

**The Patrick Principle: Ruth M. Patrick, River Ecology and the Transformation of the
Academy of Natural Sciences of Philadelphia, 1935-1975**

by
Ryan James Hearty

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Abstract

Ruth Myrtle Patrick (1907-2013) was a pioneering ecologist and taxonomist whose extraordinary career at the Academy of Natural Sciences of Philadelphia spanned over six decades. She was known especially for advancing an argument that biologist Thomas Lovejoy dubbed the “Patrick Principle,” the idea that the best way to assess the health of an ecosystem is by measuring its species diversity and abundance. Patrick specialized in the study of diatoms, single-celled planktonic algae, and pioneered the use of these widespread organisms as measures of stream pollution. She also devised creative experimental studies to test and refine ecological theories. Although Patrick’s major contributions, the highlights of her career and the discrimination she faced as a woman in a male-dominated scientific world have all been well documented in obituaries, interviews, documentaries, newspaper articles and her own brief memoir, none of these sources has explored her unusual career trajectory in great detail, or explained how she was able to attain such distinction in ecology.

In my analysis of Patrick’s publications, her recently available archival material at the Academy and her correspondence with close advisors, such as George Evelyn Hutchinson, I argue that her role as limnologist, pollution expert and department chair not only shaped her own scientific career, but also transformed the Academy from a struggling natural history museum to one of the leading environmental research centers in the northeastern United States. By working for industries, she funded the Academy while creating research opportunities in the Department of Limnology, which she established in 1948. Leveraging her expertise in taxonomy and ecology, Patrick sustained a synergistic relationship between her applied work on pollution and basic research in river ecology for over three decades.

Primary Reader: Sharon E. Kingsland

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The Patrick Principle: Ruth M. Patrick, River Ecology and the Transformation of the Academy of Natural Sciences of Philadelphia, 1935-1975

She is one of the very few Americans who are completely trusted by both the academic and industrial communities. – G. Evelyn Hutchinson and F. Herbert Bormann, 1972

Introduction

Ruth Myrtle Patrick, who died in 2013 at the age of 105, was a pioneering ecologist and taxonomist whose extraordinary career at the Academy of Natural Sciences of Philadelphia spanned over six decades. She was known especially for advancing an argument that biologist Thomas Lovejoy dubbed the “Patrick Principle,” the idea that the best way to assess the health of an ecosystem is by measuring its species diversity and relative abundance. Patrick specialized in the study of diatoms, single-celled planktonic algae, and pioneered the use of these widespread organisms as measures of stream pollution. She also established her own department at the Academy, as well as two research centers outside of Philadelphia, and devised creative experimental studies to test and refine ecological theories. By 1975, she was a nationally-acclaimed scientist and recipient of the Tyler Ecology Award (now called the Tyler Prize for Environmental Achievement), with prize money that was, at the time, greater than the Nobel Prize. She was also the first woman to chair the board of trustees at the Academy, a testament to how her work had transformed the old Philadelphia museum since she first arrived with her PhD in botany in 1935.

Several recent biographical sketches of Patrick from newspaper articles, obituaries and published memoirs have documented her scientific achievements. These sources emphasize that she mastered the systematics and ecology of diatoms, conducted a

groundbreaking survey in 1948 of the Conestoga Basin in Lancaster County, Pennsylvania, received contracts from potentially polluting industries to conduct more surveys throughout the 1950s and 1960s, and established the field of river ecology. They also emphasize that Patrick achieved all this while working in a male-dominated scientific world.¹ These details are also described in interviews with Patrick, as well as in her own autobiographical memoir from 1997.²

Although these sources describe many of the striking characteristics of Patrick's scientific life, they do not fully explain why Patrick's career had such an unusual trajectory, how she rose to eminence in the field of ecology or what role she played at her home institution. Some sources have even ignored her central role at the Academy. For example, Margaret Rossiter, in her landmark work on the history of American women scientists, stressed only that Patrick was not paid during her first decade at the Academy, and listed her and her husband, Charles Hodge IV, in a table of notable scientist couples. But there is no

¹ Margaret W. Rossiter, *Women Scientists in America: Before Affirmative Action, 1940-1972* (Baltimore: Johns Hopkins University Press, 1995), 244–46; Barbara Mandula, "Ruth Patrick," in *Women in the Biological Sciences: A Bibliographic Sourcebook*, ed. Louise S. Grinstein, Carol A. Biermann, and Rose K. Rose (Westport, CT: Greenwood, 1997); Lisa Yount, "Ruth Patrick," in *A to Z of Biologists* (New York: Facts on File, 2003), 242–43; Sandy Bauers, "The Den Mother of Ecology," *The Philadelphia Inquirer*, February 26, 2007; "Ruth Patrick Inducted into National Women's Hall of Fame," *Limnology and Oceanography Bulletin* 18, no. 4 (2009): 97–97; Robert McCracken Peck and Patricia Tyson Stroud, *A Glorious Enterprise: The Academy of Natural Sciences of Philadelphia and the Making of American Science* (University of Pennsylvania Press, 2012), 324–42; William Dicke, "Ruth Patrick, a Pioneer in Science and Pollution Control Efforts, Is Dead at 105," *The New York Times*, September 23, 2013, sec. U.S., <https://www.nytimes.com/2013/09/24/us/ruth-patrick-a-pioneer-in-pollution-control-dies-at-105.html>; Julie Zauzmer, "Ruth Patrick, Ecology Pioneer, Dies at 105," *The Washington Post*, September 23, 2013; Robert McCracken Peck, "In Memoriam: Ruth Patrick (1907–2013)," *The American Naturalist* 183, no. 2 (2014): ii–iv; John Cairns Jr., "Ruth Patrick 1907–2013," *Bulletin of the Ecological Society of America* 95, no. 1 (2014): 11–13; David Hart, "Ruth Patrick, 1907–2013," *Limnology and Oceanography Bulletin* 23, no. 2 (2014): 54–54; Thomas L. Bott and Bernard W. Sweeney, "Biographical Memoirs: Ruth Patrick 1907–2013" (National Academy of Sciences, 2014), <http://www.nasonline.org/member-directory/deceased-members/51792.html>; Rex Lowe, "Ruth Patrick: The River Doctor," *Limnology and Oceanography Bulletin* 24, no. 4 (2015): 108–11.

² Ruth Patrick, "The Development of the Science of Aquatic Ecosystems," *Annual Review of Energy and the Environment* 22, no. 1 (November 1997): 1–11; "Ruth Patrick," *Hometown Legends* (Philadelphia: WHY-TV, October 29, 2004), <https://video.whyy.org/video/whyy-specials-ruth-patrick/>.

mention of Patrick's unusual expertise, or the fact that she established a Department of Limnology at the Academy in May 1948 to study pollution, or that the department was renamed the Patrick Center for Environmental Research in 1983.

In this thesis, I explore, in much greater detail than previous sources, Patrick's work at the Academy from the 1930s to the mid-1970s and the reasons for her success. I argue that by sustaining the three different roles of ecologist, pollution expert and department chair, Patrick generated knowledge relevant to several different expert communities and, in the process, deeply transformed the Academy from a struggling natural history museum to one of the leading environmental research centers in the northeastern United States. Her work for industry both funded the Academy and created new research opportunities in ecology, toxicology, sanitary biology and environmental management. At the same time, her work in ecology both altered the Academy's philanthropic support system and stimulated new scientific theories. For over three decades, Patrick sustained this synergistic relationship between her applied work and her ecological research.

To understand the middle part of Patrick's lengthy career, from recent PhD to nationally acclaimed scientist, I have drawn heavily from her published works between 1948 and 1970, as well as from her correspondence with George Evelyn Hutchinson, with whom she developed a kind of scientific partnership. Hutchinson, one of the most distinguished ecologists of the twentieth century, would have a significant effect on Patrick's thought, and he supported her work at crucial moments. Patrick's archive at the Academy of Natural Sciences of Philadelphia consists mostly of her correspondence, internal reports and scientific data starting roughly around 1950, and is still being processed and organized. Due

to these limitations, much of our knowledge of Patrick's early life and career at the Academy still depends on her autobiographical memoir and documentary interviews.

Throughout my analysis, I show that several factors contributed to Patrick's success as a scientist and institution builder. Above all, her active intellect and perseverance explain many of her unparalleled achievements. Early in life, she was fascinated by diatoms, and was inspired by her father to pursue a scientific career. After obtaining her PhD in botany, Patrick developed her expertise in two phases: first, through distributional and paleolimnological studies of diatoms and, then, through more theoretical and ecological studies, which were guided by Hutchinson. She and her husband moved to Philadelphia, where the Academy housed one of the largest diatom collections in the world. After a relatively quiet decade at the Academy, Patrick found an opportunity to work with industrial managers by studying how pollution discharged from their plants affected aquatic life. She developed and led a new kind of river survey, one of unprecedented taxonomic and organizational complexity, that studied the effects of pollution not just on one or two organisms, but on the entire aquatic community. Her method slowly changed how experts thought about the problem of industrial waste. Since pollution proved increasingly difficult to manage after the Second World War in the United States, especially in Pennsylvania, there was significant need for river surveys and Patrick quickly rose to become an expert in these studies, some of which were long term, and many of which could also fund basic research.

Academy leaders were initially thrilled by how lucrative these river surveys were, but they soon overwhelmed Patrick, who needed to train and maintain a team of taxonomists and toxicologists. To respond to these demands, she designed a new instrument, the diatometer, that not only made her river surveys simpler and cheaper, but also allowed her to test her

ideas in ecologically diverse regions. She amassed growing evidence for the relationship between ecosystem health and the diversity and relative abundance of species, and gradually gained expertise in river ecology, a relatively unexplored field within limnology. While limnologists had studied lakes since the late nineteenth century, advancing theories and experimental approaches, it was Patrick who pioneered the study of rivers and published her five-volume *Rivers of the United States* throughout the 1990s and 2000s, using the funds from her Tyler Award.³

Patrick's two areas of expertise, river ecology and stream pollution, shaped her scientific life. Her early expertise in diatom taxonomy, the growing influence of Hutchinson's ecological ideas on her thinking, and the Academy's willingness to accept the corporate money Patrick earned for her work all enabled her career to evolve in unexpected ways. We might at first think of the demands of river ecology and stream pollution as competing, the first more basic and academic, the second more applied and industrial, but Patrick found ways to render them compatible. The two sides of her work built upon each other, yielding important new ideas, such as the "Patrick Principle."

