

# **Village of Bald Head Island Environmental Services Contract**

## **2023 Annual Report**

### **Bald Head Island Conservancy**

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## Organization Overview

The Bald Head Island Conservancy is an independent non-profit 501(c)3 organization located on Bald Head Island in southeastern North Carolina. Founded in 1983, the Conservancy's Vision is to Champion the Sustainability of Barrier Islands through Environmental Research and Stewardship. With a full-time staff of 12, part-time staff and intern group of up to 25, and an engaged Board of Directors, the organization facilitates scientific research and provides coastal environmental services to the Village of BHI through a partnership that helps ensure the current and future health of the island's habitats and species. The Village of BHI's recognition of the link between environmental health and community well-being uniquely positions BHI to use environmental outcomes to drive wise management decisions. This report provides an overview of services that were developed in collaboration with Conservancy staff and Village of Bald Head Island managers.

## Summary Statement

The Conservancy recognizes the commitment of the Village of Bald Head Island to understanding and protecting the habitats and species that make the island a special place for all residents and visitors. Similarly, the Conservancy recognizes that the Environmental Services Contract is funded by taxpayers and thus we are committed to performing all work in a fiscally sound and scientifically objective manner. In the 2023 - 24 Contract, the Conservancy has continued valuable environmental monitoring projects in the maritime forest, tidal creeks, aquifer, and dunes, with the focus being long-term sustainability of island ecosystems and wildlife habitats. This report will focus on data collected in 2023.

A few highlights of the Conservancy's work for the 2023-24 Environmental Services Contract:

1. White-tailed deer population size was estimated at 173 individuals in fall 2023. The population is still below the current target, but is growing.
2. Bald Head Creek bacteriological water quality was generally not of concern this year, except for September 2023. Salinity was higher than usual this year, indicating decreased freshwater input.
3. A large focus has been on identifying and eradicating Beach Vitex, including concluding a controlled experiment on treatment methods. We have been successful at eradicating many smaller plants; however, many larger sites requiring multiple treatment applications still exist.
4. The diamondback terrapin conservation project was successful, providing >100 crabpot terrapin excluder devices and conducting a population survey with 28 terrapin sightings.
5. Predator population surveys indicate larger populations of alligators and coyotes than in past years. A population genetics study estimated 8-18 individual coyotes on BHI, with connectivity to Fort Fisher populations.
6. Least terns have returned to nest on BHI for the first time since 2017.

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## Forest Health

### Maritime Forest Assessment

#### Background

The most distinguishing characteristic of Bald Head Island among North Carolina barrier islands is its vibrant maritime forest. It is critical for the Village to protect the forest by evaluating the primary threats that could alter its basic ecological functioning such as overpopulation of deer, invasive species, storms, and saltwater intrusion into the island's freshwater aquifer. The largest tract of intact maritime forest on Bald Head Island is the Bald Head Woods Coastal Reserve, which is managed by the North Carolina Coastal Reserve, part of the Department of Environmental Quality. The Conservancy acts as a partner and member of the Local Advisory Committee of the Reserve.

In the past few years, the Conservancy has worked with collaborators to re-evaluate the health of the maritime forest 10+ years after baseline data were collected in the 1980s (R. Peet) and mid-2000s (Taggart & Long). Paired fenced and unfenced plots were established in the early 2000s in the Bald Head Woods Coastal Reserve to evaluate impacts of deer on forest vegetation (Brewer, Taggart & Long). At that time, the target number of 200 deer was established. These plots still exist but were damaged by a series of hurricanes (Florence, Dorian, Isaias) and were no longer excluding deer in 2020. Dr. Jodi Forrester (NCSU) and the Conservancy collected data from these plots in 2020-21 to provide a new baseline so that we could re-establish the exclosures and use them to evaluate deer impacts in the future.

#### Project Goals

- Evaluate forest health: species diversity, forest structure, openness, downed deadwood, disease
- Continue repairing and maintaining deer exclosures in the forest
- Compare Forrester's results (2020-21) to previous studies to estimate deer impacts on the forest
- Use the forest plots to evaluate long-term effects of herbivory and other disturbances

#### Monitoring

The Bald Head Island Conservancy monitors the fenced forest plots monthly to ensure they are intact. There are currently 15 fenced monitored plots with 10 in the south woods and 5 in the north woods off of the Creek Trail (Fig. 1). Five plots have been abandoned (100, 99, 98, 97, and 101) due to being destroyed by storms or no longer being needed in the study. Monthly forest plot monitoring consists of evaluating the fencing to determine if any fixes need to be made to keep the deer out. Small holes or tears in the fencing are repaired with zip ties and overgrown vegetation is removed from the fencing with loppers. When there is a storm event, large, downed trees may need to be removed from the fencing with a chainsaw.





**Fig 1. Current Forest Plots**

Progress & Significant Findings

- All exclosures were assessed and repaired in 2023 and this will continue in 2024.

Future Directions

We recommend continuing to maintain exclosures in the maritime forest to allow for future assessment of deer and other impacts. No vegetation surveys are proposed for the plots at this time, but may be requested for 2025.

**Bald Head Woods Well Monitoring**

Background

The Bald Head Woods (BHW) Monitoring Advisory Group is focused on securing the ecological functioning of the Bald Head Woods Coastal Reserve by: 1) assessing hydrologic conditions within BHW, 2) analyzing the potential effects of water withdrawals from the aquifer below BHW, and 3) making recommendations about management actions to prevent or mitigate those effects. For six years (July 2017 - June 2023), BHI Conservancy verified accuracy and precision of continuous depth-to-water (DTW) measurements in 16 wells associated with Bald Head Woods (BHW) (Fig. 2) through monthly manual measurements that we have shared with the BHW Monitoring Advisory Group. The Monitoring Plan also requires assessment of vegetation in BHW after 5 years of water withdrawals. Special attention is given to wells within the swales (low-lying areas resulting in ephemeral freshwater ponds) because these are the only natural freshwater features on the island, and are known to contain unique plant species.

Project Goals

- Evaluate aquifer levels below the Bald Head Woods Maritime Forest Reserve

- Provide data to Applied Resource Management (ARM, hydrogeology consultants previously hired by the Village) to ground-truth automated sampling equipment
- Assist the Advisory Group with assessing vegetation species composition in BHW swales (low-lying areas) as required by the Monitoring Plan



**Fig. 2.** Locations of wells associated with Bald Head Woods Coastal Reserve. “EW” wells follow an east-west transect; “NS” wells are in a north-south line. “SM” wells are within swale marshes (low-lying ponding areas). “HG” and “M” wells are in outlying areas of the Reserve.

### Progress & Significant Findings

- Over the 2017-2023 time period, groundwater depth relative to mean sea level (proxy for aquifer volume / water table) varied by location and through time (Fig. 3). In general, wells in the swales had a positive trend in groundwater depth through time, while wells in more inland areas (north-south within the forest and outside of the forest preserve) had a negative trend in groundwater depth through time. Trends were dominated by a severe drought period near the project start, followed by significant flooding after Hurricane Florence (late 2018 - 2019).
- After discussion with the BHW Monitoring Advisory Group, it was decided to end monthly manual well sampling in June 2023. Monthly data have been shared with ARM for detailed analysis.



**Fig. 3.** Depth of groundwater relative to mean sea level (MSL) for each Bald Head Woods well, 2017 - 2023. Higher values represent larger aquifer volume at a particular site through time. Wells HG7D1 and HG7S were removed in 2021 due to development of the lot.



- Automatic samplers placed by ARM are still deployed in swale wells, and multiple pieces of equipment (old batteries, solar panels) from previous ENO auto samplers and owned by ARM are still in the forest.
- The Conservancy initiated and assisted with swale vegetation sampling in September 2023. Dr. Mike Schafale from the NC Natural Heritage Program and botanist Dr. John Taggart led these efforts.

### Future Directions

The need for continued monitoring is decided on by the BHW Monitoring Advisory Group. Conversation during the BHW Local Advisory Committee in 2022 led to the general agreement that enough data has been collected, especially since the swale wells have automated sensors monitored by ARM. Wells are still present and can be re-sampled if there are future concerns. Therefore, the Conservancy ceased monthly sampling in June 2023. Vegetation sampling was conducted in September 2023 but data have not yet been analyzed to compare to the 2017 pre-sampling period. We recommend that the Conservancy analyzes vegetation data and submits a report to the BHW Monitoring Advisory Group in 2024-25. In addition, the Village should request an analysis of the well sensor data from ARM to fulfill their agreement with the NC Coastal Reserve.

## **Deer Management**

### Background

The Conservancy quantifies the island's white-tailed deer population and analyzes the efficacy of the immunocontraceptive GonaCon for managing the population (current target = 200 deer). These data are then used to provide recommendations for deer population management. Sound population management decisions ensure stable and productive island habitats that continue to provide ecosystem services (e.g., storm protection, positive elevation growth, biodiversity, enhanced tourism, and recreation).

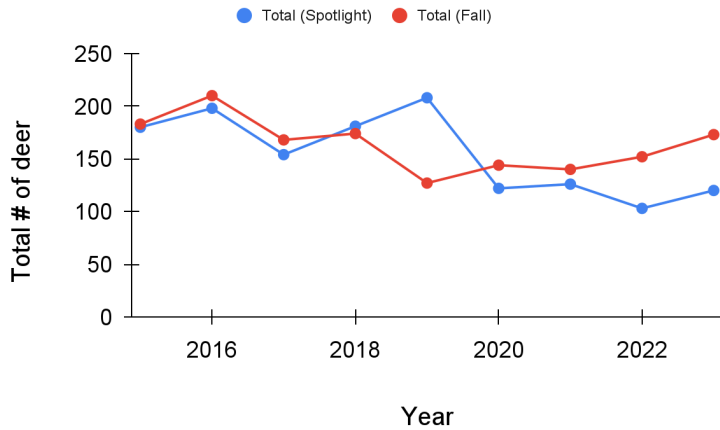
### Project Goals

- Monitor the population size of BHI's white-tailed deer herd
- Evaluate potential impacts of deer herbivory on maritime forest ecosystem and determine need for management (see [Maritime Forest](#) project)
- Data determine the Conservancy's recommendations to the Village for renewal of the immunocontraception permit (current management method)
- Combination of both summer spotlight (male:female ratios) and fall camera index (population number of females and fawns) are needed for accurate estimates
- Biweekly radio telemetry tracking of collared does from immunocontraception project continues until collars drop off
- Data analysis and proposal writing for new immunocontraception permit if required

### Progress & Significant Findings

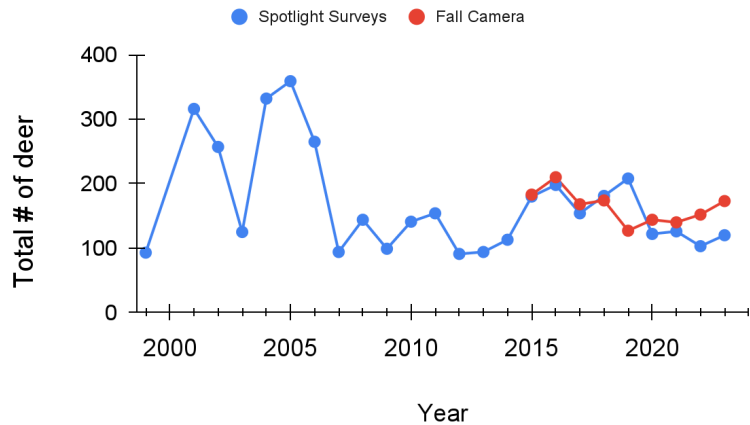
- Fall 2023 Camera Index: 173 individuals = 96 does, 51 bucks, 26 fawns (Fig. 4, [Appendix 1](#))
- Summer 2023 Spotlight Survey: 120 individuals, female:male ratio of 1.92
- Population size is below target of 200 deer; there are an estimated 33 unvaccinated does (original immunocontraception permit requires  $\geq 30$  viable does).

