Understanding the Past and Present in **North Carolina's Bay Lakes**

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Just as there are many names for soils, so too are there a variety of names for lake sediments. One name that has stuck with me in the decades since my limnology class is the Swedish word "gyttja." This name came to mind as I pulled up a rake (Figure 1) loaded with the filamentous cyanobacteria *Lyngbya,* and gooey-looking sediment: "Oh, that's gyttja!" (However, I had learned an incorrect pronunciation, "yoot-ya," rather than the correct one, "yit-cha," – I am now straight, thanks to a YouTube video.)

The lakes in North Carolina that I work on were investigated in the late 1940s-early 1950s by limnologist David Frey, who at that time had a position at the University of North Carolina-Chapel Hill. He assessed their similar morphology and shallow depth profiles (Figure 2) and referred to them as a unique lake type that he called "bay lake." He called the organic-rich sediments found in these lakes "pulpy peat," although he also used the term gyttja in later sediment studies.

Figure 1. The rake toss method used to sample submerged aquatic vegetation is a good way to collect the coarse filamentous cyanobacteria Lyngbya*, as well as incidental sediments.*

Lake sediments offer a glimpse of the past

The basic components of sediments are clay, silt, sand, and rocks of various sizes, plus organic matter in various stages of decomposition. The organic matter may originate from the plant and tree life around the lake, or from the algae, plant, and animal life within the lake itself. Therefore, lake sediments can serve as time capsules of the past conditions within and around the lake, since tiny particles such as pollen grains are continually raining down onto the lake surface, gradually settling down to the lake bottom. The deeper you go into lake sediments, the further you go back in time.

Dr. Frey initiated his career-long interest in what is now known as paleolimnology with his studies of the bay lakes, collecting sediment cores from them to identify the kinds of pollen grains buried in sectioned sediment layers. From this painstaking work he concluded that there have been types of trees and other plants present in the past (such as hemlock) which no longer occur in the region, while some types of trees now found were only occasionally found during the time of the last ice age (Frey 1953).

Present-day study of lake sediments as climate archives has been advanced with newer and more sophisticated dating and mapping technologies as well as ways to identify ancient forms of plant and animal life, including the ability to analyze ancient DNA that has been recovered from sediment samples. In addition, rates of sedimentation (the process that causes a lake to become shallower over time) and lake ages can also be more accurately assessed with present-day methods.

Waccamaw's rich lake life depends on the lake bottom

Lake Waccamaw is unique among the blackwater bay lakes because of its geology: It lies in an area with ancient marine limestone deposits that keep its waters near neutral rather than acidic. A recent find of a whale skull in the lake is a reminder that this region was once underwater (Figure 3).

David Frey inventoried the fishes of the bay lakes and found that Lake Waccamaw had substantially greater numbers of fish and greater diversity as well, with several species that were unique to the lake (Frey 1946). Mollusks – snails, mussels, and clams, all of which need calcium to produce their shells – are also abundant in Waccamaw and are absent in the other lakes. The same holds for burrowing mayflies, which hatch from the lake every spring.

Most of the animal life of the lake is dependent on the plants, algae, and organic material associated with the lake's sediments and nutrients. Filamentous algae and submerged vegetation tend to be more abundant during droughts, when the swamp creek input is low, and the water is clearer. During a drought period in 2012, the abundance of submerged aquatic vegetation spiked, and the aquatic weed *Hydrilla* was found mixed in with native vegetation. This invasive species was successfully managed with a seven-year herbicide treatment program.

Lake Waccamaw was designated as Outstanding Resource Waters by the State of North Carolina, because of the special lake life found there. This has conferred

How Did the Bay Lakes Form?

Carolina bays are abundant and distinctive landforms found along the Atlantic Coastal Plain, and their origins have long been shrouded in mystery (formation theories have included depressions created by spawning fish, a meteor shower, or debris from the comet that caused the demise of the dinosaurs). Most of the Carolina bays are presently wetlands with dense vegetation (including three types of bay trees, hence the bay moniker), although some bays have been converted to agriculture. The six bay lakes studied by David Frey are Carolina bays located in Bladen and Columbus Counties, North Carolina (Figure S1-1).