Developing Expertise in Taxonomy and Ecology

Patrick developed her expertise in diatom taxonomy from an early age, but her parents disagreed about her future as a scientist. Her father, Frank Patrick, encouraged her interest in the natural world. A lawyer by profession, he had studied biology at Cornell University and loved natural history. He taught Patrick how to identify different species, especially diatoms,

³ Ruth Patrick, *Rivers of the United States, Vol. I: Estuaries* (John Wiley & Sons, Inc., 1994).

which they collected on field expeditions near their home in Topeka, Kansas, and examined together under his microscope. He bought Patrick her own microscope at age seven, when she could identify diatoms by herself, and supported her subsequent scientific education, against the wishes of her mother. While Patrick's mother wanted her to remain local, raise a family and take care of her sister, who had contracted polio, her father wanted her to become an independent scientist. She majored in botany at the co-educational University of Kansas against the wishes of her mother, who persuaded her to transfer to Coker College for Women in Hartsville, South Carolina. With the help of her father, Patrick found summer research opportunities at various institutions in the eastern United States, including Woods Hole Oceanographic Institution and Cold Spring Harbor Laboratory.⁴

During her summers at Woods Hole and Cold Spring Harbor, Patrick received state-of-the-art biological training and made important connections. At Woods Hole, she met her doctoral advisor, botanist Ivey Foreman Lewis, with whom she studied at the University of Virginia from 1929 to 1934. Patrick was one of the few women on the Charlottesville campus at that time, but persevered, she recalled, because of her immense interest in diatom taxonomy and her belief that Lewis was “one of the two most distinguished, if not the best, algae researchers” in the United States.⁵

Lewis introduced Patrick to interdisciplinary research. As a graduate student, Patrick was interested in how taxonomy might inform broader questions in science. She applied her training in diatom identification, especially her knowledge of the distribution of marine and

⁴ Patrick, “The Development of the Science of Aquatic Ecosystems,” 2–4; “Ruth Patrick.”

⁵ Patrick, “The Development of the Science of Aquatic Ecosystems,” 4.

freshwater species, to interdisciplinary studies of long-term geological and ecological change in a given region. With Lewis and one of his other students, Elton Cocke, Patrick studied sediment cores from the Great Dismal Swamp in southeastern Virginia. Cocke had been studying the succession of plant life in the swamp. Whereas his analysis of the fossil pollen provided no clear answers, diatoms supplied the missing link. Patrick discovered an abrupt transition from freshwater to saltwater diatoms between two layers of sediment. She and her colleagues concluded that the coastline was low enough to permit saltwater into the swamp for a period of time. “This piece of work thrilled me,” she later recalled, “because I realized that diatoms could help us interpret what was going on in the larger world.”⁶

Patrick continued her paleolimnological studies the following year. She wrote another article in 1936 that analyzed the diatoms in sediment cores from Great Salt Lake, Utah. Patrick found that the deepest layers of sediment contained only freshwater diatoms, while upper layers contained a varying proportion of freshwater and brackish water forms but never any marine forms. Patrick’s results supported the theory that the Great Salt Lake was originally a freshwater lake and had not connected with the ocean.⁷

Another connection from her summers in the northeast would ultimately lead Patrick to Philadelphia, home of the Academy of Natural Sciences and one of the largest diatom collections in the world. At Cold Spring Harbor, Patrick met her future husband, Charles Hodge IV, whom she married in 1931 while finishing her master’s degree. She kept her

⁶ Elton Cromwell Cocke, Ivey Foreman Lewis, and Ruth Patrick, “A Further Study of Dismal Swamp Peat,” *American Journal of Botany* 21, no. 7 (July 1934): 374. Patrick, “The Development of the Science of Aquatic Ecosystems,” 5.

⁷ Ruth Patrick, “Some Diatoms of Great Salt Lake,” *Bulletin of the Torrey Botanical Club* 63, no. 3 (1936): 157–66.

maiden name out of respect for her father, who wanted “the name Patrick to amount to something in science.” Over the next few years, she split her time between Charlottesville and Philadelphia, where her husband worked as entomologist and professor of biology at Temple University.

In Philadelphia, Patrick worked on her dissertation and attempted to gain access to the Academy’s diatoms. She first wrote to Academy entomologist and secretary James A. G. Rehn in spring of 1934 to request access to their collection, but Rehn ignored her repeated requests. She then wrote to Charles Cadwalader, the Academy’s managing director, who referred her to Thomas Stewart, curator of the Department of Microscopy. It is unclear what ultimately convinced Stewart to accede to Patrick’s requests, but Academy historians Robert Peck and Patricia Stroud suggest that the quality of Patrick’s dissertation convinced Stewart that she was a committed diatom researcher. Patrick officially became a member of the Academy in 1935 and published her dissertation in its *Proceedings* in 1936.⁸

Patrick’s dissertation focused on the distribution of diatoms in the waters near Thailand (formerly Siam) and the Malay Peninsula. Expeditions to that relatively remote region were scarce, and no previous botanists had identified and classified its diatoms. Rather than plan an expensive collecting expedition, Patrick acquired diatoms from existing collections using an ingenious technique. She asked several museums to borrow their tadpole specimens, scraped diatoms from their intestines, and returned them. From the Museum of Natural History in Washington, DC, the Natural History Museum in London and the Raffles

⁸ Patrick, “The Development of the Science of Aquatic Ecosystems,” 4; Zauzmer, “Ruth Patrick, Ecology Pioneer, Dies at 105”; Peck and Stroud, *A Glorious Enterprise*, 300.

Museum of Singapore, she assembled an essentially complete taxonomy for the region. Patrick identified 185 new varieties of diatoms and five new species. She challenged the assumption, common among taxonomists before the 1930s, that any diatom species can be found in similar habitats across the world. She instead argued that “certain forms are confined to definite geographical localities,” and she called for further distributional studies to understand how many diatoms were endemic to specific regions. Since distributional studies might correlate certain diatoms with specific ranges of physical and chemical conditions, Patrick suggested a new area of research: “one might be able to foretell the conditions of the water by the occurrence of certain diatoms.” The relationship between diatoms and their local environment would become Patrick’s major research interest in subsequent years.⁹

When Patrick arrived in Philadelphia, the Academy of Natural Sciences was a century-old natural history museum nearing the end of its golden age of exploration. Its managing director since 1928, Charles Cadwalader, was struggling to keep the Academy solvent in the wake of the Depression. Cadwalader came from an old and well-connected Philadelphia family, and he managed to attract wealthy, amateur naturalists, such as Clement Newbold and George Washington Vanderbilt III, to fund several collecting trips. These trips helped to balance the museum’s budget, which was heavily dependent on stocks and other securities. Cadwalader also updated the museum’s exhibits, which had remained largely the same for almost a century, to attract the public and generate new sources of revenue. He installed several new and exotic dioramas under the guidance of Clarence Rosenkranz, who

⁹ Ruth Patrick, “A Taxonomic and Distributional Study of Some Diatoms from Siam and the Federated Malay States,” *Proceedings of the Academy of Natural Sciences of Philadelphia* 88 (1936): 367–470.

had served as artist for the American Museum of Natural History in New York in the 1920s. Cadwalader also established educational programs for Philadelphia schoolchildren and launched a new popular magazine, *Frontiers*, to highlight Academy activities. Some members criticized Cadwalader's plan. Entomologist Eleanor Carothers claimed that the new dioramas distracted curators from the goals of science and taxonomy. Most, however, went along with these changes. Yet despite his efforts to sustain the Academy through the Depression by creating more public displays, Cadwalader's innovations did not guarantee the museum's survival. In 1932, he had to cut all salaries by ten percent. He restored them in 1936, only after a massive fundraising campaign. For most of the 1930s and 1940s, the Academy's paid staff remained small and its future uncertain.¹⁰

After Patrick gained access to the Academy's vast but disorganized diatom collections, Stewart appointed her curator of the Leidy Microscopy Club, an unpaid and largely peripheral position at the museum. As a botanist with a PhD, Patrick was overqualified for this position, which required that she prepare the tables and benches for the elite Philadelphia men who regularly met and traded amateur knowledge of specimens. But she was also tied to Philadelphia through her husband's work, and volunteering at the Academy ensured her access to its collection of over 25,000 diatom specimens. In 1937, two curatorial achievements endeared her to Academy leaders. First, she organized the collections into a single herbarium using a system of uniform index cards. Second, she arranged a popular microscope display of diatoms for Cadwalader's enormous fundraising

¹⁰ Robert McCracken Peck, "To the Ends of the Earth for Science: Research Expeditions of the Academy of Natural Sciences: The First 150 Years, 1812-1962," *Proceedings of the Academy of Natural Sciences of Philadelphia* 150 (2000): 15-46; Peck and Stroud, *A Glorious Enterprise*, 270-77, 284-86.

event, the International Symposium of Early Man. Partly due to her work in reorganizing the diatom collection and partly for her help at the symposium, Patrick obtained a slightly better, yet still unpaid, position as associate curator in Stewart’s Department of Microscopy, and Cadwalader endorsed her application for a Guggenheim Fellowship.¹¹



Figure 1 – This photograph of Ruth Patrick was taken on 24 March 1937, when she was curator of the Leidy Microscopy Club at the Academy of Natural Sciences of Philadelphia. Although Patrick was overqualified for this position, it gained her access to the Academy’s enormous diatom collections. Photo courtesy of the Historical Society of Pennsylvania Digital Library, ID 4940.

In the late 1930s, Patrick continued her distributional studies and promoted diatoms as valuable to science and industry. She studied diatoms from recent expeditions to Brazil,

¹¹ Marina Potapova, “The ANSP Diatom Herbarium: An Important Resource for Diatom Research,” *Proceedings of the Academy of Natural Sciences of Philadelphia* 160 (November 2010): 5; Peck and Stroud, *A Glorious Enterprise*, 300–301. Although Cadwalader’s letter is saved in the Academy archives, I have been unable to determine the purpose of the grant, which Patrick did not receive.

using methods similar to those she developed for her dissertation. She also wrote about diatoms in *Frontiers* magazine, referring to them as “the useful jewels of the sea.” Patrick listed their many uses, including in dynamite, silver and automobile polishes, long-lasting perfumes and purifiers for beer and sugar. She ended the article by summarizing her own active research program. “Some of them are very specific for the types of environment which they prefer. Thus some species are valuable in water analyses as indicators of specific conditions.”¹²

Patrick continued her interdisciplinary work with diatoms through the early 1940s. From 1940 to 1943, she identified diatoms deposited in lake sediment under the guidance of George Evelyn Hutchinson, an ecologist at Yale University, who was researching the biological history of Linsley Pond near Yale’s campus. Patrick, together with two of Hutchinson’s graduate students, Edward Deevey and Anne Wollack, studied sediment cores from the pond to understand how fossil pollen, diatom communities and chemical concentrations changed over time, and how those changes were related. As her earlier studies demonstrate, Patrick already understood how her knowledge of diatoms could help investigate broad questions of geological change. She had suggested that water conditions might correlate with the species of diatoms present. But until her study of Linsley Pond, she had not worked closely with a water chemist. Wollack’s analysis and Hutchinson’s guidance strengthened her ideas about the relationship between diatoms and their environment.¹³

¹² Ruth Patrick, “Diatoms of Northeastern Brazil. Part I: Coscinodiscaceae, Fragilariaceae and Eunotiaceae,” *Proceedings of the Academy of Natural Sciences of Philadelphia* 92 (1940): 191–226; Ruth Patrick, “Diatoms - The Useful Jewels of the Sea,” *Frontiers*, February 1938.