- As of spring 2024, all deer telemetry collars have dropped off: weekly telemetry is no longer required.
- Estimates of deer population size and available habitat on BHI rely on land cover calculations made in 2016. With the amount of development on the island, the available habitat for deer is decreasing, but we do not know by how much.

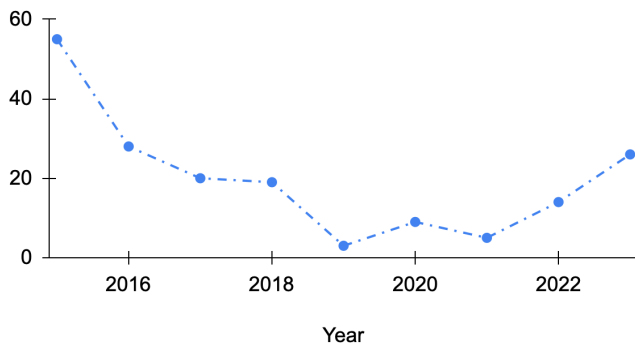


**Fig. 4.** White-tailed deer population size, 2015 - present. Immunocontraception operations began in 2014. Official population numbers are estimated using camera surveys; spotlight surveys provide sex ratios and a comparison to historical data.

**Fig. 5.** Historical deer population index using spotlight surveys, 1999 - present.



**Fawns**



**Fig. 6.** Fawn population on BHI from fall camera index, 2015 - present.

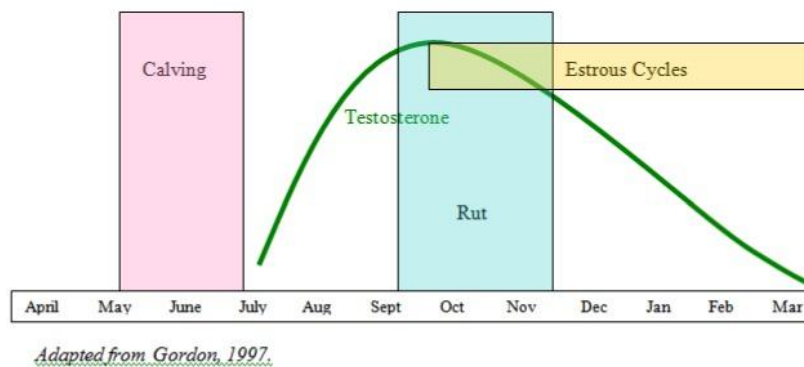
## Future Directions

We recommend continued monitoring of the deer population using the same methods. Weekly radio telemetry is not currently required because deer are no longer wearing collars. The land cover and habitat quality calculations should be re-done in 2024-25 since it has been almost 10 years since these estimates were made. This is important to evaluate the deer population size relative to available habitat. These data will be used to inform the decision whether to pursue a permit for immunocontraception operations in late 2025 - early 2026.

## **Deer Immunocontraception**

### Background

To manage the white-tailed deer population to <200 individuals, BHI Conservancy led the deer immunocontraception program for the Village from 2014 - 2020 under a research permit through the NC Wildlife Resources Commission. We used GonaCon, a drug manufactured by the USDA, to prevent pregnancy by initiating an immune reaction to female sex hormones. This drug is administered by injection after a female deer is captured through darting with a sedative. This specialized and labor-intensive process is highly regulated, including the seasonal timing of when operations can occur. Under the original permit, darting operations were only allowed after hunting season on the mainland (Feb - April). This meant that the drug was administered after the reproductive season (rut), possibly reducing the drug's efficacy (Fig. 7).



**Fig. 7.** White-tailed deer reproductive cycle. Reproductive hormones are highest during the rut.

Despite this seasonal constraint, the immunocontraception project from 2014 - 2020 was successful at reducing pregnancy rates, and is currently the only feasible non-lethal management method that exists for BHI. Deer population numbers have remained at or below 200 deer for the past several years. Based on deer population numbers below the target set by the original NCWRC permit, the Conservancy recommended a continued pause in the immunocontraception program for spring 2024. However, the Village and the Conservancy agreed to pursue an “operational permit” with NCWRC for any future immunocontraception operations.

The benefits of an operational permit are that it would allow the Village flexibility in deciding each year whether to conduct immunocontraception operations. In contrast, a research permit would require a scientific question outside of population management and a commitment to pursue the program for the number of years required to address that question. The downside of pursuing an operational permit is that this type of permit does not currently exist in the State of

NC, and it was unknown whether the NCWRC would support such a permit request. In 2023, the Conservancy formally inquired about how to apply for an operational permit, anticipating a long process and effort to write a proposal, and possibly meetings with the new NCWRC about the immunocontraception program. However, response from NCWRC was that the process to apply for an operational permit would be relatively simple, consisting only of a form and short project description. NCWRC also indicated that they would no longer require darting operations to occur after hunting season. This means that immunocontraception operations could potentially occur during the fall rut, allowing the drug to be administered at the time of year when it would be most effective (Table 1).

As shown in Table 1, deer population numbers from the previous fall, made available in January, would be used to decide whether to pursue the immunocontraception program for fall of the same annual year. An operational permit would need to be used in the same calendar year as it is received, so recruitment of seasonal staff would begin in late spring. The operational budget would be voted on by Village Council in spring, with the fiscal year beginning in June, and seasonal staff hired in early September. Darting operations could begin as early as October.

**Table 1.** Potential seasonal model of immunocontraception operations. Green = deer biology; orange = population studies done by Conservancy; pink = timing of administrative actions; blue = immunocontraception / captures fieldwork.

Month	Reproductive cycle	Previous model	Future model	Future logistics
January	Estrous cycles		Population #	
February		Immuno captures		Permit app
March				
April				
May	Fawning			Budget / Hiring
June		Spotlight survey	Spotlight survey	
July				
August				
September				Training
October	Rut / Estrous cycles		Immuno captures	
November		Camera survey		Camera survey
December				

*Target Deer Population Number*

The target population of 200 deer was based on a study by Taggart and Long (2015) in the BHI maritime forest in 2011. No observable impacts from deer browsing were found when fenced plots (excluding deer) and unfenced plots (allowing deer access) were compared for tree density and species composition. At that time, approximately 200 deer were on the island. However, a previous study by Stransky (1969) recommended a capacity of 19 deer km<sup>-2</sup> for healthy barrier island habitats and Sherrill et al. (2010) recommended managing the BHI deer

population to its level in 2007 - 2009, which equated to 15 - 17 deer km<sup>-2</sup>. As of 2023, Bald Head Island had 22 deer km<sup>-2</sup> of available deer habitat, and habitat continues to decrease as development increases. This is potentially putting more strain on the maritime forest. The Conservancy and partners are pursuing long-term study about impacts of deer and other stressors on the maritime forest ([Maritime Forest Assessment](#)), but currently the data do not exist to allow us to re-evaluate sustainability of the deer population or carrying capacity of the island. A more conservative population target number might be between 15 - 19 deer km<sup>-2</sup>, which would be equivalent to a maximum of 102 deer on BHI with current available habitat. A new immunocontraception permit proposal could request management of the herd to this new target level, which would take a number of years to obtain without an initial cull. This is a decision that should be made by the Village and Conservancy with input from the Wildlife Resources Commission.

### Future Directions

The Conservancy will evaluate deer population numbers in January 2025 to make a recommendation to the Village about whether to pursue an operational permit for immunocontraception operations in the following year. If it is possible to move operations to the fall, it would be feasible to apply for the permit and conduct captures in fall 2025. If we need to conduct captures in winter months when the island is less busy, we would need to apply for a permit in January 2026 to conduct operations as soon as possible that spring.

## **Bald Head Creek and Salt Marsh Health**

### Background

The tidal creek-salt marsh complex supports an abundance of human activities including recreational fishing, kayaking, and birding. Further, the root system of a healthy marsh plant community stabilizes the island's soundside by resisting strong erosional forces produced by semi-diurnal tides and storm surges. Thus, understanding the health of Bald Head Creek and its bountiful salt marsh habitat is a key aspect of the sustainability of Bald Head Island's way of life. However, understanding this system is challenging because its health is influenced by many factors including chemical loads in the Cape Fear River, stormwater runoff on Bald Head and Middle Islands, and natural and human induced alterations to creek flow.

### **Creek Water Quality**

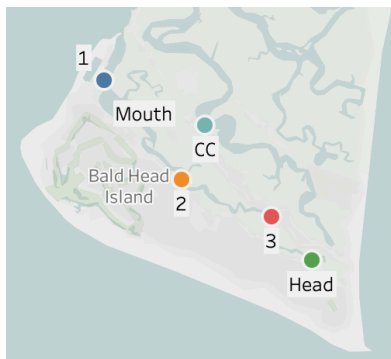
#### Project Goals

- Gain a comprehensive understanding of Bald Head Creek water quality
- Investigate potential deleterious human influences on the health of the tidal creek complex
- Weekly monitoring of physical attributes (temperature, salinity, dissolved oxygen, turbidity, pH), chlorophyll, nutrients (nitrogen and phosphorus) and chlorophyll at 4 sites (3 in Bald Head Creek and 1 in Cape Creek, Fig. 8)
- Quarterly sampling at two sites to monitor diurnal changes, especially hypoxia
- Shoreline survey for potential sources of contamination if triggered by high fecal coliform concentrations from regular monitoring ([Creek Bacteria](#) project), or under high and low flow conditions

