to the Wareham and Weweantic Rivers.
- To maximize nutrient removal benefits, bogs that should be prioritized for restoration are flow-through bogs, bogs closest to the estuary, and those that intercept water carrying a lot of nitrogen from upstream developed areas.



UMass | Cranberry  
Amherst | Station