¹³ Edward S. Deevey, “Studies on Connecticut Lake Sediments, Part I: A Postglacial Climatic Chronology for Southern New England,” *American Journal of Science* 237, no. 10 (October 1, 1939): 691–724; G. Evelyn Hutchinson and Anne Wollack, “Studies on Connecticut Lake Sediments, Part II: Chemical Analyses of a Core

As Patrick's relationship with Hutchinson developed, she pursued more ecological research. She investigated how the presence of certain diatoms correlated with specific physical and chemical properties of the environment, and began a massive literature review that summarized four hundred articles on the sensitivities of various diatoms to light, temperature, salinity, pH, nitrates, phosphates and other chemicals present in water. Despite this ecological turn, Patrick still found opportunities to continue her paleolimnological studies in the 1940s. For example, with another Academy curator, she participated in the first deep-oil tests of the Atlantic Coastal Plain for the Ohio Oil Company, analyzing the diatoms from sediment cores brought from one thousand feet. At conferences, however, she promoted her ecological research, and one of her presentations sparked a serendipitous encounter that greatly affected both her own and the Academy's future.¹⁴

Finding Opportunity

In March 1946, an opportunity arose that would shape Patrick's subsequent scientific career. That month, the American Association for the Advancement of Science met in St. Louis, Missouri, for the first time in two years. The scientific gathering was enormous: forty-one other scientific societies, including the Limnological Society of America, joined at this first postwar scientific conference.¹⁵

from Linsley Pond, North Branford," *American Journal of Science*, Studies on Connecticut Lake Sediments, 238, no. 7 (July 1, 1940): 493–517; Ruth Patrick, "The Diatoms of Linsley Pond, Connecticut," *Proceedings of the Academy of Natural Sciences of Philadelphia* 95 (1943): 53–110.

¹⁴ Ruth Patrick, "Factors Effecting [sic] the Distribution of Diatoms," *Botanical Review* 14, no. 8 (1948): 473–524.

¹⁵ George H. Lauff, "A History of the American Society of Limnology and Oceanography," in *Limnology in North America*, ed. David G. Frey (University of Wisconsin Press, 1963), 672.

Patrick's presentation, on diatoms as indicators of the chemicals present in a body of water, attracted the attention of William B. Hart, a toxicity expert who managed the Waste Control Laboratory of the Atlantic Refining Company of Philadelphia. Hart was investigating the effects of oil industry wastes on freshwater fish. To this end, he had devised a "toxicity evaluation method," which placed fish in test solutions of river water with varying concentrations of a given pollutant and determined the "median tolerance limit," or the concentration at which half the fish died and the other half survived. This became a widely accepted procedure for evaluating the toxicity of wastewater.¹⁶

Despite the positive reception of his method, Hart saw value in Patrick's proposal that diatoms were indicators of water conditions. According to Patrick, Hart "cornered" her at the AAAS meeting and asked for her help. He intended to enlist not just Patrick but other members of the Limnological Society, and offered financial support from his company. Patrick wrote to Hutchinson for advice, expressing some interest in the idea: "[Hart] said that not only would this be of great service to oil companies, but would also net a good deal of money for the individuals involved or for the Society as a whole to have the support of the oil company for this work."¹⁷

Hart sought help from Patrick and the Society because his company was involved in a lawsuit over the effluent from one of its refineries. By 1946, lawsuits over water pollution were common in Pennsylvania, one of the largest industrial producers in early twentieth-

¹⁶ William B. Hart, Peter Doudoroff, and John Greenbank, *The Evaluation of the Toxicity of Industrial Wastes, Chemicals and Other Substances to Fresh-Water Fishes* (Waste Control Laboratory of the Atlantic Refining Company, 1945).

¹⁷ Ruth Patrick to G. Evelyn Hutchinson, April 12, 1946, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers, Sterling Memorial Library, Yale University, New Haven.

century America. Coal mines, steel mills, pulp and paper mills, tanneries, distilleries, canneries, milk plants, textile mills, dye houses and petroleum industries all dumped their effluent into local streams and rivers. As cities and towns grew, more untreated sewage entered local waterways. These industrial and municipal wastes threatened the water supply and livelihoods of thousands of residents, a problem that officials handled with legislation and monitoring of water quality. The Purity of Waters Act of 1905 authorized the state's Department of Health to control sewage discharge. In 1923, the department assembled a Sanitary Water Board to monitor and reduce stream pollution throughout Pennsylvania. The Stream Pollution Control Act of 1937 further authorized the department to monitor industrial wastes.¹⁸

This increased attention to pollution led to more legal disputes between Pennsylvania's government, utilities and industries. For example, *West Penn Water Company v. Sunnyhill Coal Co.*, lasted from April to September 1945. West Penn supplied drinking water to eight thousand residents of Allegheny and Washington Counties. Sunnyhill began mining operations in 1942 and in 1944 released ten million gallons of mine water into the local supply. Mining had irrevocably altered the landscape and rendered the water supply undrinkable. After much legal wrangling, the two companies reached a half-million-dollar settlement that allowed West Penn to develop a new water supply.¹⁹

Hart hoped that his toxicity evaluation method could prove that his company's effluent was harmless, but he ran into a problem. Although fish survived in his laboratory

¹⁸ Russell E. Teague, *Protection of Streams against Pollution: The Pennsylvania Plan* (Symposium on Stream Pollution and Industrial Wastes: American Association for the Advancement of Science, 1950).

¹⁹ Francis J. Gafford, "Antipollution Measures in Pennsylvania," *Journal (American Water Works Association)* 41, no. 4 (1949): 309–14.

tanks filled with river water, some developed a fungal infection. It appeared that the effluent was not, in fact, safe. The infection caused “considerable concern,” he wrote to Patrick, and “the one way this could be answered properly would be a survey of these waters to establish that they constitute a normal shore region habitat for that particular section of the country.” He also hoped that “the Limnological Society could function, for a fee, and tender an unbiased report on their findings.”²⁰

Patrick expressed interest in Hart’s plan to Hutchinson, who was recently elected president of the Limnological Society, but Hutchinson hesitated to involve himself or the Society in applied work. Patrick wrote to him in July 1946 and clarified her vision, which involved using the available funds to simultaneously conduct basic research:

Of course, I am naturally more interested in pure research than I am in applied science. However, I do feel that through this medium money might be secured for various projects[,] if they were well organized[,] that are of a pure research nature. If you would like to have a more definite plan from [Hart], as to funds available and problems of research, I shall be glad to ask him to formulate such a plan.²¹

Patrick was much less bothered by the prospect of industry-funded research. Months later, Hutchinson answered that he was “extremely uncertain what to do” on “the question of applied limnology,” and “well aware of the dangers which might be inherent in such a scheme.”²² He may have felt that by accepting corporate funds, even if its bylaws allowed it, the Society would compromise its scientific reputation. Hutchinson suggested they discuss

²⁰ W. B. Hart to Ruth Patrick, June 28, 1946, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

²¹ Ruth Patrick to G. Evelyn Hutchinson, July 8, 1946, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

²² G. Evelyn Hutchinson to Ruth Patrick, October 28, 1946, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

the matter at the next Society meeting in late December, and agreed to meet with Hart. Patrick was ill and could not attend, and there is no indication that the Society took up the offer of outside pay for stream pollution research.²³

With no foreseeable help from the Society, Hart approached Patrick and the Academy. By December 1947, he was less interested in the particular lawsuit from 1946 than in long-term pollution abatement, using new methods that Patrick had proposed to him in their conversations. Since he met Patrick in St. Louis, he visited her several times back in Philadelphia, and was convinced that she had important ideas about how to study pollution.

Hart was well-connected to circles of influence in both the Philadelphia corporate world and Pennsylvania's state government. In addition to running Pollution Abatement Activities for Atlantic Refining, he was also chairman of the Stream Pollution Committee of Oil Industries of America and president of the Pennsylvania Chamber of Commerce. He had persuaded the state's Sanitary Water Board to develop standards of stream health as part of a larger state anti-pollution campaign. Using his connections, Hart raised \$65,000 (about \$700,000 today) for Patrick to design and lead a new kind of river survey that might determine the effects of various pollutants on aquatic communities.

The Academy needed the money, but Cadwalader, then president at the Academy, wanted someone other than Patrick to lead the survey. According to Patrick's memory of these events, Cadwalader was "horrified" that if Patrick managed the funds and personnel

²³ Ruth Patrick to G. Evelyn Hutchinson, December 27, 1946, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers. There is some evidence that Hart and Patrick influenced the Limnological Society of America, which formed a Committee of Ecological Effects of Waste Disposal in 1955. The committee dissolved after a year. Its three members (Patrick, John Lyman and Clifford E. ZoBell) were all part of the larger National Advisory Committee, which included Hart from 1951 to 1954. See Lauff, "A History of the American Society of Limnology and Oceanography," 680.

involved in such a large-scale pollution study, she would just “waste money.” Cadwalader eventually relented at Hart’s insistence, but wanted assurance that Patrick would not endanger the new relationship. He enlisted Charles Stine, a top manager from E. I. Du Pont de Nemours and Company and Academy trustee since 1941, to watch over her work.²⁴

Although Stine knew little about limnology, Patrick remembered his perceptive questions, which encouraged her to form an informal “advisory committee” to assist her with the technical details of the survey. This committee consisted of Hutchinson and three other scientists: Arthur D. Hasler, a professor of limnology at the University of Wisconsin; Villiers W. Meloche, a water chemist at the University of Wisconsin who worked with Hasler and shared an interest in diatoms; and Ernest A. Lachner, an ichthyologist at the Smithsonian’s National Museum of Natural History, who had conducted river surveys in New York. With the help of these scientists, Patrick convinced men like Cadwalader and Stine that she could manage the river survey. Their confidence in her grew over the summer and fall of 1947, and by early 1948 Patrick began preparations for the survey.²⁵

Leading a New Kind of Survey

In early 1948, Patrick mapped out her survey and assembled a team of both young and experienced scientists, from within and outside the Academy. With the help of a geologist, and with a map provided by the Sanitary Water Board of industrial sites in the region, she identified 170 collection stations within the Conestoga Basin to the north and east of

²⁴ Patrick, “The Development of the Science of Aquatic Ecosystems,” 7. The story about Cadwalader was repeated by David Hart, who began working in Patrick’s department in the mid-1980s; see Hart, “Ruth Patrick, 1907-2013.”

²⁵ Mandula, “Ruth Patrick.”

Lancaster, Pennsylvania, where measurements would be taken. She used Hart's money to hire graduate students for the meticulous work of collecting specimens. Senior curators from the Academy, such as ichthyologist Henry Weed Fowler and malacologist Henry Augustus Pilsbry, would help with the more difficult identifications. She also assembled a team of specialists from outside the Academy, which included her "advisory committee," to serve as scientific consultants.

Patrick wanted the Academy to recognize the legitimacy of her survey work and the extensive management it required, so she convinced managing director H. Radclyffe Roberts to establish a new Department of Limnology in May 1948, with Patrick as chair. Some of the graduate students she hired that summer, such as John H. Wallace and John Cairns, Jr., became the department's first full-time staff after the survey. The justification for this new department might have been partly mundane and bureaucratic, since these new staff would need some location within the Academy organization for accounting purposes. But it also gave Patrick the legitimacy she sought and carried the expectation to conduct more surveys.