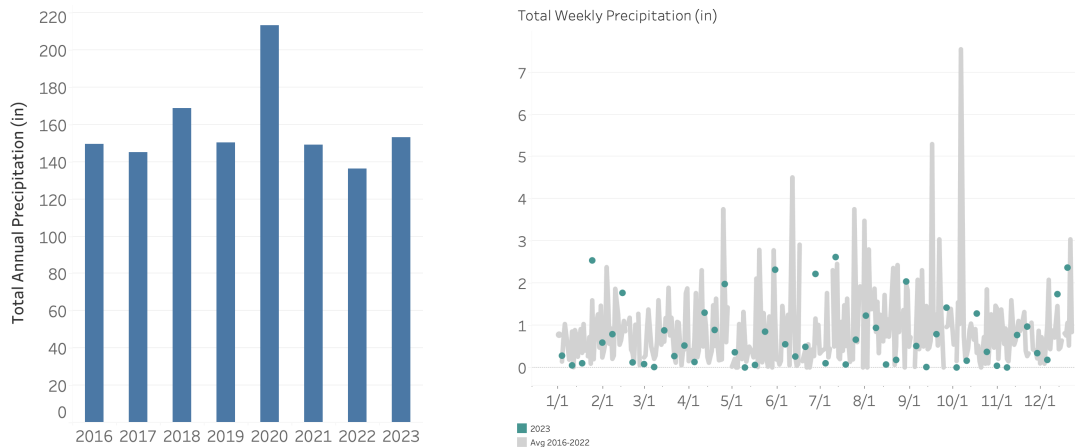


## Progress & Significant Findings

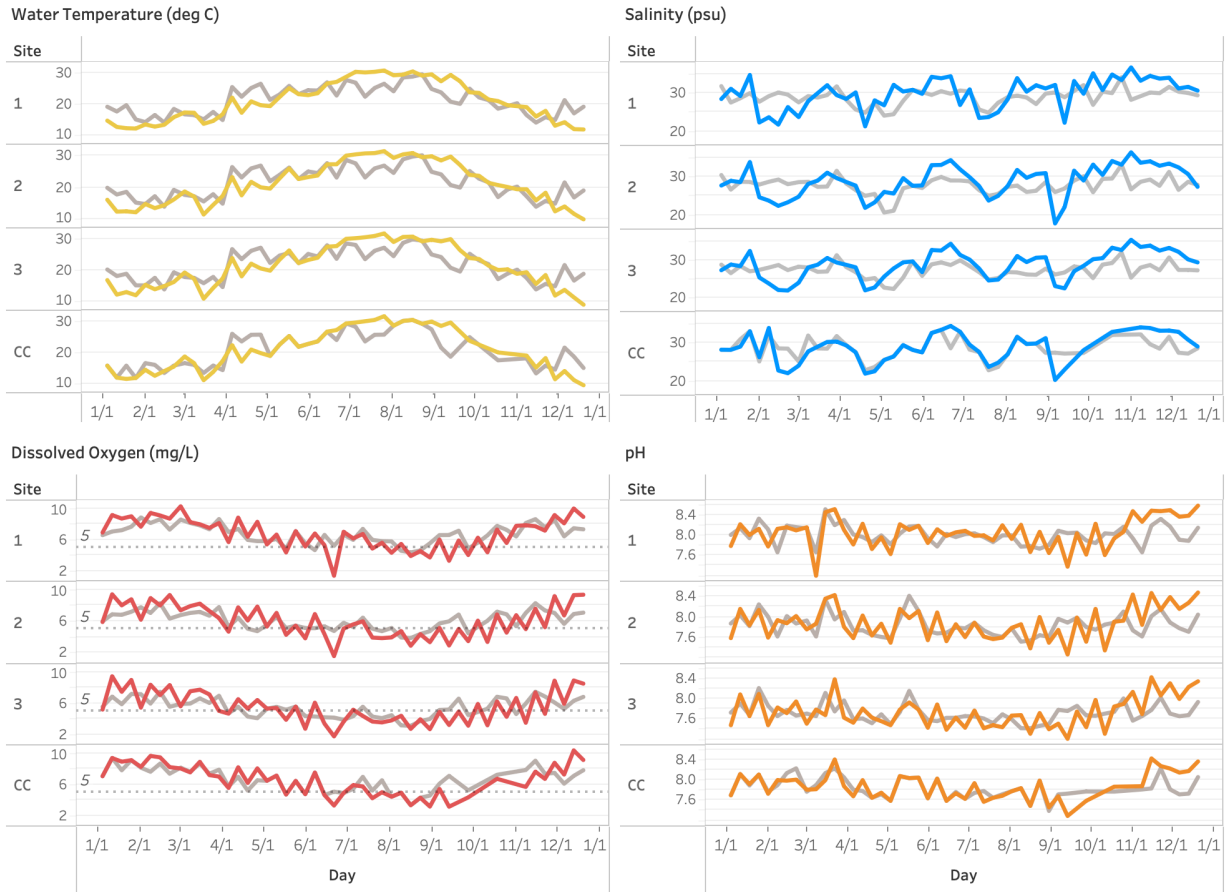
- Precipitation was average in 2023 (Fig. 9), which resulted in average salinity overall (Fig. 10), but slightly higher salinity in summer and fall, which was likely due to the relative input of Cape Fear River discharge.
- Water temperatures showed the usual seasonal pattern, but it was a hotter-than-usual summer, with water temperatures above average from July - September 2023 (Fig. 10).
- Dissolved oxygen and pH were moderate in 2023 (Fig. 10), however, BHI Creek experienced hypoxia (D.O. < 5 mg/L) for 20 - 40% of samples (Fig. 11). These hypoxic conditions seem characteristic of each site, with upstream sites experiencing more hypoxia than the mouth.
- Chlorophyll is a proxy for phytoplankton biomass and is an indicator of water quality. Chlorophyll spiked a few times, including in September (Fig. 12). High phytoplankton biomass may contribute to low dissolved oxygen concentrations in summer - early fall.
- All dissolved nutrients (nitrate, ammonium, and phosphate) were relatively low on average in 2023, with the exception of high nutrient concentrations recorded across all sites in September 2023 (Fig. 12). This nutrient input may have fueled the phytoplankton bloom noted in September.



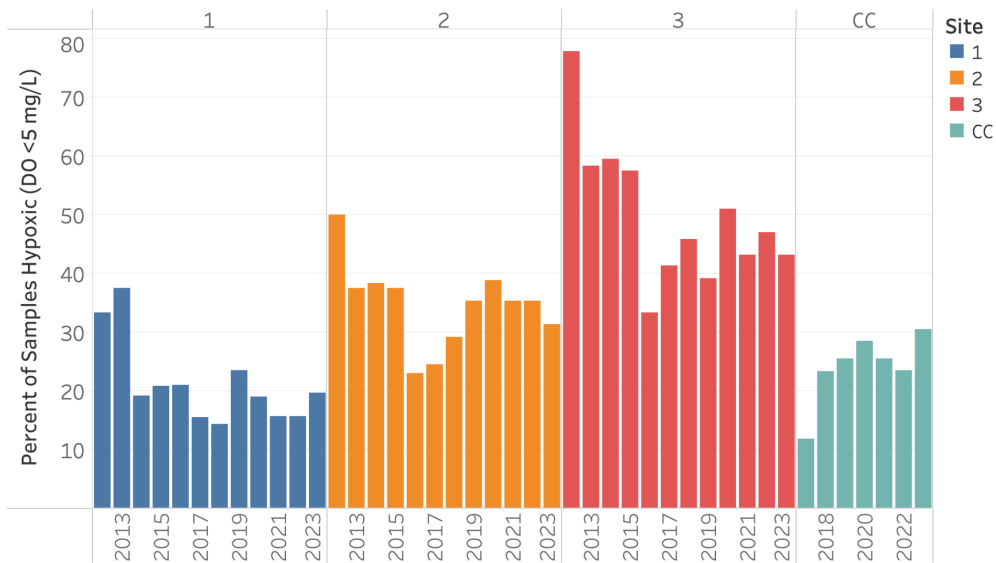
**Fig. 8.** Creek water quality sites. Sites sampled weekly within Bald Head Creek include (downstream to upstream) Sites 1, 2, and 3, and Cape Creek (Site CC, mid-creek). Sites sampled quarterly for 24 hours within Bald Head Creek include “Head” and “Mouth”. “Mouth” is the same as Site 1.



**Fig 9. A.** Total annual precipitation from the Bald Head Island weather station, 2016 - 2023. Note that 2018 is an underestimate due to power loss to the weather station during Hurricane Florence. **B.** Total weekly precipitation by week in 2023 compared to the weekly average, 2016 - 2023.



**Fig. 10.** Comparisons of weekly creek water quality parameters for 2023 (colored lines) to the average for 2012-2022 (gray line) for a given site and day of the year. Dashed line for dissolved oxygen indicates the minimum critical concentration (5 mg/L).



**Fig. 11.** Percentage of dissolved oxygen samples that were characterized as “hypoxic” (< 5 mg/L) for each site and year. Daytime samples were taken weekly, year-round.

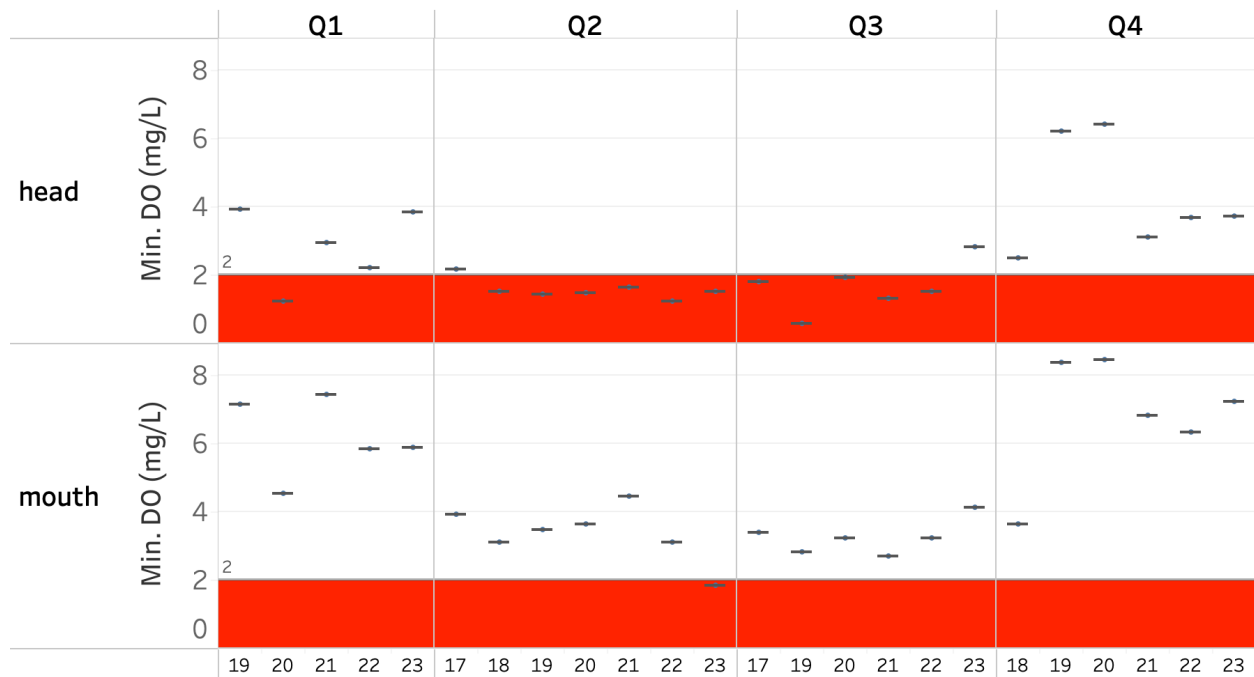


**Fig. 12.** Comparisons of weekly creek water quality sampled in 2023 (colored lines) to the average for 2017-2022 (gray line) for a given site and day of the year. Chlorophyll average was for 2021 - 2022 only.

Nitrate concentration from 9/6/23 at the mid-Creek site (Site 2) was very high (14.29 uM); this was an unusually high value for this time of year. The Creek experienced higher than usual phosphate concentrations throughout all sites at the same time. Fecal indicator bacterium *E. coli* concentrations were not high at Site 2 at this time, but were elevated at Sites 1 and 3. Together, these results indicate a source of nutrients to the creek that may have been wastewater-derived. The following week (9/13/23) all four sites experienced high chlorophyll concentrations consistent with a phytoplankton bloom that may have been stimulated by these high nutrient concentrations.

Our 24-hour Creek sampling from two sites (Head and Mouth of BH Creek) has revealed that BH Creek experiences both diurnal and seasonal hypoxia (<5 mg/L), with minimum oxygen concentrations occurring overnight in the pre-dawn hours (Fig. 13). More concerning is that in quarters 2 and 3 (June and September), the Head site consistently experiences *anoxia* (dissolved oxygen <2 mg/L). Anoxia means that there is not enough oxygen to support marine life if experienced continuously. The Mouth site does not usually experience anoxia because of tidal flushing from the Cape Fear River.

24h Min DO



**Fig. 13.** 24-hour creek sampling revealed that water at the Head of the creek has regularly gone anoxic (< 2 mg/L) overnight during Quarters 2 and 3 (June and September). This does not generally happen at the Mouth site, or during Quarters 1 and 4 (March and December).

Future Directions

We recommend continuing with creek water quality monitoring using the same methods in 2023. Data are being enhanced by a grant-funded project with NC State University where a YSI EXO data sonde has been deployed providing near-continuous monitoring of water quality at the creek mouth. This instrument was deployed for most of 2023 and we are currently working on a web interface to display the data.

*Freshwater Ponds*

After growing concerns from residents and our own observations of blooms of an aquatic plant (duckweed) at the Ibis Pond (Middle Island), two of our summer interns worked on a project (not funded by the Village Contract) in summer 2023 examining water quality and biodiversity parameters at the Ibis Pond and the Wildlife Overlook pond (Stede Bonnet Rd.). They found alarmingly high chlorophyll and nutrient concentrations and low dissolved oxygen in both ponds, with the Ibis Pond in worse (eutrophic) condition than the Wildlife Overlook. Algal blooms in freshwater ponds are concerning for many reasons: algal species such as cyanobacteria can be toxic to wildlife, and low dissolved oxygen concentrations can kill fish and other aquatic life. The Village and BHI Club should consider more intensive water quality monitoring of freshwater ponds and lagoons, identification of bloom-forming algal species, examination of factors that could contribute to poor water quality, and implementing measures to improve water quality in freshwater ponds (e.g., introduction of native vegetation species on borders, addition of fountains or other devices to create water flow and add oxygen).