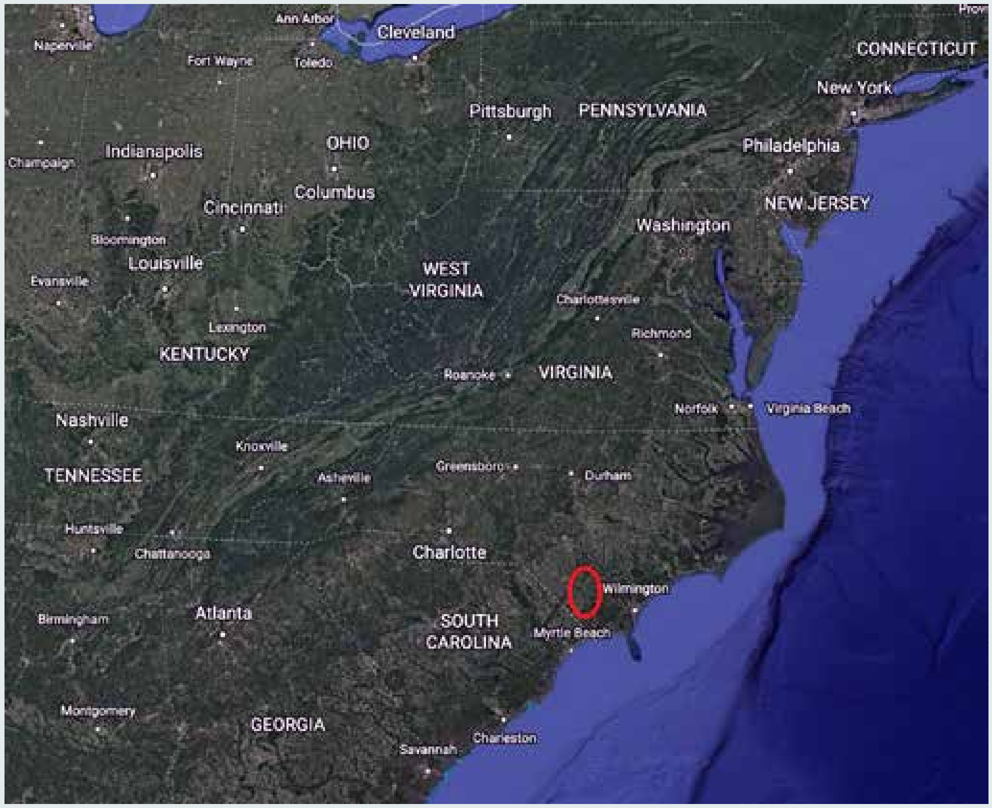

Figure S1-1. Google Earth image showing the location (red oval) of the lakes studied by David Frey.

These bay lakes are situated in elliptically shaped basins which have a NW-SE orientation, due to sculpting by prevailing winds and wave action (Figure S1-2). Frey determined that Lake Waccamaw (left), the largest lake of the group (at 9,000 acres), comprised 91 percent of the area of its bay (with the remainder consisting of wetlands), while Jones Lake (right), the smallest lake of the group (at 225 acres), comprised just 34 percent of the area of its bay (Frey 1953).

Figure S1-2. Google Earth images of two of the bay lakes. Left: 9,000-acre Lake Waccamaw and right: 225-acre Jones Lake.

A 2021 blog posted to the NASA Earth Observatory web site by Adam Voiland and Joshua Stevens, titled "Ice Age Carolinas," refers to Carolina bays as relict thermokarst lakes, with the depressions formed from melting ice and thawing of permafrost soils. The post is based on an interview with U.S. Geological Survey paleogeologist Christopher Swezey, who noted that modern Light Detection and Ranging (LiDAR) data have proved to be ideal for spotting many more Carolina bays than were previously recognized, with most of them likely formed from 40,000 to 11,000 years ago. https://earthobservatory.nasa.gov/images/147904/ice-age-carolinas