As she worked through the logistics of the survey, Patrick continued to develop and articulate the more theoretical aspects of the survey. Patrick's approach was based on a biological measure of a stream's health, namely the diversity and abundance of species. She got this idea from the German limnologist August Thienemann, who had written an article on this subject in 1939, arguing that optimum environments supported large numbers of species with relatively small populations. Another influence was Robert Earl Richardson, who studied river pollution from 1913 to 1928 for the Illinois Natural History Survey, and had identified certain species as more or less tolerant of a given pollutant. Richardson had

collected more taxa within the aquatic community than other biologists, who often concentrated on one or two taxa, such as fish or invertebrates.²⁶

Patrick's idea of the biological survey developed not just from knowledge of these predecessors, but also from what she already knew about diatoms: different species were sensitive to different environmental conditions. There were saltwater, brackish and freshwater species of diatoms that thrived in each of those environments. Some diatoms could withstand certain industrial pollutants, or the nitrogen-rich runoff from farms, while others were weakened by the presence of such chemicals. Without any pollutants, as in a natural stream, diatom communities tended to be diverse, with many species competing for limited resources and each species held in check by others. Exposed to a certain pollutant, less tolerant diatoms died while tolerant ones survived. A particular distribution of diatoms indicated the presence or absence of a pollutant: many species, each with a relatively small number of individuals, indicated a "healthy" stream, while few species, each with many individuals, indicated an unhealthy one. The river survey would test this idea not just for diatoms, but for the entire aquatic community of algae, bacteria, protozoa, fish, insects and other invertebrates. This required the taxonomic expertise of a multidisciplinary team that the Academy, with its departments of fish, mollusks and entomology, was uniquely capable of providing.²⁷

²⁶ August Thienemann, "Grundzüge Einer Allgemeinen Ökologie," *Archiv Für Hydrobiologie* 35 (1939): 367; Robert E. Richardson, "Changes in the Bottom and Shore Fauna of the Middle Illinois River and Its Connecting Lakes Since 1913-1915 as a Result of the Increase, Southward, of Sewage Pollution," *Bulletin of the Illinois Natural History Survey* 14 (December 1921): 33-75. For a contemporary survey that used far fewer taxa to assess stream pollution, see Arden R. Gaufin and Clarence M. Tarzwell, "Aquatic Invertebrates as Indicators of Stream Pollution," *Public Health Reports* 67, no. 1 (1952): 57-64.

²⁷ Patrick, "Factors Effecting [sic] the Distribution of Diatoms," 500; Ruth Patrick, Matthew H. Hohn, and John H. Wallace, "A New Method for Determining the Pattern of the Diatom Flora," *Notulae Naturae of the Academy of Natural Sciences of Philadelphia*, no. 259 (July 21, 1954).

At this point, Patrick's definition of "health" was an ecological one, based on the ability of a stream to sustain a range of species. "A 'healthy' stream," she wrote in a prominent sanitary engineering journal just after the Conestoga Basin survey, "is one which has a balance of organisms or in which the biodynamic cycle is such that conditions are maintained which are capable of supporting a great variety of organisms." This would have struck sanitary engineers as strange, and Patrick was the first in that journal to introduce the idea that a stream, rather than humans or fish, could be healthy. After she introduced the term, sanitary engineers slowly began using it, citing Patrick. They also broadened its scope to imply that water from a healthy stream was, after treatment, fit for human consumption. But Patrick was not, at first, concerned with human health.²⁸

In addition to selecting sites and assembling her team, Patrick also developed a specific procedure to monitor each station in the Conestoga Basin. Water chemists and bacteriologists analyzed stream samples using standard methods defined by the American Public Health Association, while the team collected specimens using traps, seines, scrapers, plankton tows, dredges and aspirator bottles. Patrick split her team into two groups, each consisting of an algologist, protozoologist, invertebrate zoologist, entomologist and ichthyologist. They bottled specimens at each station and brought them back to laboratory space that the Academy leased from nearby Franklin and Marshall College. If neither her team in the field nor the curators back at the Academy could identify a specimen, Patrick

²⁸ Ruth Patrick, "Biological Measure of Stream Conditions," *Sewage and Industrial Wastes* 22, no. 7 (1950): 930; Harald W. de Ropp, "Chemical Waste Disposal at Victoria, Texas, Plant of the Du Pont Company," *Sewage and Industrial Wastes* 23, no. 2 (1951): 194–97. See, however, my discussion in the next section of Patrick's letter to Paul Sears, written in 1953, where she expresses the value of her work from the perspective of human consumption of water as a resource; Ruth Patrick to Paul Bigelow Sears, November 16, 1953, MS 649, Box 41, Folder 651, Sterling Memorial Library, Yale University, New Haven.

mailed it to one of the consultants in her extended academic network. With this efficient organization, Patrick completed the massive survey in less than a year and published her results by December 1949 in the *Academy Proceedings*.²⁹



Figure 2 - Ruth Patrick and her team for the Conestoga Basin survey, Lancaster County, Pennsylvania, 1948. Left to right: Charles Wurtz, James Jones, Herbert Levi, Ruth Patrick, Mary Gojdics, John Cairns, Sarie Lynn Carter, John Wallace, John Rehm, and Thomas Dolan, IV. (The man behind the truck is unidentified.) Photo Courtesy of Academy of Natural Sciences of Philadelphia.

Patrick conveyed the survey results with an innovative graphical method, which translated complex taxonomic lists into a format that would better serve her broad audience.

²⁹ Ruth Patrick, "Why Study a Stream?," *Frontiers*, October 1948, 25, Academy of Natural Sciences of Philadelphia. Ruth Patrick, "A Proposed Biological Measure of Stream Conditions, Based on a Survey of the Conestoga Basin, Lancaster County, Pennsylvania," *Proceedings of the Academy of Natural Sciences of Philadelphia* 101 (December 27, 1949): 277–341.

She knew that government officials and industrial managers needed a quick and simple way to determine whether a stream was polluted. Whereas the biologists on earlier stream surveys had compiled and published their results as long lists or tables of species, Patrick visually represented the number of species found at each station on a particular day using a histogram (Figure 3). She divided all species of aquatic organisms into seven groups, based on their similar sensitivities to certain ecological conditions, such as change in temperature or nutrient enrichment. These groups represented the seven columns along the horizontal axes. Patrick and her team sorted the species found at each station into one of these seven taxonomic groups.

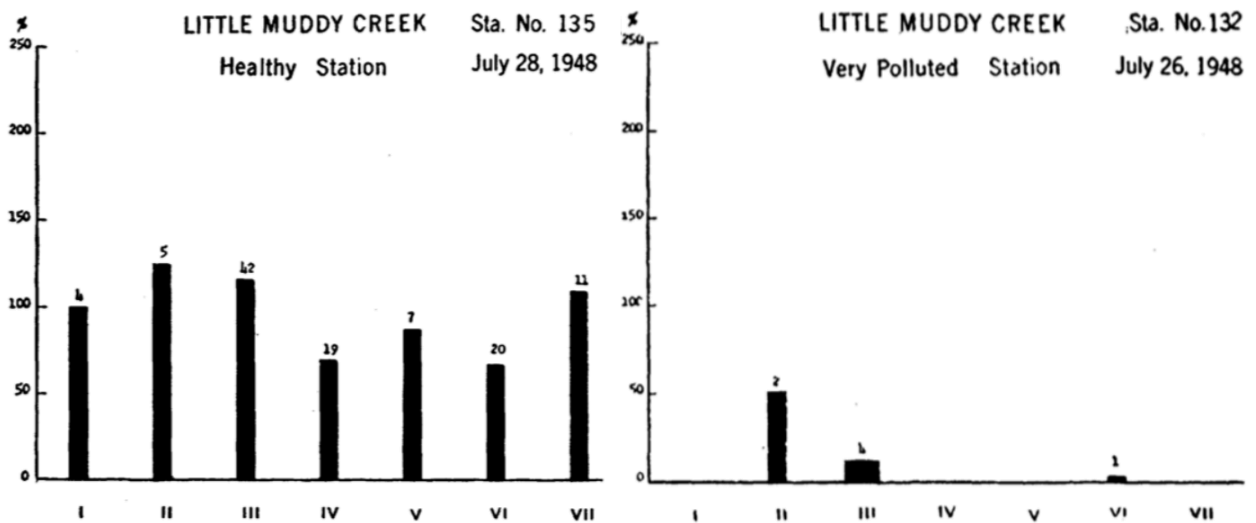


Figure 3 – Patrick displayed her results from each station as histograms, graphically representing the “balance of life.” The x-axis showed seven species groups, which Patrick defined based on their similar sensitivities to certain pollution, such as nitrates or sewage. The y-axis represented the number of species at a given station, expressed as a percentage of those expected at a typical, healthy station, a standard based on average species counts for each group across nine unpolluted stations. The numbers above each column represented the total species count found for that group at the station. At healthy stations (left), all seven groups had numbers of species relatively close to the standard. At polluted stations (right), the number of species in one or more groups diverged substantially from the standard, and some columns were missing altogether.

Although Patrick noted the total number of species above each column, the column heights did not represent these species counts. Instead, the y-axis indicated the percentage, or

ratio of the total species in a group found at the station to the number expected for that group at a typical, healthy station.³⁰ This scaled the column heights so that they could be compared: she explained that “the important consideration is the relative heights of the various columns to each other, rather than the absolute height of any one column.”³¹ Although the details of this method may seem overly complicated, Patrick intended them to simplify the process of reading the histogram; the condition of a stream could be read off the plot by comparing the relative heights of the seven columns. The histogram captured the structure of the aquatic community and served as a snapshot of stream health. For example, the healthy station in Little Muddy Creek showed that all groups of species were present, and all seven column heights were relatively similar. All seven columns were relatively close in height to one another. In the polluted station in the same creek, only three groups were present with far fewer species than expected at a typical, healthy station. The histogram conveyed what Patrick called the “balance of life” that sustained aquatic communities in the absence of pollution. By visually representing the life at each station in terms of the histogram, Patrick captured how pollution affected the entire structure of the aquatic community.

In conveying her results, Patrick had to show that her biological measure improved upon standard methods. By 1950, three different approaches were used to assess the health of rivers across the United States. First, certain physical and chemical properties had long been associated with healthy and polluted rivers, such as pH, temperature, conductivity, turbidity, dissolved oxygen, carbon dioxide, phosphorous and nitrogen. Patrick argued that physical

³⁰ Patrick defined the typical, healthy station by selecting the nine healthiest stations based on all the collected chemical, bacteriological and biological data and then averaging the number of species for each group.

³¹ Patrick, “Biological Measure of Stream Conditions,” 930.

and chemical analyses were, by themselves, inadequate. For each station Patrick surveyed, her chemist, John M. Ward, measured these properties. Patrick showed that they varied widely, even among the healthy or polluted stations. They also varied over time, so that a station with healthy properties now might have formerly experienced a temporary wave of pollutants that wiped out aquatic life. Chemical analysis might fail to capture these devastating events.

Second, sanitary engineers measured the biochemical oxygen demand and counted coliform bacteria in effluent before it entered a stream. Patrick argued that these methods, though valuable for sanitary wastes, failed to predict the toxic effects of chemicals on aquatic life. Most of the polluted streams she surveyed in the Conestoga Basin contained toxic effluent from industrial plants.³² To understand pollution, moreover, one needed to measure the life in the river, not the effluent entering into it.

A third standard method, and the one favored by most biologists, was based on so-called “indicator species.” The indicator species approach depended on the observation that certain species proliferated in certain habitats, whether natural or polluted, and so their presence or absence may serve as an indicator of the water conditions. For example, *Sphaerotilus* grew rapidly in sewage. This approach also tended to prioritize commercially important taxa, especially fish, and Hart’s toxicity evaluation method was based on the indicator species approach. Many sanitary biologists and toxicologists hoped to learn as much as possible about the environmental requirements or tolerance thresholds of a certain

³² The increasing complexity of the chemical landscape in postwar United States meant that these methods were challenged on a national scale, not just in Pennsylvania and not just by Patrick. See Martin V. Melosi, *Precious Commodity: Providing Water for America’s Cities* (University of Pittsburgh Press, 2011), 67–71.

valuable species. Patrick thought this approach had one major flaw: the organisms might tolerate some forms of pollution but not others, and the list of toxic chemicals was growing every year. Her approach had the advantage that any form of pollution would likely affect at least one of the seven groups of taxa and, since the rise or decline in its population would affect the other taxa, the effects of the pollution would spread through the aquatic community and show up on the histogram.