## Creek Bacteria

### Project Goals

- Inform the Village about potential wastewater inputs, potential need for creek closures for public health, and shoreline sampling for bacteria sources
- Biweekly monitoring for fecal indicator bacteria from 4 sites

After outsourcing fecal coliform measurements for five years, we transitioned to in-house examination of bacteriological water quality. We have begun using the IDEXX system, which is EPA-certified, and transitioned to measuring *E. coli* instead of fecal coliforms. *E. coli* and *Enterococcus* are more specific to human fecal inputs to waterways than fecal coliforms and are the standard parameters used by EPA and DEQ. We had some increased costs in the first year transition period where we purchased lab equipment needed for this analysis, but ultimately, costs will be lower and it will save time to conduct this analysis on BHI. It will also give the Conservancy the flexibility to test any needed water samples for <\$10/sample. Data are further enhanced by the NCSU grant-funded project, which includes a continuously-collecting data sonde as well as microbiological sampling for bacterial source tracking.



**Fig. 14.** Fecal coliform (orange) and *E. coli* (red) densities were lower than Recreational Water Quality Standard (200 cfu/100 ml) but occasionally higher than the Shellfishing Standard (14 cfu/100 ml).

### Progress & Significant Findings

Fecal indicator bacteria densities were lower than average in 2023 (Fig. 14). Averages were never higher than the EPA Recreational Water Quality Standard (14 cfu/100 ml). There were a handful of high *E. coli* events that were higher than the Shellfishing standard (late May at Sites 1 and 3, September 2023 at multiple sites in Bald Head Creek). This indicates that the Creek is usually safe for recreational use (swimming, kayaking, fishing).

### Future Directions

Use of the IDEXX system has been a huge improvement in time savings and control over sampling compared with sending samples to a lab in Wilmington. We plan to add a second indicator (*Enterococci*) to improve the predictive capability of our bacteriological water quality sampling. We will need to invest in a second incubator, but samples will be collected at the same time as *E. coli*, so this will not add time to our analyses. *Enterococci* is the standard used for recreational water quality in saltwater, while *E. coli* is used for shellfish sanitation.

### **Living Shoreline**

#### Background

As natural marshes are lost to erosion, sea level rise, and human activity, small created stabilization structures and marshes, called living shorelines, have gained interest as a replacement habitat. Living shorelines enhance ecological function while reducing erosion through the use of restored oyster reefs and marsh plants. Due to their ability to stabilize the shoreline with minimal impact to the ecology, living shorelines are considered a method to increase coastal community resilience to sea level rise.

In 2021, BHI Conservancy independently established three small experimental oyster reef restoration sites in Bald Head Creek. These projects were built from bagged oyster shells, and have been monitored yearly for oyster settlement, growth, and habitat for reef-associated fauna. These projects have been largely successful. In 2022, the Conservancy and Village of BHI agreed to partner on a new living shoreline project on Village property at Marina Park, a marsh site near the mouth of Bald Head Creek that has eroded substantially (Figs. 14, 15). The living shoreline at this site would help protect and build the marsh, protect an existing bulkhead, and provide an educational demonstration site for BHI residents and visitors. The Living Shoreline project was added to the 2023-24 Environmental Services Contract, and progress was made to obtain a contractor (SANDBAR Oyster Co.) to complete the work, a work plan, cost-share from the NC Coastal Federation/State of North Carolina, and permitting. The proposed living shoreline sill for Marina Park will consist of an oyster reef sill created within the intertidal zone, using two different shapes of SANDBAR's patented/patent-pending biodegradable hardscape called Oyster Catcher™ (Fig. 16).



**Fig. 14.** Location for living shoreline at Marina Park.



**Fig. 15.** Living shoreline location, facing north.



In spring 2024 it was discovered that the bulkhead behind the proposed living shoreline would need to be replaced. This work would need to be completed before the living shoreline project was installed, so the project was delayed. The bulkhead is expected to be replaced in August 2024, and the living shoreline can be completed in September 2024. Funds for this project were moved to the 2024-25 Environmental Services Contract.



**Fig. 16.** Example project using Oyster Catcher™ substrate

## Aquifer Health

### Background

The Village's ability to supply much of its own drinking water, which reduces utility costs to taxpayers, and its commitment to maximizing reuse of water, are central tenets for Contract projects aimed at understanding the island's freshwater resources. Further, the island's susceptibility to drainage issues and flooding has dictated an extensive stormwater management plan for which an understanding rainfall infiltration into the aquifer is important. The aquifer also supplies freshwater to the maritime forest, creek, and marsh, helping to sustain the island's plants and animals.

## Aquifer Volume and Water Quality

### Project Goals

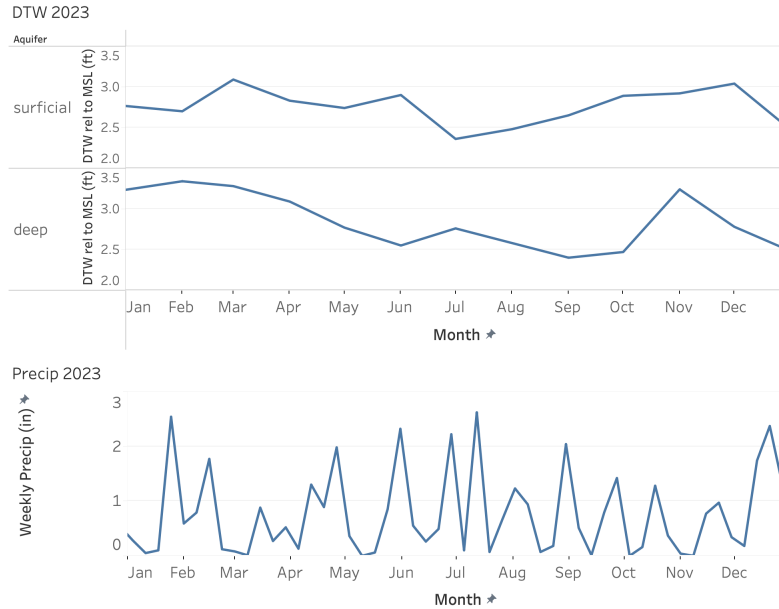
- Examine the response of the BHI aquifer to water usage and environmental emergencies (e.g., drought, storm events, outside contaminant inputs) by collecting data for analysis of aquifer storage volume and aquifer water quality
- Monthly sampling for depth-to-water and quarterly sampling (pumping) for water quality

### Progress & Significant Findings

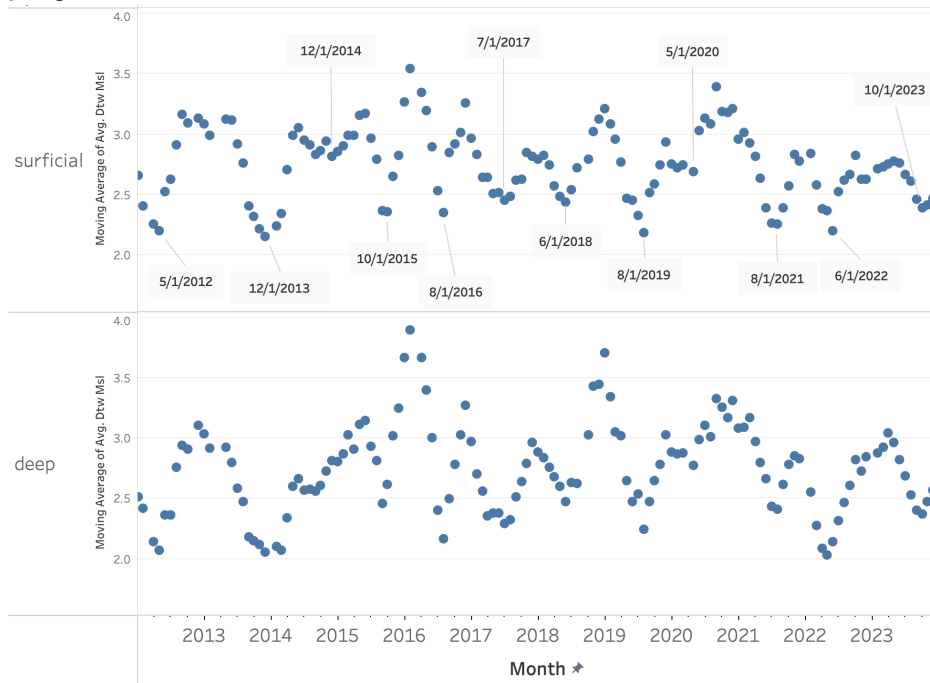
- 2023 measurements exhibit a relatively stable water supply.
- Historical analysis for wells measured since 2012 indicates seasonal trends in groundwater levels where since 2016, groundwater minima have occurred in summer.
- Groundwater table is highest in the middle of the island and lowest near the southwestern perimeter.
- Groundwater salinity levels have been mostly in the acceptable range since monitoring began, particularly at interior well sites. Several peripheral wells show signs of saltwater

intrusion, with the highest conductivities measured at Middle Island sites and perimeter sites at the southwest of the island (Cape Fear Trail, BHI Club)

- High ammonia levels in some wells are still of concern, but do not seem to be from a recent wastewater source.

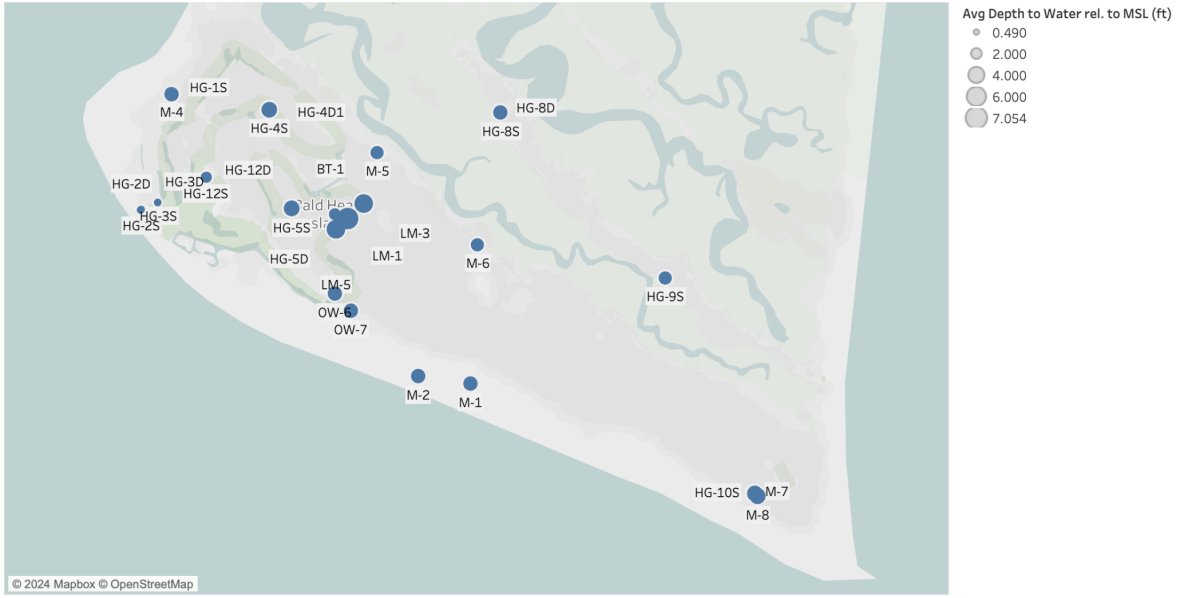


**Fig. 17.** Depth to water relative to mean sea level was lowest in July for wells in the surficial aquifer and September for wells in the deep aquifer. Depth to water relative to mean sea level was highest in late winter-early spring.