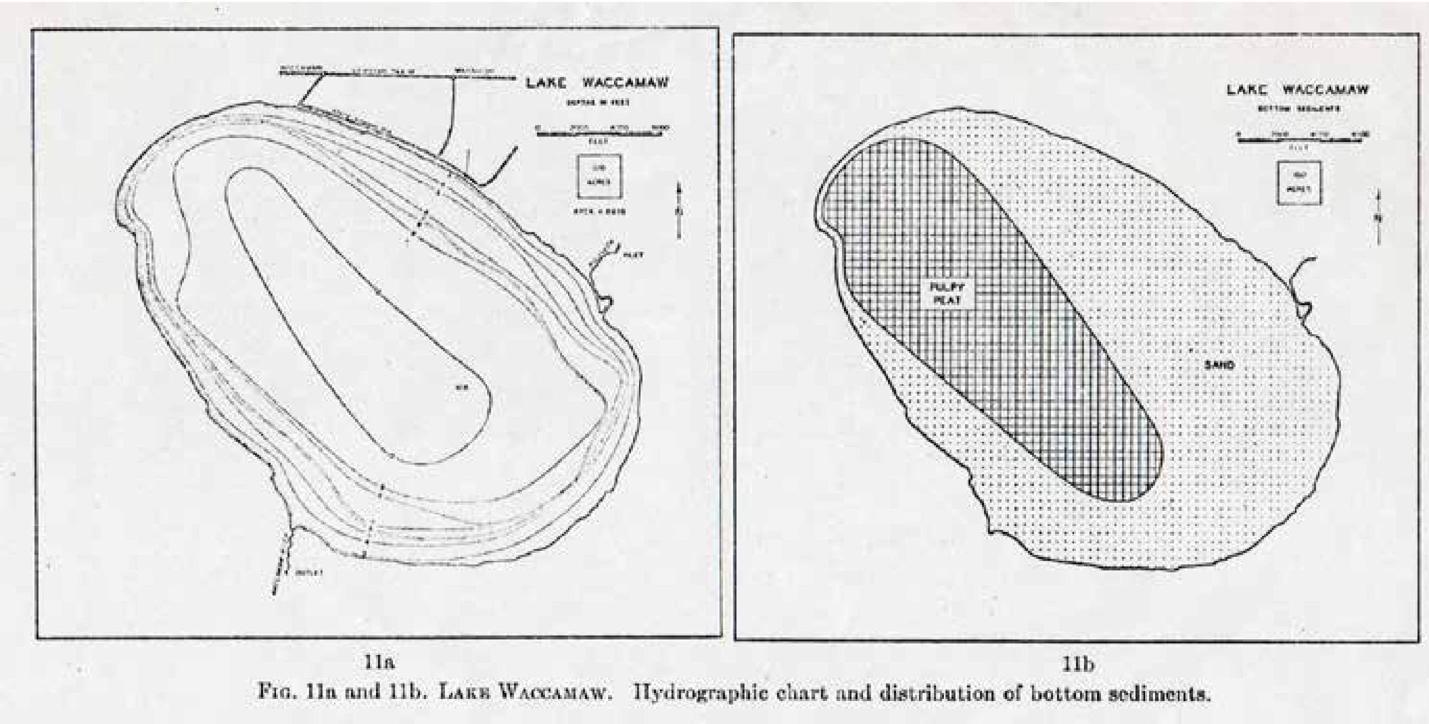

Figure 2. David Frey's maps of Lake Waccamaw, one of the bay lakes: the left map shows depth contours in feet, with the lake inlet, on the SE shore, and lake outlet in the SW; the right map shows the sediment types he found in the lake (Frey 1949).

some protections, including stormwater requirements for the town of Lake Waccamaw, which encompasses two-thirds of the 15-mile shoreline.

Since my first introduction to Lake Waccamaw as a graduate student, I have considered it to be a very special place – because of its origin theories, natural history, cultural history, and the friends I have made there. It is one of several bay lakes that have long been important recreational assets for (mostly) North Carolinians.

Understanding the bay lakes – how they are unique, and how they are changing – is, I believe, best accomplished by comparing them to one another, and it seems that David Frey felt the same way. While he moved on from UNC-Chapel Hill to take a position at Indiana University, he recognized that his early work on these lakes would provide a foundation for future researchers to build upon. It certainly has and will continue to do so.

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Figure 3. Lake Waccamaw State Park's Visitor's Center showcases an extremely rare, 2.75-million-year-old Balaenula whale skull fossil that was found in the lake by a local resident in 2008. Photo courtesy of NC State Parks.