Patrick explained her method in terms of the biodynamic cycle, an expression of the interdependence of all life in an aquatic community. To Patrick, pollution altered this cycle, so the most direct way to measure pollution was to measure changes in the number and relative abundance of species in the aquatic community. It was an ecological view that both challenged the indicator species approach and its reductive reliance on laboratory tests, and warranted her holistic, taxonomic alternative. The metaphor of the food chain also expressed this interdependence:

This food chain does not consist, however, of a single series of links, but rather of a series of chains that are sometimes interlinked. Thus, pollution may break one series of links, yet not completely destroy the chain. It is only when pollution is extreme that the chain is completely broken and the higher forms of life are completely eliminated. Thus, when one is concerned with the problems of waste disposal and river conservation, he must concern himself with the whole pattern of life in the river rather than just one group; for example, the fish.³³

³³ Ruth Patrick, "Aquatic Organisms as an Aid in Solving Waste Disposal Problems [with Discussion]," *Sewage and Industrial Wastes* 25, no. 2 (1953): 210–11.

Patrick stressed the ecological relationships between species, not just their presence or absence. By selecting only certain species in this chain, proponents of the indicator species approach could only approximate the effects of pollution in a stream.

Through the Conestoga Basin survey, Patrick tested a new idea, developed a new river survey method and secured a vast academic network. She posited a relationship between biological diversity and the health of an ecosystem, the first articulation of what would later be called the “Patrick Principle.” She demonstrated the effectiveness of a multidisciplinary river survey to measure pollution. To achieve this, she first needed to convince powerful members of the Academy, especially Stine and Cadwalader, that she was capable of leading a large team and managing a significant amount of money. Patrick formed an extensive network, within and outside the Academy, that included several limnologists and taxonomists across the US. Her connections could help her with different aspects of the survey or provide graduate students for summer work. These students, the majority of her survey team, collected specimens in the field and identified them in the laboratory. They were committed and enthusiastic, and some continued to work for the meager salaries Patrick could provide during the first years of her department. Their advisors could also assist in the survey either by helping with identifications or by supervising their students’ work.

The innovative aspects of Patrick’s approach can be appreciated by examining some criticisms made in 1952 at a conference of the Federation of Sewage and Industrial Wastes Associations by two other stream pollution specialists, Arden R. Gaufin and Clarence M. Tarzwell. Gaufin and Tarzwell had recently conducted a river survey of their own but collected far fewer taxa. While Patrick measured most major taxa present at each station, except fungi and flowering plants, Gaufin and Tarzwell counted the number of individuals of

a select group of macroinvertebrates and conveyed their results as long lists of present or absent species. They argued that a small set of indicator species sufficed to determine the presence of pollution: “pollutional organisms must be found and clean-water species must be missing in delineating the zones of pollution in a stream.”³⁴

In their discussion of Patrick’s work, it was clear that they not only viewed her approach as too complicated and hence too expensive, but also saw little value in the ecological method she was advocating. For example, they argued that most biologists can tell whether a stream was polluted without collecting all the species present. They also cited rivers in Colorado and Utah that contained few species but were perfectly healthy. While Patrick acknowledged that a well-trained biologist could tell the difference between a healthy stream and a polluted one, she argued that only her method was capable of showing definite, quantitative trends over time. Although Colorado rivers may have fewer species, her results were consistent across any two ecologically similar regions, such as two rivers in Pennsylvania or two in Colorado: pollution affected the biodynamic cycle similarly within each region.³⁵

Patrick’s survey was the first extensive study that linked the number and relative abundance of species in a river to its water quality and overall health. It also began Patrick’s decades-long connection with industries that would fund her new department. Some, such as Hutchinson, would have called her work “applied limnology.” From this perspective, the Academy’s taxonomic studies and the survey work for the Sanitary Water Board were two

³⁴ Gaufin and Tarzwell, “Aquatic Invertebrates as Indicators of Stream Pollution,” 63.

³⁵ Patrick, “Aquatic Organisms as an Aid in Solving Waste Disposal Problems,” 214–17.

separate things—one basic, the other applied. Patrick saw things quite differently. In her letter to Hutchinson, she expected the applied work could fund basic science, which is what she said she really cared about. From another perspective, however, Patrick's idea to link diversity with water quality was valuable both as basic and as applied knowledge. It uncovered fundamental ecological relationships in rivers that no one had explored before. Pollution could be understood ecologically as a stress on the aquatic community, and Patrick's idea suggested a relationship between that stress and the community structure. This second perspective, which may have taken Patrick herself some time to appreciate, was even stranger for many of Patrick's contemporaries. The mixed reception of Patrick's survey back at the Academy implied that some were not comfortable with either of these perspectives.

Building Connections and Managing Growth

After the 1948 survey, Patrick crafted the river survey into the main service of her department that would not only bring independent funding, but also provide research opportunities for her and her staff. Despite the success of the Conestoga Basin survey of 1948, Patrick and her supporters at the Academy still faced three significant hurdles: they needed to fund and build a new laboratory, grow their corporate connections and hire new staff. With the help of crucial supporters, including Hart, Hutchinson, Roberts and DuPont executives, Patrick overcame these problems. This section examines how Patrick built upon the success of the 1948 survey, balanced her different roles as curator, ecologist and pollution expert, and attracted and maintained a staff of mostly young assistants.

Even before the Conestoga Basin survey had ended, Patrick, Hart and Academy leaders Cadwalader and Roberts succeeded in procuring laboratory space for the new

department. In October 1948, Patrick outlined her vision for a new laboratory to the board of trustees, who agreed unanimously to begin raising the required funds. This achievement was significant, given that the board at the time included old Philadelphia elites, such as Cadwalader; Academy naturalists of an earlier generation, such as 79-year-old John Percy Moore; older Academy members who had been leading academic zoologists, such as 84-year-old Edwin G. Conklin (who had been on the faculty of the University of Pennsylvania and Princeton University); a younger generation of naturalists, including ornithologist Rodolphe Meyer de Schauensee; and local businessmen, including Brandon Barringer and Cary W. Bok of Curtis Publishing Company—all of whom were present to pass the resolution supporting the growth of Patrick's department, alongside her steadfast supporters, Hart and Roberts. By the end of 1949, with some small donations and a large contribution from R. R. M. Carpenter, a DuPont executive and another trustee of the Academy, Roberts converted rooms from the old and struggling Department of Mineralogy into a new state-of-the-art laboratory.

In addition to new laboratory space, Patrick needed corporate contracts to bring in new staff. The Sanitary Water Board was so impressed by Patrick's survey that they continued funding the department through 1949. That same year, Patrick worked for the Freeport Sulphur Company, who was accused of polluting the local oyster populations in Freeport, Louisiana. Hart worked his connections within the oil industry and convinced the American Petroleum Institute to fund Patrick's studies for the next five years. Hutchinson supported Patrick's ideas in letters to Roberts, convincing him that Patrick's work for these industries was still legitimate science. In 1950, Patrick brought in a three-year contract from the US Public Health Service, the first federal contract, and one of two her department would

receive before 1957.³⁶ Roberts described even more progress at the Academy's annual meeting in February: "we are studying methods for controlling the carrier, an aquatic snail, of the tropical disease called schistosomiasis, for the Pennsylvania Salt Manufacturing Company; we are studying the poisoning effect of certain chemical wastes on our streams for a number of gas and electric companies." The list of companies was growing so fast that there was hardly any reason to name each one. Many of the first companies to sponsor Patrick's new department had close relationships with the Academy; for example, board member Richard L. Davies was the president of Pennsalt. For the next decade, the advances of Patrick's department would dominate discussions not only at the annual meetings, but at the monthly board meetings as well.

Although Hutchinson, Hart and Roberts all helped obtain funding for the young Limnology Department, Patrick was ultimately the one responsible for sustaining its corporate relationships. The difficult question of how she would continue pursuing basic research in light of this new work remained unresolved. Despite Patrick's growing sense that her young department would depend on corporate money, she developed a capacious vision of scientific work. As pollution expert, Patrick advertised three kinds of services. First, she offered baseline surveys to establish the condition of a river before a plant opened. In 1953, Patrick wrote to one industrial scientist, Eugene D. Crittenden of Allied Chemical and Dye Corporation, that "often a river has been damaged, and state authorities are unaware of the condition, and later blame the company for conditions which they have not produced." She

³⁶ The other federal grant, \$31,500 over three years, 1953 to 1956, was from the National Science Foundation, and supported Patrick's reference work on the diatoms of the United States (award #5300256). The vast majority of the Limnology Department's federal grants were from the late 1960s to the early 1970s. See E. L. Anderson, "The Academy of Natural Sciences of Philadelphia, Division of Limnology and Ecology, Summary of Work Performed, 1950 Thru 1977," September 1, 1978, Ruth Patrick Papers, Box 27, Folder 50.

sold this kind of method as “insurance against further accusations.” Second, the river survey could assess new waste disposal systems that companies recently installed. DuPont designed a new facility at their plastics plant on the Guadalupe River, and cited the Academy survey that convinced them of its efficacy.³⁷ Third, a pair of surveys, one upstream and one downstream, could isolate plant effluent from other effects in the river. This kind of survey was particularly attractive to DuPont, and merged with a later development in Patrick’s department, the diatometer program.

Patrick may have directly contacted some industrial managers, as in the case of Crittenden, but in other cases those managers found her and sought out her services, as word of her growing department and expertise spread through corporate circles. For example, F. J. Giffen, an industrial manager at the Canadian International Paper Company in Montreal, contacted Patrick in 1954. He knew little of Patrick, and even less of the Academy, which he falsely assumed was an institution dedicated to pollution abatement—perhaps an association that Academy board members feared. When Patrick responded to his request, she enclosed a list of her department’s services and invited him to visit her in Philadelphia so that he could “see some of our work first hand [sic].” Patrick depended on her correspondence network for new sources of funding, and was prepared with documents that summarized the kind of support she described in her earlier letter to Crittenden.³⁸

Patrick established the Limnology Department not simply to conduct river surveys for corporations, but to study fundamental ecological relationships in rivers across the United

³⁷ Harold R. Murdock, “Du Pont Uses the Biodynamic Method of Stream Evaluation in Evaluating River Pollution,” *Industrial & Engineering Chemistry* 43, no. 10 (October 1, 1951): 129A-132A.

³⁸ F. J. Giffen to Ruth Patrick, December 14, 1954, Ruth Patrick Papers, Box 3, Folder 15; Ruth Patrick to F. J. Giffen, December 23, 1954, Ruth Patrick Papers, Box 3, Folder 15.