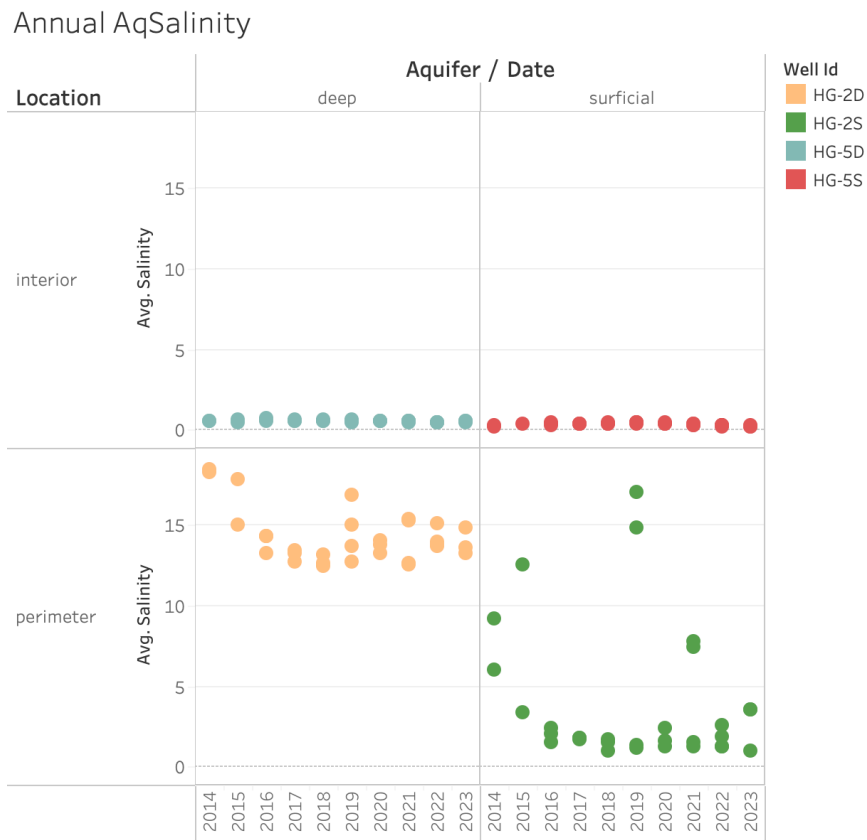


**Fig. 18.** 3-month running averages of groundwater depth to water relative to mean sea level revealed annual maxima and minima in groundwater levels. From 2016 onwards, groundwater minima were in summer, when the island population and water withdrawals were highest.





**Fig. 19.** Groundwater table, indicated by depth to water relative to mean sea level, is highest on average in the center of the island, and lowest near the southwestern perimeter.



**Fig. 20.** Groundwater salinity by date for example wells from locations at the interior of the island vs. perimeter, and sampling the surficial vs. deep aquifer.

### Future Directions

We recommend continued monitoring of aquifer volume and water quality. We are also planning to test out a new “low flow” method for aquifer water quality monitoring. This involves installing pumps in each well and sampling them at a lower flow rate until water quality parameters stabilize. We are testing this method on three wells alongside the existing high-flow pumping method to determine whether the new method will be more efficient, easier on equipment, and collect better quality data. This will ultimately reduce costs of groundwater monitoring in the future.

## **Dune Health**

### Background

Native dune species properly designed by nature for barrier island habitats hold together the island’s dune system against the forces of wind and water. Invasive species such as Beach Vitex are a substantial threat to many types of these native dune plants and must be vigorously controlled. Also, healthy dunes provide critical habitat for our threatened nesting sea turtle population. In 2020-21, the Conservancy intensified efforts to treat all existing plants after substantial interruptions in 2018 and 2019 due to hurricanes. In 2021-22, unoccupied aerial vehicle (UAV) technology allowed visualization of Vitex plants, and we added a controlled experiment on herbicide effectiveness. In 2022 and 2023, all Vitex plants were treated in fall, following the guidance of our experimental findings.

## **Beach Vitex**

### Project Goals

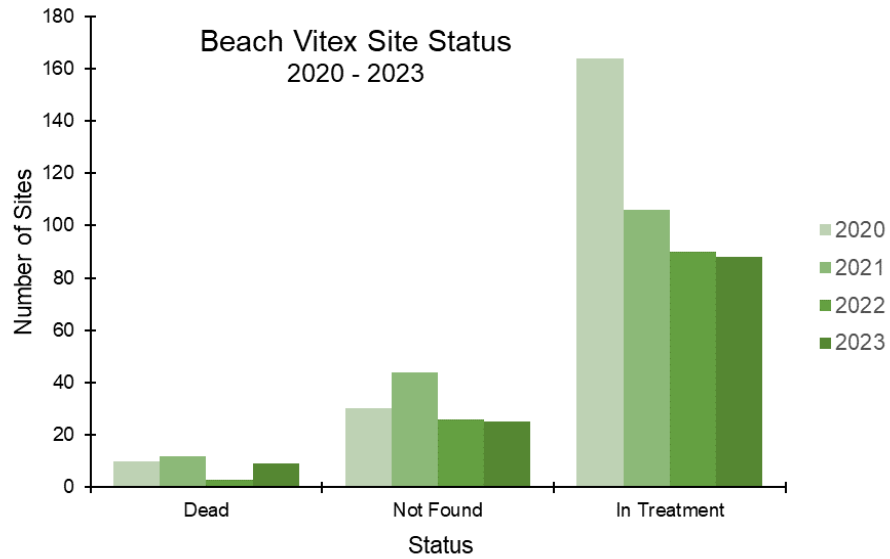
- Find and eradicate existing Beach Vitex to prevent species proliferation and to allow for growth of native dune-building species
- Conduct a controlled experiment on eradication methods and season of herbicide application

### Progress & Significant Findings

- All known Vitex sites were treated in 2023 (Table 2).
- There was a net loss of 76 Beach Vitex sites from 2020 - 2023 (Fig. 21)
- Experimental data shows higher percent control of herbicide-treated plants than non-treated plants; these differences were more apparent in plants treated in fall. “Remove and paint” was the most successful treatment method.

**Table 2. Beach Vitex Treatment Fall 2023**

2023 Status	# Sites
Dead	9
Not found	25
In Treatment	88



**Fig. 21.** Number of Beach Vitex sites through time. In 2020, there were 164 active sites being treated (including 36 sites that were taken out of treatment 2021-22 for the herbicide experiment); in 2023 the total number of sites in treatment (still alive) is 88.



**Fig. 22.** The map shows the remaining active locations of Beach Vitex on the island that are in treatment for next season (Fall 2024). There is a large concentration on SBHW, especially in between Muscadine and BA 34.

### *Beach Vitex Treatment Experiment*

This experiment tested the interactive effects of two treatment methods and three treatment seasons on control of Beach Vitex (*Vitex rotundifolia*) on Bald Head Island. On BHI, almost all Beach Vitex plants have been previously treated with imazapyr, which made this experiment differ from previous studies. Treatment methods included:

1. "Hack and Paint" = (Hack) current treatment method involving slicing into plant runners and painting with the imazapyr herbicide
2. "Remove and Paint" = (Remove) cutting the plant at the soil surface, removing above-ground vegetation and painting the stump/stem with imazapyr
3. Control = cutting plant back to same level as herbicide treatments but applying no herbicide.

Treatments were applied to plants before the growing season (early March), in the growing season (June), and at the end of the growing season (September). Four replicate plants were used for each treatment method within each season (36 plants total, 12 plants per season). Plants used for this experiment were growing in a variety of locations (primary dune, secondary dune, residential yards) on Bald Head Island. Plants have been treated with imazapyr within the year prior to the experiment, but were still living and classified as "medium" sized, without obvious connections to other plants.

### *Methods*

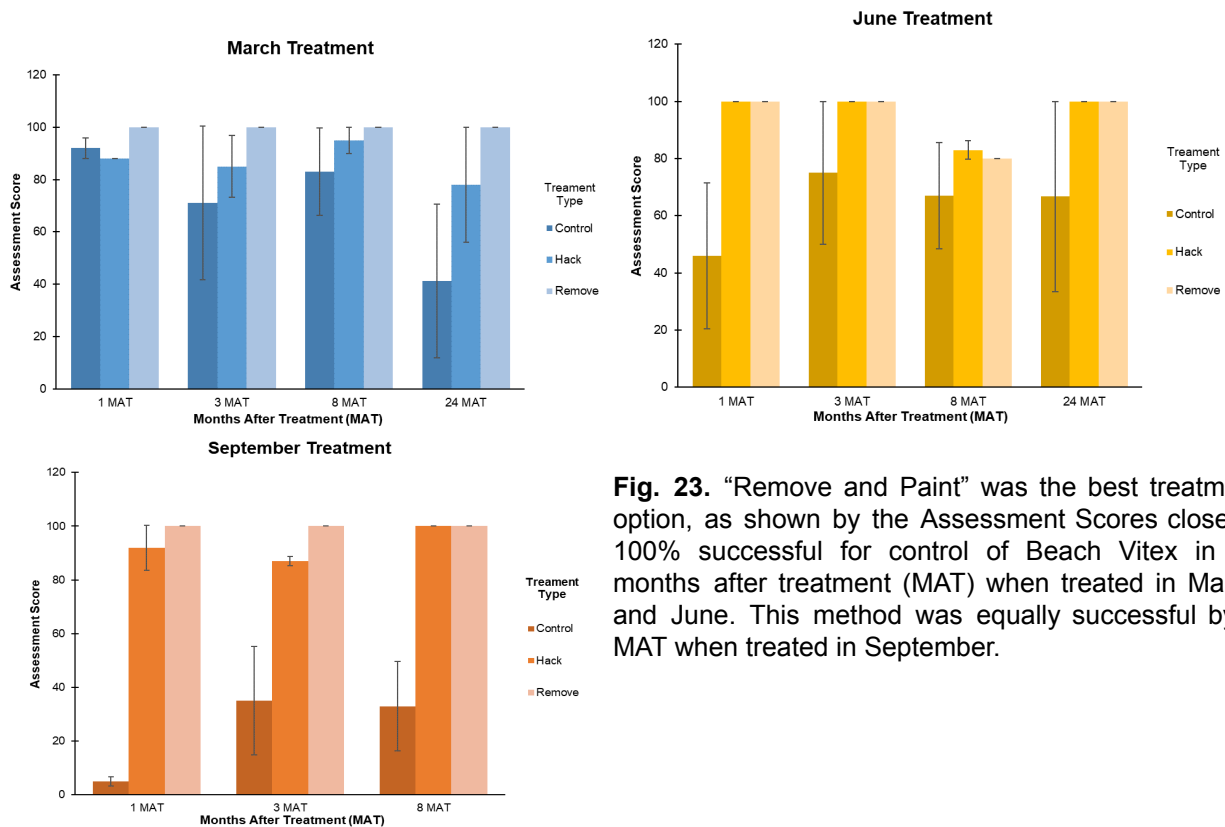
Plants were randomly assigned to "Hack", "Remove", or Control treatments. On the treatment date, all runners were cut back to approximately 1 m (except for Remove treatments, immediately cut to 2" of soil surface). Non-herbicide control treatments consisted of removing BV stems to within 5 cm (2 in) of the main stem. The treatments consisted of: H - slicing plant runners horizontally to the cambium and applying 2 ml imazapyr herbicide (50% v/v solution of Arsenal AC Concentrate - 53% active ingredient, 27% ai total) per plant; and Remove - cutting off one main stem per plant with clippers and removing it and spotting 2 ml of the herbicide solution on the stem immediately following cutting.

Experimental plants were visually rated with 0 = no control and 100 = complete kill (defoliated and brown) at 1, 3, and 8 months after treatment (MAT). The Assessment Score looks at level of impact of the treatment on plants, including yellowing, stunting, and lack of growth. Plants were observed for regrowth annually for at least two years after the initial experiment period.

### *Results*

For plants treated in March, Remove was the best treatment method, with the average assessment score at 1, 3, 8, and 24 MAT being 100 (complete kill). Minimal to low regrowth was observed for the Remove treatments. Impact of Hack treatment was intermediate but overlapped with Controls.

For plants treated in June, Remove was also the best treatment method, with the average assessment score at 1, 3, and 24 MAT being 100 (complete kill, minimal regrowth). Impacts of the Hack treatments were similar to Remove for June-treated plants.



**Fig. 23.** “Remove and Paint” was the best treatment option, as shown by the Assessment Scores close to 100% successful for control of Beach Vitex in 24 months after treatment (MAT) when treated in March and June. This method was equally successful by 8 MAT when treated in September.