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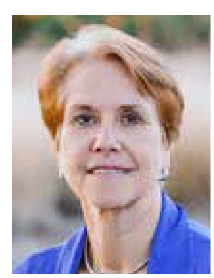

Lake Sediments are a Storehouse for Phosphorus

The nutrient phosphorus (P) is a critical variable in regulating lake productivity, and development of a nutrient budget (an inventory of the sources and their relative importance) is an important initial step in lake management and restoration. Lake sediments contain what is sometimes called legacy phosphorus – the P that has come into the lake from the watershed that eventually winds up in the sediments – and this is often a substantial budget line item.

Can legacy P fuel algae blooms? This is a burning question in lake assessments. Sediment P is generally bound up with other elements such as iron (Fe), aluminum (Al), and calcium (Ca), and these compounds are not "ready P" sources for algae growth (Soluble Reactive Phosphorus, or SRP, is a measure of this form of P). Under certain lake conditions bound, or locked up P can become unlocked, transforming into available P (SRP) (Figure S2-1).

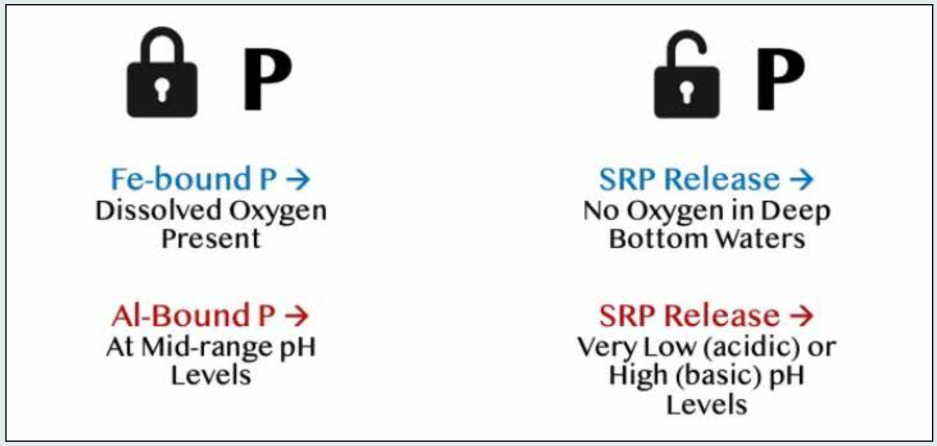

Figure S2-1. Lake chemistry conditions under which sediment phosphorus (P) is locked up compared to conditions which can cause the release of bioavailable, or soluble

Sediment core samples can be sliced into small layers, which can then be analyzed for a variety of constituents, including iron-bound P, aluminum-bound P, calcium-bound P, and Total P. Phosphorus levels are generally highest in the top few inches and decline substantially in lower sections of a sediment core.

In many lakes, iron (Fe) is the primary P binding agent in sediments. In lakes which stratify during the summer, oxygen levels remain higher in upper waters but become depleted in bottom waters. Phosphorus can be released from sediments in its available form (SRP) during this period in a process called internal P loading. Lake management options to reduce its influence include aeration of bottom waters to prevent hypoxia, addition of a different kind of binding agent to keep P locked up (this is called sediment P inactivation), or in very small water bodies such as stormwater ponds, removal of P-rich sediments by dredging.

At this point I am going to circle back to that photo of *Lyngbya* in Lake Waccamaw. There was concern that this nuisance cyanobacteria would spread throughout this shallow lake (although it seemed to wax and wane from year to year, staying in the general area around a boat landing). I wondered whether sediment P inactivation might be more effective as a management tool than algicides (which were being considered), so we collected sediment cores to better understand sediment phosphorus dynamics (Figure S2-2).

Figure S2-2. A sediment core taken from Lake Waccamaw by John Holz and Tadd Barrow in February 2019.

These sediment studies indicated that there was plenty of naturally occurring aluminum in the gyttja/pulpy peat sediments to lock up P, with no SRP release under hypoxic conditions (Lauritsen et al. 2020). Lake Waccamaw is, in essence, a system with natural sediment P inactivation, with >50% of total P bound to aluminum. It is also a very dynamic blackwater system, with fluctuations in lake levels, lake clarity, and lake productivity related to fluctuations in rainfall. The large, dense mats of *Lyngbya* that were once considered problematic have not been seen around the boat landing in the past few years.