States. The surveys accomplished several goals at once: they monitored industrial effluent, paid for Patrick's own research, trained a new generation of taxonomists and collected new evidence from ecologically diverse regions—even occasionally unearthing new species that could be reported in the Academy's publications. She had already expressed this capacious vision for how applied work might fund basic research in her letter to Hutchinson from July 1946. By 1953, she was developing two kinds of relationships. She cultivated her connections with managers like Crittenden and Giffen, who struggled to solve their pollution problems and address legal disputes. But she also sought further academic allies, people like Hutchinson, to legitimate her river studies. For example, Patrick explained the goals of her department to Paul Sears, chair of Yale University's new conservation program, in strikingly different terms than in her letters to Crittenden and Giffen:

This department was founded to study the various factors involved in maintaining the natural balance of aquatic life in a river. As is well known the life in rivers and streams under most natural conditions can keep the water in a desirable condition. As most of the water used by municipalities and industries flows through our river beds and is acted on by the aquatic life in them, it is necessary to learn how to keep these organisms functioning normally if they are to continue to maintain a desirable water supply. Although considerable research has been done on lakes relatively little study of the fundamental relationships involved in the biodynamic cycle of rivers has been carried out.³⁹

For Patrick, basic and applied research began to merge and were no longer easily distinguishable. Her department conducted taxonomic and ecological studies that had important implications for society and conservation. Patrick wanted to understand not just how the biodynamic cycle operated in rivers, but also how species could maintain water

³⁹ Ruth Patrick to Paul B. Sears, November 16, 1953, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

quality, providing a service to humans. She articulated an early version of an idea that would later become prominent: that ecosystems provided humans with services, such as drinkable water, and that preserving their biological diversity and balance of life ensured that these services would also be preserved. The letters to Crittenden, Giffen and Sears demonstrate how Patrick maintained good rapport with diverse audiences with different interests, but they also convey the flexibility with which she viewed her own department and the purpose of her department's research.

To realize the capacious vision outlined in her letters, Patrick needed to attract scientists with PhDs who were willing to work for corporations. This was difficult, and Patrick's young department experienced heavy turnover rates. At first, most staff members were assistants to Patrick or graduate students working toward their dissertations or on short-term grants. For example, three students joined the department, under her grant from the Public Health Service, to study toxicity in fish and other aquatic organisms of various industrial chemicals.⁴⁰ Although she had no problem finding graduate students to work part-time in the new department, Patrick could not always attract her preferred candidates to full-time positions. In a letter to Hutchinson, Patrick inquired about one of Hutchinson's former students at Yale, Tommy Edmondson, to whom she had offered a position in the new Limnology Department with a starting salary of \$4,200 per year. The job required someone "willing to do practical work such as running toxicity tests for industries, as well as pursue

⁴⁰ These students, Natalie Wallace, Sidney Kantor and Francesco B. Trama, joined the department in 1951. Trama enjoyed a long academic career after working under Patrick. In the late 1960s, he helped reassure academic biologists who were critical of Patrick's applied work (see below). Although I only briefly mention toxicity tests here, Patrick continued to support them in her department throughout the 1950s and 1960s and they became an important part of her research program. See Anderson, "Summary of Work Performed, 1950 Thru 1977."

the problems of theoretical research.”⁴¹ But Hutchinson responded to Patrick a few days later that his student had another offer in Seattle that came with “a rank and salary considerably better than anything you would be able to offer him.”⁴²

Despite the lack of prestige and low salaries, Patrick managed to sustain a team of committed senior scientists. Some graduate students from her original survey team, such as John Cairns and John Wallace, became full-time staff in the department. Cairns studied toxicology and helped identify protozoa and fish for subsequent river surveys. While Cairns worked to complete his PhD at the University of Pennsylvania, some new staff already had their PhDs. Selwyn S. Roback joined the team in 1951, after completing his PhD in entomology at the University of Illinois. He became the head entomologist for most river surveys, and remained at the Academy until his death in 1988. In 1952, Patrick hired Matthew H. Hohn, with a PhD in economic botany from Cornell, and Charles Reimer, with a PhD in botany from Michigan State. Hohn and Reimer eventually became Patrick’s chief diatom experts.⁴³ With Cairns, Wallace, Roback, Hohn and Reimer, Patrick had amassed a

⁴¹ Ruth Patrick to G. Evelyn Hutchinson, March 9, 1950, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

⁴² G. Evelyn Hutchinson to Ruth Patrick, March 13, 1950, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

⁴³ Hohn left in 1961 to become a professor at Carnegie Mellon University and Reimer remained with the Academy until his death in 2008. Patrick and Reimer’s work culminated in the massive, two-volume *Diatoms of the United States*. See Eugene F. Stoermer and J. Patrick Kociolek, “Charlie: A Tribute to Dr. Charles W. Reimer (14 May 1923—30 November 2008),” *Diatom Research* 24, no. 2 (November 1, 2009): 521–36. Ruth Patrick and Charles W. Reimer, *The Diatoms of the United States, Exclusive of Alaska and Hawaii*, vol. 1 (Philadelphia: Academy of Natural Sciences of Philadelphia, 1966); Ruth Patrick and Charles W. Reimer, *The Diatoms of the United States, Exclusive of Alaska and Hawaii*, vol. 2 (Philadelphia: Academy of Natural Sciences of Philadelphia, 1975).

committed team of specialists to help with the river surveys. By 1953, the department had twenty full- and part-time staff.⁴⁴

Of all her new sources of funding, DuPont would become Patrick's most dependable support through the 1950s and 1960s, when her department's future was unstable, and so it is worth exploring Patrick's relationship with DuPont in greater detail. Several DuPont executives were trustees of the Academy when Patrick began her surveys, including Carpenter, who donated the funds for Patrick's new laboratory, and Stine, who had quizzed Patrick on her ability to manage the Conestoga Basin survey. According to Patrick, Stine was so impressed with her ability to lead and manage the project that he referred her to the president of DuPont, Crawford H. Greenwalt, who is most responsible for DuPont's continual relationship with the Limnology Department. He funded Patrick's department for over a decade, and succeeding presidents of DuPont continued this support. By 1975, DuPont had provided the Limnology Department with more than three million dollars to survey hundreds of sections of over eighteen rivers near their industrial plants in the United States, Canada and Ireland.⁴⁵

When DuPont first began funding Patrick's river surveys, Greenwalt had just issued a memo to his staff that subjected every new plant to a baseline survey of the receiving body of

⁴⁴ "Abstract of Minutes of the Annual Meeting of the Academy of Natural Sciences of Philadelphia," *Proceedings of the Academy of Natural Sciences of Philadelphia* 105 (1953): 231–38.

⁴⁵ This figure includes sections of rivers that were monitored using the diatometer, which I discuss below. Much of DuPont's funding was issued evenly between 1950 and 1977. The Potomac Electric Power Company provided more funds than DuPont—about six million dollars—but most of this was paid later, between 1965 and 1977. See E. L. Anderson, "The Academy of Natural Sciences of Philadelphia, Division of Limnology and Ecology, Summary of Work Performed, 1950 Thru 1977," September 1, 1978, Box 27, Folder 50, Ruth Patrick Papers.

water.⁴⁶ His work for the Manhattan Project during the war had alerted him to the harm caused by new forms of industrial pollution. Historians have praised Greenewalt's relatively cautious approach to the problems of nuclear wastes at the Hanford plutonium plant in Washington.⁴⁷ For example, in her work on the nuclear cities of Richland and Ozersk, historian Kate Brown characterizes Greenewalt as an overconfident blueblood who was nonetheless concerned about the health of his workers at Hanford. In 1943, he had hired ichthyologists to study the Columbia Basin to determine an ideal location for plant effluent pipes, as well as a meteorologist to study wind patterns and design appropriate smokestacks. The meteorologists warned him that these wind patterns made it inevitable that workers in nearby towns would be exposed to radioactive downdrafts.⁴⁸ Adding to his knowledge of the new problems of industrial pollutants, Greenewalt was also an amateur naturalist, who developed new techniques for photographing birds in flight and theorized on the iridescence of hummingbird feathers.⁴⁹ This interest in natural history may have predisposed him to support the Academy and Patrick's taxonomically complex approach to river surveys. In addition, Patrick and Greenewalt seemed to have got on pretty well; they were still friends well into their retirement.⁵⁰

⁴⁶ Edward G. Jefferson, "Crawford Hallock Greenewalt (16 August 1902-27 September 1993)," *Proceedings of the American Philosophical Society* 139, no. 1 (1995): 95.

⁴⁷ As one example, two environmental historians have remarked that "when viewed in the context of time, there is much to praise in DuPont's environmental record at Hanford;" see Benjamin Ross and Steven Amter, *The Polluters: The Making of Our Chemically Altered Environment* (London: Oxford University Press, 2012), 133.

⁴⁸ Kate Brown, *Plutopia: Nuclear Families, Atomic Cities, and the Great Soviet and American Plutonium Disasters* (Oxford University Press, 2013), 53-60.

⁴⁹ Crawford H. Greenewalt and Frank Morton Jones, "Photographic Studies of the Feeding of Nestling House Wrens," *Proceedings of the American Philosophical Society* 99, no. 4 (1955): 200-204; Crawford H. Greenewalt, Werner Brandt, and D. D. Friel, "The Iridescent Colors of Hummingbird Feathers," *Proceedings of the American Philosophical Society* 104, no. 3 (1960): 249-53.

⁵⁰ Crawford H. Greenewalt, "Speech, Dedication of New Research Building," April 4, 1979, Ruth Patrick Papers, Box 7, Folder 1.

Companies like DuPont partnered with Patrick for various reasons, but above all they sought to prevent, rather than remediate, environmental harm, to maintain a favorable public image and to avoid lawsuits and government regulation. Industrial managers were concerned that their plants' effluents, with unknown toxicities, might affect local communities and lead to lawsuits and regulation. In 1952, a DuPont corporate manual praised the "enlightened industrial policy" of its Pollution Abatement Committee but stressed the growing public concern over pollution and the outcry over corporate inaction:

No matter how skillfully industry may present its case, the downstream recipient of industrial waste and the housewife whose wash has been soiled by industrial soot may feel that *any* form of regulation of industry would be desirable. An industry that takes a "public be damned" attitude toward pollution abatement should not be surprised if the public takes an "industry be damned" attitude when, say, industrial prices and profits are under attack.⁵¹

As evidence of DuPont's responsible policies, the manual contained three photographs from the Academy surveys of the Guadalupe River near their plastics plant in Victoria, Texas. Since Patrick's surveys year after year did not seriously implicate DuPont in any harmful activities, the company was also more than happy to advertise itself as an environmentally progressive company that consulted scientific experts like Patrick.

By the mid-1950s, Patrick succeeded in building a strong department by procuring laboratory space and some early institutional support, hiring new staff—many of whom had PhDs and would remain with the department for decades—and establishing new and lasting corporate connections. Despite these successes, Patrick had created a new problem: there was too much work. She not only needed to manage a growing number of requests for river

⁵¹ Excerpts of the manual were republished in E. I. Du Pont de Nemours & Company, "Pollution Abatement--A Problem in Community Responsibility," *The Journal of Southern Research*, June 1952, 23–27.

surveys, which required significant labor, but also needed time to conduct basic research.

One of the keys to managing the complexity of her growing department was her development of a new instrument, the diatometer.

Inventing New Instruments

Patrick anticipated the intense workload of her surveys, so by 1950 she began developing an instrument called the diatometer that allowed her to reorganize her entire approach to river surveys. The diatometer floated in a river and collected live diatoms that gathered on several microscope slides mounted near its center. Patrick could leave the diatometer tethered in a river, retrieve it after two weeks to remove the slides, and scrape off and clean the diatoms before counting them under a microscope. Without having to conduct a full river survey, this device could test her idea of how pollution affected the number and relative abundance of species in aquatic communities by focusing exclusively on her area of expertise, the diatoms.