Remove was the best treatment method for September-treated plants, with the average assessment score 1, 3, and 8 MAT being 100 (complete kill, minimal regrowth). September-treated plants were not assessed at 24 MAT. Hack treatment impacts were intermediate between Remove and Control. We did not calculate the time it would take to conduct these treatments during typical management, since collecting data on the plants took more time than the actual treatment, but we expect that management using Remove would take approximately the same amount of time as Hack overall. Remove would take less time than Hack to treat/cut plants, but more time to transport and dispose of plant material.

### Conclusions

Season of treatment was important, with largest differences between treatment and controls seen in the September-treated plants. Treating plants in September when they are still photosynthetically active but headed into their dormant stage allow for translocation of the herbicide into the plant, and also delay of growth in the spring season. We therefore recommend treating Beach Vitex in the fall season, and if logistically possible, using the “Remove and Paint” method for all plants.

Recommendations for management of Beach Vitex in 2024-25 will be to physically remove all plants and paint the stems with imazapyr herbicide. To do this will require transportation of plant material off-island so that it does not enter the mulch site and get reintroduced. It is estimated that the volume of plant material will require approximately eight 40-cubic-yard Dumpster loads. We have submitted a grant proposal to the US Fish & Wildlife Service to support eradication of

Beach Vitex on BHI: if funded, the grant will fund the Beach Vitex portion of the Village Contract for three years.

## Wildlife Health

Bald Head Island is rich in a diversity of wildlife, and the community strives to live in harmony with nature. The Conservancy monitors, protects, and advises the Village on management of wildlife species that can have negative interactions with humans, resulting in either unsafe situations for humans or harm to the animal. Current projects focus on predators that are of concern to residents and visitors, and on shorebirds and diamondback terrapins that need special protection.

### Predator Populations

#### Background

Bald Head Island possesses diverse, healthy habitats that are home to a variety of wildlife species. The wildlife exists in a delicate balance, with prey species population levels controlled by predators and predator populations limited by the number of prey species present. In recent years the population sizes of these species have fluctuated; however, little is known about their population dynamics.

#### Project Goals

- Monitoring of canid and alligator relative numbers and locations on the island
- Evaluation of predator management methods when needed
- Additional understanding about locations, home ranges, and movements of alligators will be achieved by collaboration with Dr. Scott Belcher (NCSU) to apply satellite tags to up to 5 alligators >5 feet in length (done - funded by 2021-22 Contract). This information will be immediately useful to address public safety and visitor concerns about habits of large alligators

#### Progress & Significant Findings

- Coyote densities were higher on roads and the golf course in summer 2021 than any previous year. Numbers of coyote sightings dropped off precipitously in 2022, but a small number were seen in 2023.
- Coyote population on BHI may be impacted by trapping activities at Fort Fisher, especially because there is genetic connectivity between Fort Fisher and BHI
- There were at least 30 alligators on the island in summer 2023, with the majority of these being 1-3 ft in length and found at Golf Course hole 15
- Size class structure of the alligator population has been relatively stable over the past four years.
- Alligator satellite tagging was conducted in spring 2022. Five adult alligators were tagged: 4 males and 1 female. All alligators stayed on the island during their tagging period.

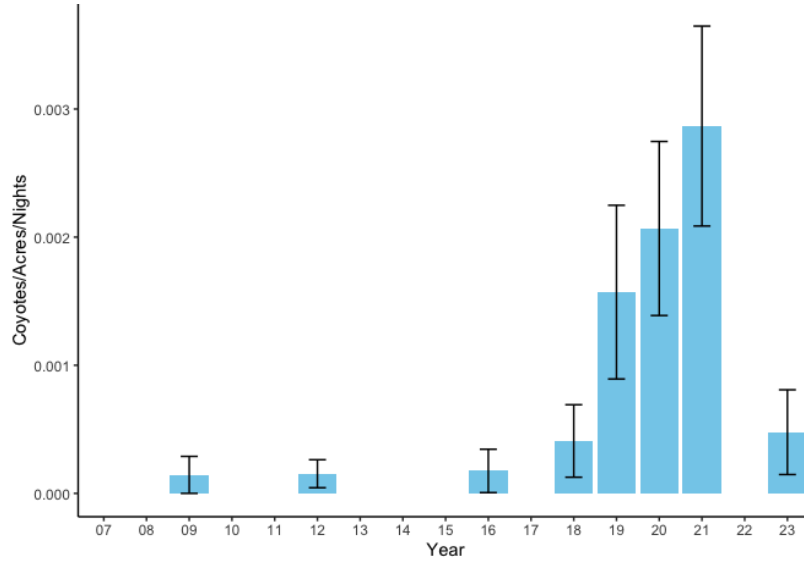
## **Coyotes**

Coyotes are non-native to North Carolina, and can be problematic due to their predation on sea turtle eggs and hatchlings and shorebird eggs and chicks. In 2019, over 2,000 sea turtle eggs were lost on BHI to coyote depredation. For the first time, this year we compiled all existing historical data on coyote population numbers from our deer spotlight survey data collected since 2007 (Fig. 24). Coyotes were first documented on the island in 2007, but not during spotlight surveys until 2009. Survey sightings were relatively low until 2018-2019, when sightings quadrupled. Fluctuations in coyote population size may be affected by management efforts on our sister sea turtle nesting beach at Fort Fisher State Recreation Area (FFSRA). FFSRA undertakes a trap-and-cull program for coyotes and foxes prior to each sea turtle nesting season, to protect nesting shorebirds and sea turtles (Fig. 25). The year that FFSRA did not conduct trapping activities (2019) was the worst season for coyote depredation of sea turtle nests on BHI. Questions arose about the coyote population size on BHI, and whether BHI coyotes are linked to mainland populations.

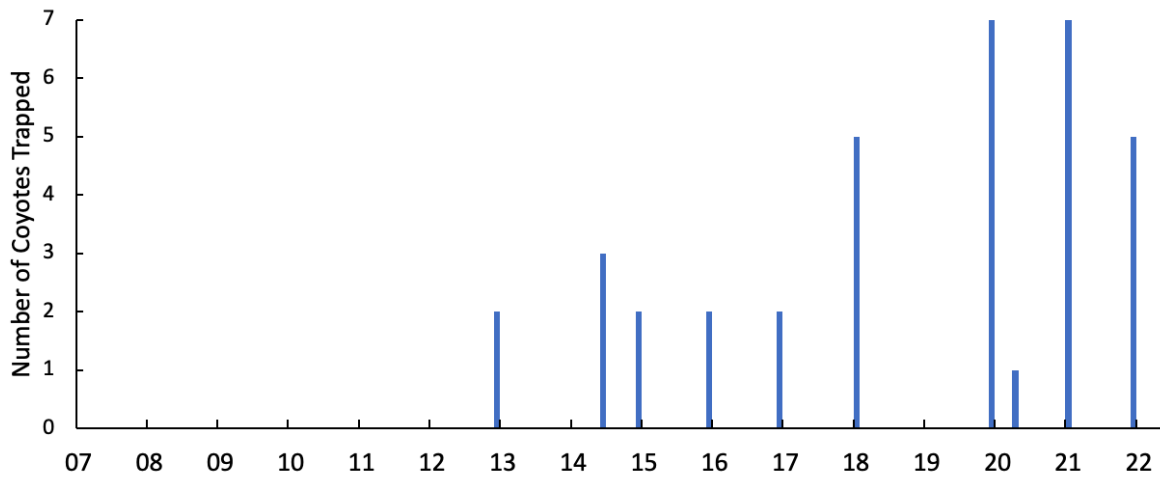
In fall-winter 2022-23, we worked with Dr. Liz Kierepka from the NC Museum of Natural Sciences to conduct a population study of BHI coyotes using genetic markers from coyote scat. Results revealed the presence of 9 individuals on BHI: 3 female and 6 male. This led to a population estimate of between 8-18 individuals, with 8 individuals on BHI proper and 4 on Middle Island & Ft Fisher (Fig. 26). The genetic data also revealed that there were two family groups (consisting of first-degree relatives): one on BHI and one on Middle Island/Ft Fisher, plus two unrelated individuals. The study confirmed that there is population connectivity between Middle Island and Fort Fisher, meaning that coyotes could use Middle Island as a refuge from Ft Fisher, and/or that individuals could travel from Middle Island to Ft Fisher to fill in a population niche that opens up when trapping occurs.

In 2020-21, despite being present in high numbers, coyotes were less successful at infiltrating sea turtle nests than in 2019 due to improvements in nest predator exclusion cage material partially funded by the Village in 2020. In 2023, one nest fell victim to coyotes, and a total of 10 nests were affected by a mixture of island predators, including coyotes, ghost crabs, and fire ants. Predators accounted for the loss of 442 eggs (3.2%). Coyotes still present a relevant threat to the sea turtle nests on BHI, but a combination of improved predator cages and full-night patrols has drastically reduced predation since 2019.





**Fig. 24.** Sightings of coyotes during summer spotlight surveys, 2007 - 2023 (average number of coyotes per acre per night, +/- standard error). Years with no bars represent zero sightings during surveys.



**Fig. 25.** Number of coyotes trapped by Fort Fisher State Recreation Area. Coyotes and foxes are trapped at the beginning of the season to help protect nesting shorebirds and sea turtles.





**Fig. 26.** Individual coyotes (numbered 1 - 9) and geographic range of family groups (yellow polygon = Group 1; pink polygon = Group 2). Coyotes 2 (male) and 7 (female) were individuals unrelated to the two family groups.

### ***Alligators***

Alligators are native predators to North Carolina. Human-alligator interaction poses a potential threat to both humans and alligators on BHI. Therefore, understanding the population structure and individuals' movements among lagoons will assist in reducing unexpected/negative interactions. The BHI alligator population is centered on the west end of the island, where they are found in golf course lagoons and other man-made ponds. Alligators are occasionally seen in the salt marsh or on the ocean beach. Weekly nighttime spotlight surveys in summer allow the BHI Conservancy to assess the current population status and provide management recommendations.