The diatometer developed in the wake of Patrick's 1948 river survey and began with a local connection. Later that year, the Catherwood Foundation, a small philanthropy based in Philadelphia, offered to fund Patrick to survey a river in Trinidad that would both add new specimens to the Academy's collections and test her idea about the relationship between biological diversity and ecosystem health. Likely due to the Korean War, they abandoned their plans for an international expedition by 1950. As an alternative, Patrick suggested that they help her develop an instrument for measuring pollution. Like the river surveys, this device would test her idea of how pollution affected the number of species and relative abundance of individuals in an aquatic community. Unlike the surveys, however, the device

would also continuously monitor the condition of a river. Patrick described this plan in a letter to her friend and colleague, G. Evelyn Hutchinson:

We wish to see if we can develop a method of stream measurement by means of sampling apparatus which could be placed in a stream for a period of time and then raised and examined to see what organisms have grown on them or in them. Such “traps” would have to be constructed so that they would be suitable for the growth of littoral organisms which would be useful as index organisms.⁵²

At the time, Patrick expected that this instrument would capture either diatoms or one of the other microscopic taxa. She also expected it would produce similar results as the river survey but in less time and with fewer resources.

Patrick’s “sampling apparatus” was ready within three years. Patrick and two young members of her department, Hohn and Wallace, designed the instrument in 1951 and completed field tests by 1953. They settled on a device about a foot and a half long, with two metal toilet float balls on each end, microscope slides mounted vertically, a heavy metal bar running along the bottom as ballast and an adjustable deflector near the slides that helped stabilize the instrument in strong river currents and controlled the rate of flow across the slides. To secure the diatometer in place, they left it tied to a cinder block along the stream. Patrick ran tests to determine how long to leave the instrument floating in place at a collection site. She settled on two weeks: any shorter, and rare but important species would fail to colonize the slides; any longer was unnecessary, since the same distribution persisted. She also determined that at least 8,000 diatoms needed to be counted to include all the rare species that colonized the slides. In a healthy stream, most species had anywhere from two to

⁵² Ruth Patrick to G. Evelyn Hutchinson, November 21, 1950, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

thirty individuals. In a polluted stream, there were often a few diatom species with over a thousand individuals.⁵³

By 1953, the team had enough confidence in their methods that they advertised the new instrument in the *Science News Letter*. “Called the Catherwood diatometer, it indicates what is happening to the aquatic life in a river by collecting and measuring the changes in the numbers and kinds of diatoms in the water.”⁵⁴ After the Catherwood Foundation funded the prototype design, the American Petroleum Institute supported further development. Patrick led two diatometer studies over four years: first, at the Rehoboth Canal and locations around Baltimore, Maryland; second, in Galveston Bay, Texas.⁵⁵ These were important locations for the oil industry, and Patrick suggested that her diatometer could determine how refineries had polluted their local rivers. The significant funding from the API—\$41,000, equivalent to almost \$400,000 in 2019—allowed Patrick to “calibrate” the diatometer over a wider geographical range and refine their methods.⁵⁶

The earlier success of the Conestoga Basin survey had taught Patrick the importance of graphical, quantitative methods to convey the relationship between water quality and community structure, so she developed a new graphical method that would work just as well with the diatometer. This new method preserved the histogram’s ability to capture a snapshot

⁵³ Patrick, Hohn, and Wallace, “A New Method for Determining the Pattern of the Diatom Flora.”

⁵⁴ “Pollution Indicator,” *The Science News-Letter* 64, no. 21 (1953): 324.

⁵⁵ Department of Limnology, Academy of Natural Sciences of Philadelphia, “Catherwood Diatometer Studies in Bay-Like Areas,” April 1954, Ruth Patrick Papers, Box 74, Folder 22; Department of Limnology, Academy of Natural Sciences of Philadelphia, “Catherwood Diatometer Studies in the Galveston Bay Area of Texas,” September 1955, Ruth Patrick Papers, Box 74, Folder 22.

⁵⁶ Ruth Patrick and Matthew H. Hohn, “The Diatometer—a Method for Indicating the Conditions of Aquatic Life,” *Proceedings of the American Petroleum Institute* 36, no. 3 (May 16, 1956): 332–39.

of the balance of life. Her audience could then quickly infer the presence of pollutants from the diatom community alone.

Patrick represented the diatometer results not as a histogram of the relative number of species in each of seven groups, but as a curve that fit a statistical distribution. This approach was based on a method developed by Frank W. Preston, an engineer who applied his mathematical background to problems in population ecology. Preston graphically represented a community using a log-normal distribution of the number of species containing a certain range of individuals in the community.⁵⁷ Because communities consist of different species with small and large populations, he plotted the number of individuals per species on a logarithmic scale, defining intervals of octaves—one to two, two to four and so on. In this way, Preston developed a statistical representation of a community.

Patrick built upon Preston's method by applying it to the diatometer slides and by interpreting large shifts in the mode and height of the distribution as an indicator of pollution (Figure 4). Patrick conveyed these differences by noting that pollution tended to lengthen or put a long "tail" on the curve and lower the height of the mode. Like the histograms, the curve became a graphical representation of the balance of life and, by reading the curve, one could determine the health of the river.

⁵⁷ Frank W. Preston, "The Commonness, And Rarity, of Species," *Ecology* 29, no. 3 (1948): 254–83.

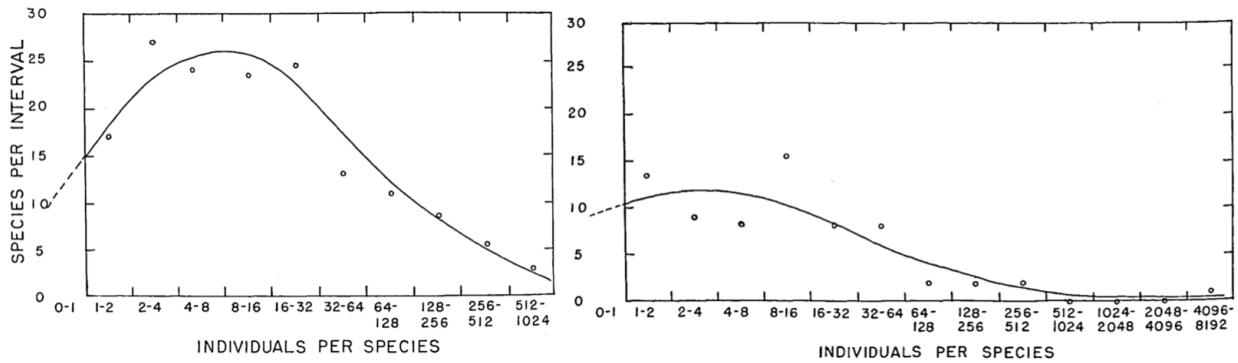


Figure 4 – Patrick’s graphical method for the diatometer was based on a curve, rather than a histogram. The plot on the left shows a diatom population from Ridley Creek, a healthy stream. The plot on the right shows a diatom population from Lititz Creek, a polluted stream in the Conestoga Basin. These plots represent the two extremes that resulted from diatometer readings, such as the “long tail” in the right plot that characterized polluted streams. Like the histograms, these plots provided a quick snapshot of the balance of life.

Patrick redesigned the diatometer twice. She first added more ballast and replaced the hollow toilet float balls, which were often punctured (sometimes with bullets) and sunk, with large cork cylinders. The corks were more easily adjusted to keep the slides just near the water surface. By the 1960s, Patrick used Styrofoam floats, a new deflector and laid the slides horizontally. This final version was streamlined, balanced, and durable (Figure 5).⁵⁸

⁵⁸ Patrick, Hohn, and Wallace, “A New Method for Determining the Pattern of the Diatom Flora”; Ruth Patrick, “Diatoms as Indicators of Changes in Environmental Conditions,” in *Biological Problems in Water Pollution: Transactions of a Seminar on Biological Problems in Water Pollution, Held at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, April 23-27, 1956*, ed. Clarence M. Tarzwell (U.S. Department of Health, Education and Welfare, Public Health Service, Division of Sanitary Engineering Services, 1957), 71–83; Ruth Patrick, “Use Without Abuse: Protecting Our Water Resources,” *Frontiers*, June 1965.

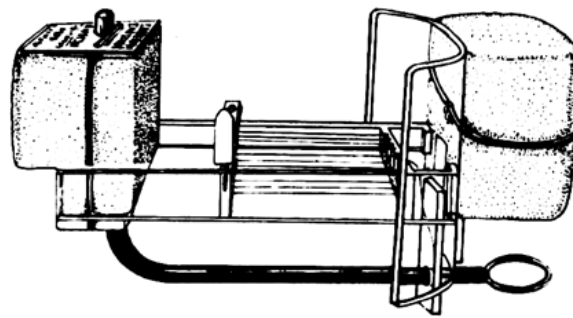
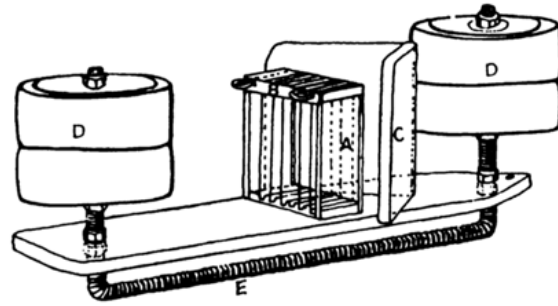
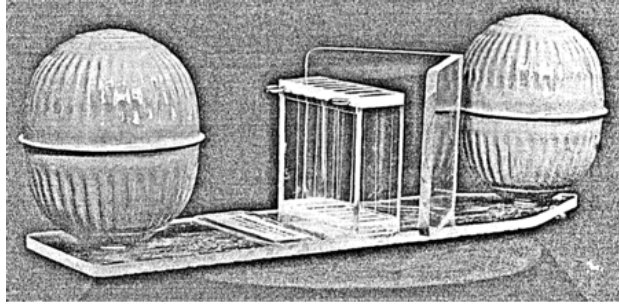


Figure 5 -The three main versions of the diatometer from roughly 1954, 1957 and 1965.

The diatometer proved useful to Patrick's expanding program, creating new avenues for both applied and basic research. Patrick now had a way to continuously monitor a river for any changes accumulated over a period of two weeks. By 1955, the instrument monitored twelve rivers and dramatically increased the speed and cost of surveys. Since the instruments were made mostly of inexpensive material, Patrick could cheaply produce dozens of diatometers, secure them along a river, and return to collect them two weeks later. Each diatometer required careful study of the slides, but Patrick constantly looked for ways to

expedite the process of identification. She trained a small team of “slide readers” to help with this task.