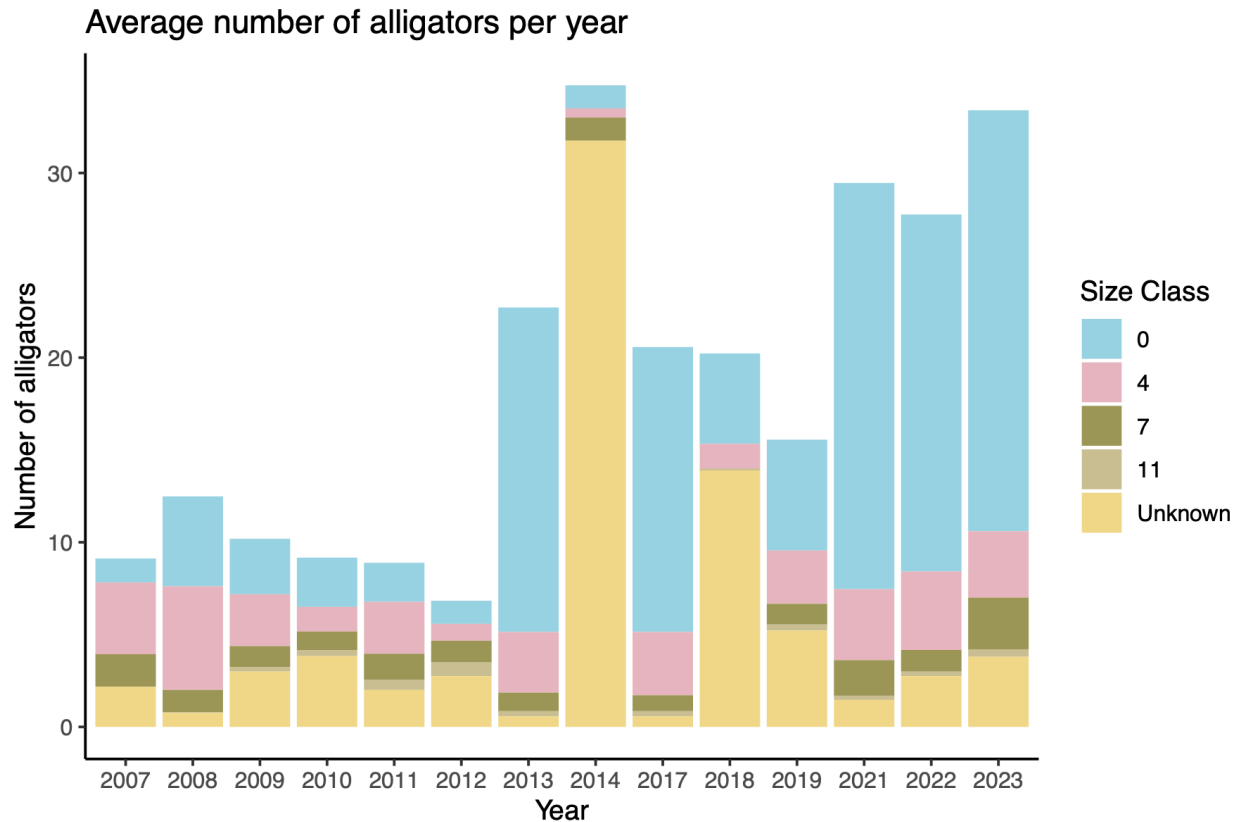
### ***Spotlight Survey Results***

In summer 2023, we conducted 12 nighttime alligator surveys. Our survey area included all BHI Club Golf Course ponds, Ibis Sanctuary Pond, Villas, and the Wildlife Overlook (Fig. 24). The average number of observed alligators viewed nightly in 2023 was 33 per night. Notably, Hole 15 had one large alligator (7-10 ft, who we believe is the mother, "Mama") and about 21 smaller alligators (1-3 ft) observed during almost every survey. In spring 2022, the Conservancy collaborated with the Belcher Lab from NC State University to conduct alligator satellite tagging to further understand the locations and movements of alligators and advise public safety

concerns. Five alligators were tagged and tracked. None of the alligators left the west side of the island and golf course area while they were tagged. Our largest (over 12' long) alligator, given the affectionate moniker “Fluffy” by island residents, retained his tag for over a year. His track can be viewed [here](#). The large female “Mama” was captured at Hole 15 - her track is mostly constrained to the eastern side of the golf course. Mama’s track can be viewed [here](#). We plan to analyze these data further to establish home range and occupancy models. Since large alligators did not leave the island (some over 1 year), we believe that the majority of any contaminants they have been exposed to have been on Bald Head Island. This adds important context to an ecotoxicology study conducted by Belcher’s lab, which showed that alligators captured on BHI in 2019 had high concentrations of PFAS “forever chemicals” in their blood (Guillette et al. 2022).



**Fig. 27.** Alligator spotlight survey route, summer 2023.



**Fig. 28.** Alligator population structure on BHI, 2007 - present.

The alligator population structure (relative sizes of individuals) seems stable, but more years of data are needed to determine long-term trends. Reports of visitors fishing and feeding alligators persist, and Conservancy staff continue to participate with Village and BHA leaders on public education efforts about wildlife safety.

Future Directions

We propose to continue with summer alligator spotlight surveys. We plan to continue conducting observational surveys of canid presence during deer spotlight and summertime sea turtle patrols, and will report losses of sea turtle nests to predation.

**Bird Conservation**

Project Goals

- Conduct weekly shorebird nest checks in spring, participate in state and international shorebird surveys
- Protect nesting shorebirds with symbolic beach postings
- Educate public about protection of nesting shorebirds by posting a scientist for a few hours weekly with our spotting scope to allow the public to view the nests
- Bi-weekly transect count surveys at different locations around the island to identify different species that use BHI

## Shorebird Nesting

Bald Head Island provides habitat for 244 documented avian species, more than half of all species documented for the state of North Carolina. Of these 244 species, eight are shorebird species listed as species with special state or federal protections. Shorebird species diversity is intrinsically linked to island biodiversity and ecosystem health. The BHI Conservancy has previously observed (in 2017) Least Terns (*Sternula antillarum*) that nest in a large colony on South Beach. The most common nesting species we currently see is the Wilson's Plover (*Charadrius wilsonia*). Wilson's Plovers are considered a species of special concern in North Carolina. They are a small, heavy-billed shorebird and specialize in hunting fiddler crabs. The Conservancy puts up a protective posting with signs and brightly-colored cord to provide awareness and protection for these sensitive species. In addition, the most common emergency wildlife calls we receive are related to birds, whether the bird is injured or a nest/chick is misplaced.

Shorebird species start arriving at their nesting grounds in the beginning of April. Due to our cooperation with the State of NC, we put up protective postings for nesting birds at Beach Access 1 and Beach Access 11 - 13. During the breeding season, these areas are monitored biweekly for any signs of nesting behavior.

A survey for the Colonial Waterbird Census in collaboration with the NC Wildlife Resources Commission was conducted on June 1st, 2023. During this survey, the Least Tern Colony was observed and 78 adult or juvenile individuals were counted as well as 3 active nests during the survey window. There were no nesting Piping Plovers on Bald Head this year.

The Least Terns between Access 11 - 13 came in two waves during the nesting season. At least 14 total nests were located. We are unsure how many were successful, but there were 2 chicks observed.



**Fig. 29.** Adult Least tern on nest



**Fig. 30.** Least tern chick

This year, we had one American Oystercatcher nest at Access 1 that failed due to washover.





**Fig. 31.** American Oystercatcher sitting on nest



**Fig. 32.** American Oystercatcher eggs

There were two Wilson’s Plover nests during the 2023 season. One was at Access 1 and this nest was successful with one chick observed. There was another Wilson’s Plover nesting pair at Access 11 and this nest also successfully hatched one chick.

**Black Rail Surveys**

Black Rails are a secretive marsh bird that hypothetically could be found in high marsh habitats on BHI, and because of their preferred habitat, they are at special risk from sea level rise. The state of North Carolina has begun conducting callback surveys for black rail and encouraged BHI to conduct these surveys because of the existence of appropriate habitat for this species on the island. If black rails were detected on BHI, this would be a big news story for our area! We conducted callback surveys three times during nesting season in 2022 and 2023. No Black Rails were detected in 2022 or 2023 surveys, although we did hear Clapper rails on our surveys.



**Fig. 33. A.** Black Rail © Hector Bottai, Macaulay Library

**B.** Black Rail sampling sites on BHI

### Progress & Significant Findings

- BHIC placed protective postings at Beach Accesses 1 and 11 in spring 2023
- There were two successful observed nesting pairs of Wilson's Plovers in summer 2023, with one chick at Access 11 and one chick at Access 1.
- A pair of American Oystercatchers nested at Access 1, but this nest was unsuccessful due to washover.
- Black rails were not detected during 2022 or 2023 callback surveys.

### Future Directions

The Conservancy proposes to continue setting up protective postings for the nesting season. We will continue our collaboration with State and Federal agencies and participate in Waterbird surveys.

## **Diamondback Terrapin Populations**

### Background

In 2021, the Village and the Conservancy successfully partnered to begin two new efforts for diamondback terrapin conservation: terrapin surveys, and production of terrapin excluder devices for crab pots, and promotion of their use in our creeks.

### Project Goals

- Lead and conduct surveys for Diamondback Terrapins, a NC Species of Concern, within the newly-established Bald Head Island Diamondback Terrapin Management Area
- Continue to educate the public about use of Terrapin Excluder Devices in crab pots (new regulation March 2021) and provide TEDs to residents and visitors

### Progress & Significant Findings

- Kayak surveys for diamondback terrapins were conducted in May-June 2023 as part of SE NC Terrapin Tallies organized by the NC Coastal Reserve. Six routes in Bald Head Creek and Cape Creek were paddled by 25 individuals (16 Conservancy staff and 9 volunteers) 2-5 times each. 28 diamondback terrapins were spotted on BHI during Terrapin Tallies, in both Bald Head Creek and Cape Creek, with the majority of terrapins sighted in the upstream waters of Cape Creek (43%).
- BHI Conservancy responded to one live terrapin stranding in April and one dead terrapin 7/24/23
- Over 100 Terrapin Excluder Devices for crabpots were given out to the public. We held 4 workshops teaching about terrapin conservation and assisting owners of crabpots with installing TEDs.





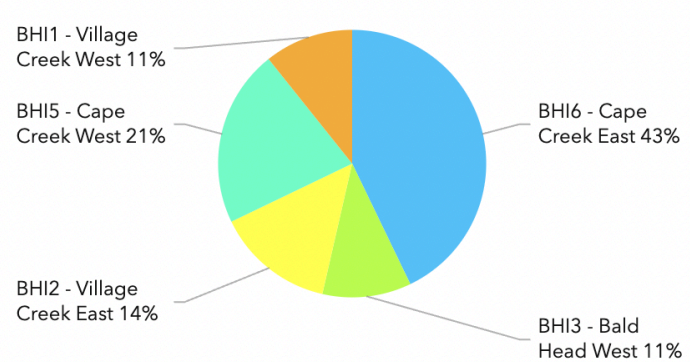
**Fig. 34.** Diamondback terrapin.



**Fig. 35.** Terrapin excluder device (TED) on crabpot.



**Fig. 36.** Terrapin Tally survey routes, spring 2023. Dots are diamondback terrapin sightings.



**Fig. 37.** Terrapin sightings by site.

Future Directions

We propose to continue with diamondback terrapin surveys in spring 2024, and to continue to provide TEDs to the public.

**VI. Conclusions**

All projects conducted in 2023 have been completed, data collected, checked, and archived. All raw data summarized here are available to the Village upon request. We are currently working towards making data more publicly visible using online dashboards.

In addition to provision of environmental monitoring data, interpretation, and hands-on conservation fieldwork for the Village of Bald Head Island on the projects delineated in this report, the BHI Conservancy has been glad to engage in discussions with Village staff and elected officials on environmental issues impacting the island, including proposed Cape Fear River channel deepening, shoreline management, land preservation, and management of sea turtle / human interactions. The Conservancy manages most emergency wildlife responses for the island, with Public Safety assistance on more complex cases when needed. We look forward to continuing our positive working relationship with the Village as the island strives to “live in harmony with nature” into the future.



## References

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Stransky, J.J. 1969. Deer habitat quality for major forest types in the South, p. 42–45. In: L. K. Halls (ed.). *White-tailed deer in the southern forest habitat. Proceedings of a symposium held at Nacogdoches, Texas.* U.S. Forest Service, Washington, D.C. 130 p.

Taggart, J. and Z. Long. 2015. Effects of white-tailed Deer (*Odocoileus virginianus*) on the maritime forest of Bald Head Island, North Carolina. *American Midland Naturalist* 173:283–293.

## Appendix 1. Deer Population Report

### Summary

Bald Head Island provides habitat for white-tailed deer (*Odocoileus virginianus*). The island provides a mild climate, lack of predators and disease, no hunting, and year-round food sources. This allows the deer to thrive and can potentially lead to overpopulation of the deer. A study on the island determined that a population of 200 or fewer individuals showed minimal impacts to the maritime forest, which provides invaluable ecosystem services to the island. From 2015 - 2020, Bald Head Island managed the deer herd with a non-lethal management plan using immunocontraception. Immunocontraceptives work to control animal population by prohibiting an animal from reproducing through the use of injected contraceptives that work with the animal's immune system. Since 2019, we have found that the deer population numbers have been under the target 200 number. To monitor the population, we conduct two population surveys methods (spotlight surveys and trail camera indices) to determine the population trends throughout time.

### Population Estimates

Two population survey methods are used: spotlight surveys and camera indices. Summer spotlight surveys have been conducted on BHI since the late 1990s and are used primarily to determine the doe:buck ratio and to examine population trends through time. Camera indices use mark-recapture methodology and are used to get a more precise estimate of the doe population.

Baited camera indices can be biased towards bucks, so we calculated sex ratios gathered during the summer spotlight survey where there is assumed to be less bias. The doe:fawn ratio was determined from the camera index as most fawns are too young in summer to be accurately represented in the summer spotlight surveys.

Spotlight surveys are conducted during the summer (June-August). Surveys are conducted via a golf cart with planned routes that start 30 minutes after sunset. There are 7 routes (see Figure 2-1) that are randomized before each survey, to see different routes during different times of night. The survey is conducted using red light spotlights on both sides of the cart, surveying as far as the spotlight will reach. When a deer is seen, the sex, age, and any ear tags are noted.

Data from the 2023 summer spotlight survey gave a sex ratio of 1.92 female:male. The total BHI deer population was estimated to be 120 individuals in summer 2023 (Table 1-1).

The fall camera index ran for 16 days (November 1-15) (see Figure 2-2 for camera locations). We estimated the doe population on Bald Head Island using the Chapman variation of the Peterson formula:

$$N=(M+1)(C+1)/(R+1)$$

where N = population estimate, M = number of marked individuals in the population, C = total number of female deer occurrences (marked and unmarked), R = total number of marked occurrences. The values of C and R were summed from all sites each day and throughout the index to calculate N. The population index was considered complete once the daily population estimate stabilized.

Within the previous two years, 59 distinct marked does had been spotted on the island and were known to be alive, so it was estimated that there were a total of 96 adult female deer in Fall 2023. The total BHI deer population was estimated to be 173 individuals in fall 2023 (Table 2-1). The fawn population in 2021-2022 was estimated at 14 based on a detailed analysis of the fall 2022 photo set. This estimate is significantly higher than single digit numbers over the past 3 years, but was still lower than estimates in the 20s-30s of fawns from the beginning of the project in 2015. However, by fall 2023 the fawn population had grown to 26 individuals, marking an increase of the fawn population to pre-immunocontraception levels.



Fig. 1-1. Summer spotlight routes



Fig. 1-2. Deer camera locations

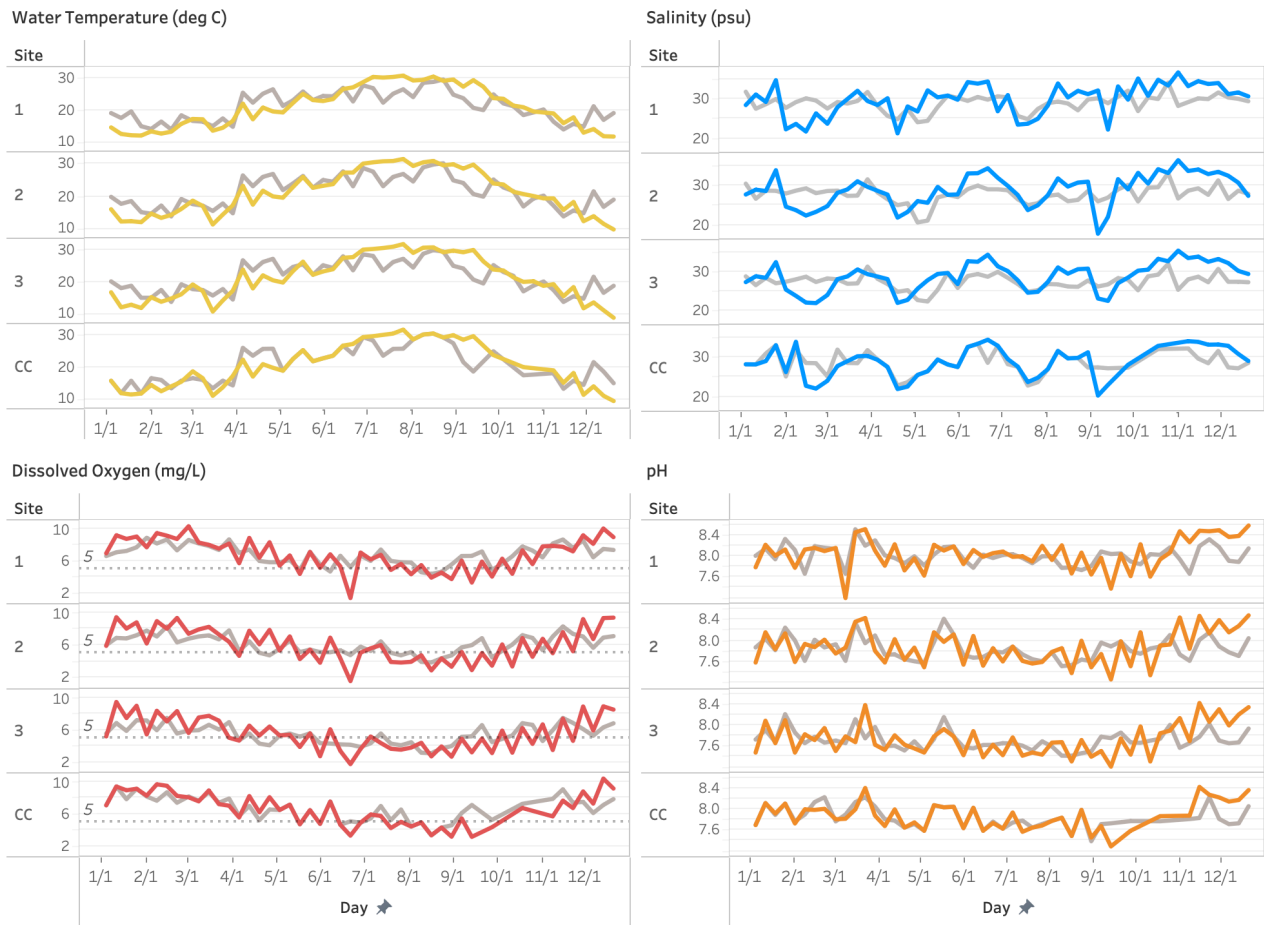
**Table 1-1.** White-tailed deer age/sex class structure and total population estimates.

	Survey Type	Does	Fawns	Bucks	Total
<b>Feb 2015</b>	camera	48	29	40	117
<b>Summer 2015</b>	spotlight	84	32	64	180
<b>Nov 2015</b>	camera	73	55	55	183
<b>Mar 2016</b>	camera	57	49	44	150
<b>Summer 2016</b>	spotlight	107	23	69	198
<b>Fall 2016</b>	camera	109	28	73	210
<b>Mar 2017</b>	camera	83	11	55	149
<b>Summer 2017</b>	spotlight	101	8	51	160
<b>Fall 2017</b>	camera	94	20	54	168
<b>Summer 2018</b>	spotlight	111	22	65	198
<b>Fall 2018</b>	camera	98	19	57	174
<b>Summer 2019</b>	spotlight	143	1	64	208
<b>Fall 2019</b>	camera	86	3	38	127
<b>Summer 2020</b>	spotlight	79	4	39	122
<b>Fall 2020</b>	camera	91	9	44	144
<b>Summer 2021</b>	spotlight	89	2	35	126
<b>Fall 2021</b>	camera	97	5	38	140
<b>Summer 2022</b>	spotlight	64	3	35	103
<b>Fall 2022</b>	camera	89	14	49	152
<b>Summer 2023</b>	spotlight	75	6	39	120
<b>Fall 2023</b>	camera	96	26	51	173

## Appendix 2. Bald Head Creek Water Quality Data

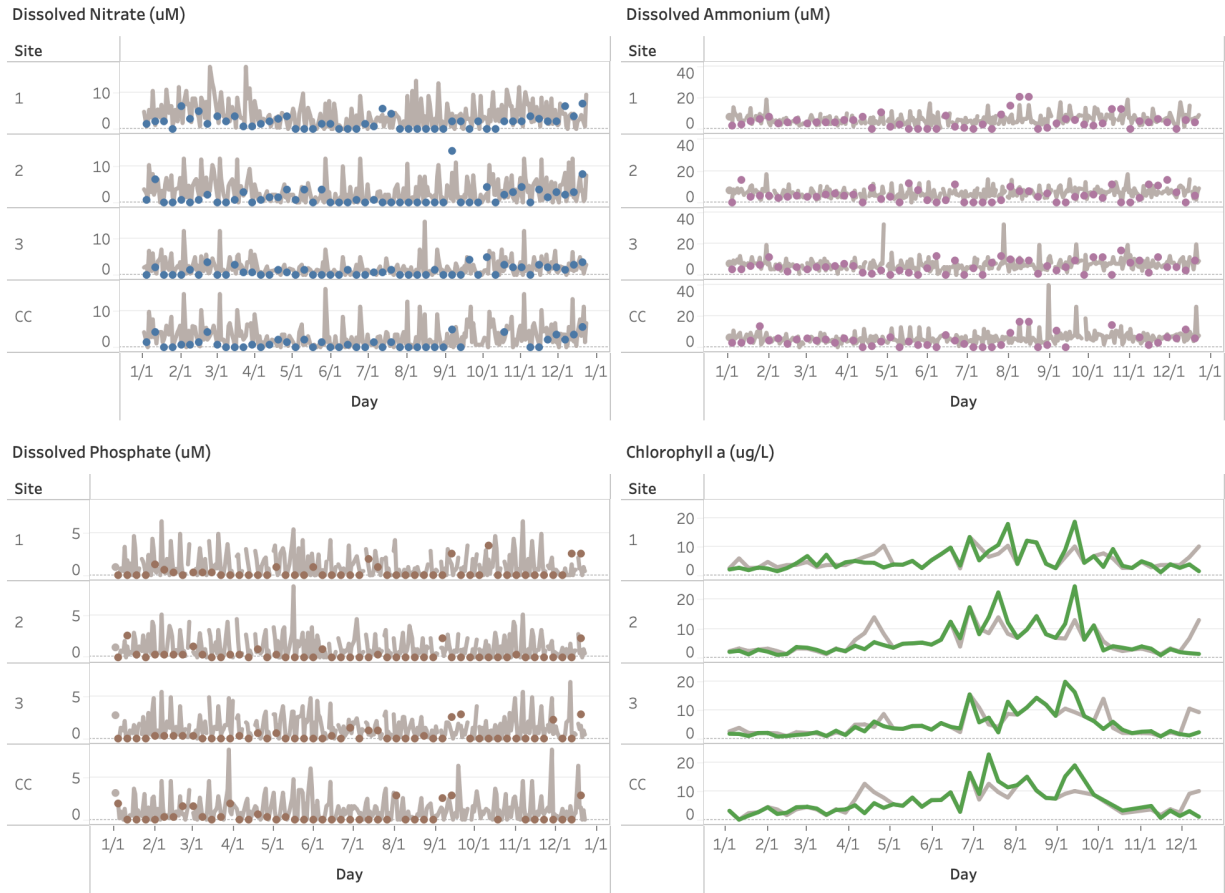
**Figure 2-1. Physical Characteristics 2012 - 2023.**

Comparisons of water quality parameters for 2023 (colored lines) to the average for 2012-2022 (gray line) for a given day of the year. Dashed line for dissolved oxygen indicates the minimum critical concentration (5 mg/L = hypoxia). Water was warmer and saltier than average in 2023, especially in summer. Creek water was hypoxic in late summer/early fall at all sites.





**Figure 2-2. Bald Head Creek Water Quality Data: Nutrients and Chlorophyll 2017 - 2023.** Comparisons of water quality parameters for 2023 (colored dots/lines) to the average for 2012-2022 (gray line) for a given day of the year. Concentrations of all nutrients (nitrate, ammonium, and phosphate) were low in 2023 relative to seasonal averages. Higher nitrate concentrations are found in spring and are associated with Cape Fear River water moving into the creek from downstream (Site 1). Chlorophyll increases with primary production in summer months when there are more hours of sunlight and warmer water. No nutrient or chlorophyll concentrations were outside of recommended water quality standard levels.



**Figure 2-3. Bald Head Creek Water Quality Data: Fecal coliform & E. coli, 2017 - 2023.** Comparisons of bacteria data for 2023 (colored dots/lines) to the average for 2017-2022 (gray line) for a given day of the year. Note that we switched to analysis of *E. coli* from fecal coliforms in 2023. Regulatory limits for Recreation (126 CFU/100 ml) and Shellfishing waters (14 CFU/100 ml) are shown as dashed lines.