The team of slide readers offers us a glimpse into Patrick’s managerial approach and the difficult work that the diatometer method required. By 1959, Patrick had assembled a team of five employees dedicated to the diatometer program. Matthew Hohn managed the team and reported to Patrick, while Joan Hellerman, Robert Grant, Anne Willard and Marge Shipley performed the laborious work of reading the slides. Patrick paid them ninety dollars per detailed slide reading (about \$750 today), which required them to clean, identify, sort and count the diatoms, and then plot the results using the graphical method she had developed. It took them a full work week to process each slide. Patrick was committed to her team, training them in diatom identification and providing them with two weeks paid vacation per year, three paid holidays and paid sick leave. But she also had high expectations, and asked Hohn to assess each worker’s progress after their brief training period had ended. His answer reveals some of the difficulty in managing the diatometer program. Out of the four slide readers, Hellerman was “the only one qualified” to continue making detailed readings. Grant lacked motivation and tended to “slow down unless he is pushed,” while Willard only intended to work until her husband finished medical school and Shipley was, he thought, incapable of working unsupervised.⁵⁹

The diatometer answered the unresolved question of how to reduce the burden of applied work and make room for basic research. It also helped attract new corporate

⁵⁹ Matthew H. Hohn to Ruth Patrick, January 7, 1959, Ruth Patrick Papers, Box 27, Folder 30; “Proposed Method of Paying Diatometer Slide Readers,” n.d., Ruth Patrick Papers, Box 27, Folder 30.

connections. For example, in her letter to Giffen, Patrick also enclosed a pamphlet on the diatometer and its benefits. Patrick maintained the diatometer program through the 1960s and 1970s, and supplemented it with a new “cursory survey,” a faster, more targeted survey that relied on data collected from previous surveys, that she tested for DuPont in 1957. By 1970, the vast majority of diatometer contracts simply continued earlier programs that were already in place.⁶⁰ Over the period that Patrick led the Limnology Department, she employed three kinds of surveys—full, diatometer-based and cursory—to monitor over seventy rivers and streams for ninety different clients (Figure 6).⁶¹

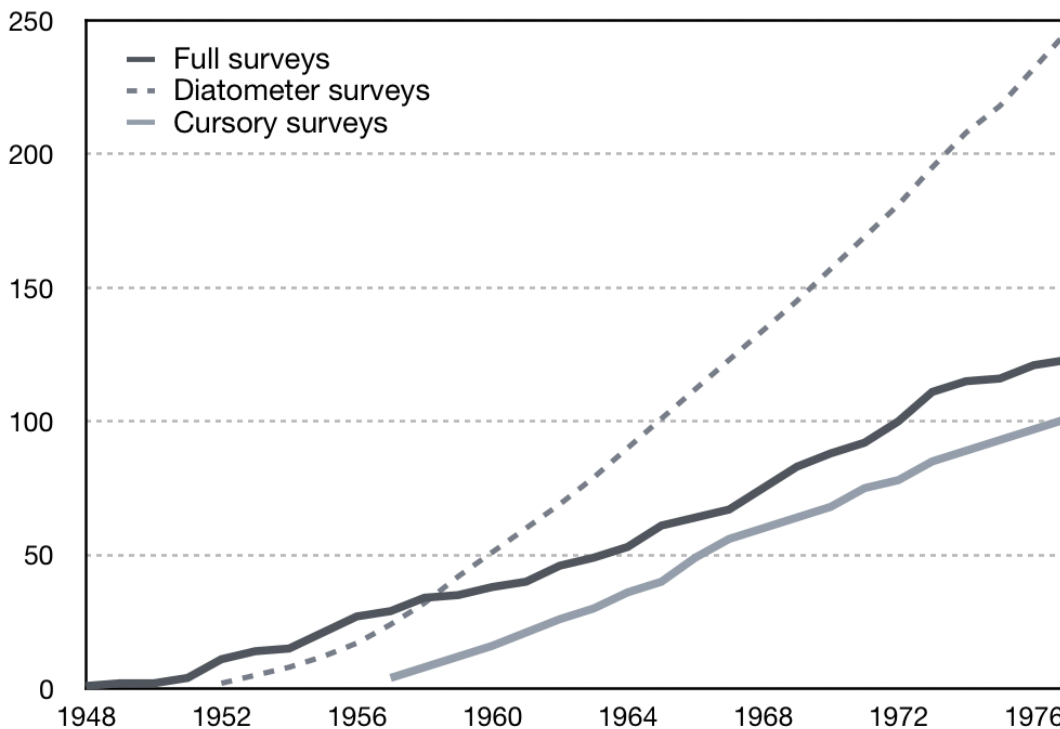


Figure 6 – The cumulative number of river surveys conducted by the Department of Limnology from 1948 to 1977. Patrick’s diatometer reduced the complexity and cost of the full survey and was supported by several companies, especially DuPont.

⁶⁰ Potapova, “The ANSP Diatom Herbarium: An Important Resource for Diatom Research,” 11.

⁶¹ Anderson, “Summary of Work Performed, 1950 Thru 1977.”

Obtaining Institutional Support

We have seen how Patrick expanded her department and network of corporate and academic connections, and how the diatometer reduced the demands of the river surveys. Patrick received mixed support for her department over its first two decades. Board members were at first eager to assist her in bringing in new corporate contracts. For most of the 1950s, however, she was left to maintain the department and pay some Academy overhead without much support. After several prominent scientists left or were on the brink of leaving Patrick's department in the early 1960s, she convinced board members to support her activities. This section examines the mixed, complicated history of support from various actors within the Academy, as Patrick struggled to keep her most senior scientists from leaving and to create new research opportunities for herself and her staff.

In the late 1940s, the most important person Patrick needed to help build her project was Academy president, Charles Cadwalader. Even before Patrick completed the Conestoga Basin survey, she had secured the support of both Cadwalader and Stine, as well as several other Academy board members, who unanimously passed a resolution to fund her new laboratory. The primary cause of this consensus was the dire financial situation of the Academy after the Second World War. The funding structures for scientific research had changed because of the war, and Cadwalader, who had balanced the Academy budget during the Depression by cultivating new private donors among Philadelphia's elite and encouraging more interaction with the public, faced another financial crisis as he neared retirement. Stine and Hart, two respected and successful businessmen, had convinced Cadwalader that

Patrick's new department could solve the crisis by not only paying for itself, but also bringing in even more money to cover some of the Academy's overhead costs. That was the case for the Conestoga Basin and, they believed, it would continue to be so.⁶²

Cadwalader also used Limnology Department projects to pay other curators. For example, in 1949, the Academy's Scientific Development Committee, which included both Hart and Patrick, hired Wendell Holmes Camp as curator of the new Department of Experimental Botany, for a three-year term. Camp worked, "with much enthusiasm," according to Academy records, on commercial contracts in Pennsylvania, including J. Franklin Styer Nurseries, a home garden business, and Riker Chemical Company (later Riker Laboratories). But these contracts were insufficient to pay Camp's full salary, which Cadwalader set at \$10,000 per year, so Patrick enlisted his help on surveys of the Guadalupe River for DuPont.

Besides Cadwalader, another crucial support of Patrick's department was managing director, H. Radclyffe Roberts. Roberts worried that applied work might lead the Academy in undesirable directions. He reached out to Hutchinson, who could help legitimate their new enterprise in academic circles. For instance, the American Philosophical Society partially funded Patrick's new laboratory only after they had received a letter from Hutchinson, sent at Roberts's request, that endorsed the new enterprise. He also urged Hutchinson to write to Cadwalader, who may have harbored continuing doubts about his decision to accept Hart's

⁶² For instance, the original contract from the Sanitary Water Board was set at \$60,000, using cost-plus pricing. Patrick and others later recalled the full initial payment for 1948 was \$65,000, but the minutes from the board meetings record the money received as \$33,899.54 by December 1948, out of an expected \$45,000. Because this figure was included in their budget calculations, it was likely whatever was left over after paying Patrick's consultants and graduate assistants. See John E. Bowers, "Minutes, Academy Trustees," December 15, 1948, Box 2, Folder 6, Board of Trustees Records.

money and so needed Hutchinson's reassurance. Hutchinson even reassured Roberts, who had to tread carefully amidst criticism of the Academy:

I am as you know enormously impressed with your limnology department. I think Ruth Patrick has done a wonderful job and hope she will be able to travel around enough this summer in Europe and see what other people are doing. I realize that the Academy has been criticized for entering this field; the criticisms seem to me quite unjustified in principle and absurd in practice.

Hutchinson then referred Roberts to Duncan McConnell, a geologist working for Gulf Research and Development Company in Pittsburgh, who was doing "very excellent work" and knew better than anyone "how a purely scientific and economic program could be integrated."⁶³

Patrick herself recalled this period, and the following years, as tumultuous and uncertain. According to Patrick, several board members thought her work was "frivolous and unworthy of the Academy."⁶⁴ Interviewed later in life, she recalled the prejudice that persisted throughout much of the 1950s, the tendency to view applied science as a second-rate or even tainted enterprise: "I was considered almost a woman of the streets for bringing corporate money to a place as hallowed as the Academy and for doing applied work instead of pure, basic research."⁶⁵

Patrick's memories of the board of trustees are difficult to corroborate, given the significant expanse of time over which she may have faced this kind of criticism. We do know about the firm support she received at the October 1948 board meeting. Ten trustees

⁶³ G. Evelyn Hutchinson to H. Radclyffe Roberts, May 8, 1950, Box 1, Folder 12, G. Evelyn Hutchinson Papers.

⁶⁴ Patrick, "The Development of the Science of Aquatic Ecosystems," 9.

⁶⁵ Peck and Stroud, *A Glorious Enterprise*, 324.

were present for that meeting: Cadwalader, her supporters Roberts, Carpenter and Hart, naturalists Moore, Conklin and de Schauensee, and businessmen Bok, Barringer and George R. Clark, a future president of the Academy. Of course, any of these men may have supported the department's growth while remaining critical of its leader and applied work. It hardly appears, however, that this was a majority opinion, at least in the department's earliest years. Other board members who were not present at the October 1948 meeting included Stine and Greenewalt, her DuPont supporters; Henry Drinker, whom Patrick remembered for his firm support; and Lewis H. Van Dusen, Jr., who would later become Patrick's second husband.

Patrick was not the only scientist at the Academy who attempted to merge basic research goals with government or corporate service. Academy director Roberts, who had trained as an entomologist and was considered a leading expert on mosquitoes, left for Shiraz in May 1950 to help Pennsalt's Health and Agriculture Service, a consultancy firm hired by the Iranian government for their first national malarial control program. While advising Pennsalt on taxonomy and microscopy, he had time to explore Iran and returned to Philadelphia with "an interesting collection of Orthoptera," illustrating the ways in which the Academy, after its golden age of privately funded exploration, adapted their collecting methods to new opportunities after the Second World War. Davies, the Academy board member and president of Pennsalt who had provided Patrick with one of her first contracts, praised Roberts's dual contribution and hoped it had opened yet another profitable avenue, in addition to Patrick's, for the Academy to sustain its legacy in natural history. This demonstrates that some board members were quite active in their support of new kinds of collaborative work at the Academy. If Patrick was criticized for bringing applied work to the

Academy's hallowed halls, such criticism was part of a much larger debate, involving several influential members, about the future of the Academy.⁶⁶

While some of Patrick's ideas and investments endured, including her new laboratory, others were short-lived. For example, Patrick likely expected Camp, who accompanied her on a trip to the International Botanical Congress in Sweden, to help her build the Limnology Department and open new avenues for funding. His "enthusiasm" for industrial work might have helped shield Patrick against some criticism. Camp, however, did not renew his three-year term, and in 1953 accepted an offer to chair the Department of Botany at the University of Connecticut. By that time, Patrick's situation was tenuous. Her task was to manage her unusual department, maintaining scientific staff that might leave at any moment. She could expect only mixed support from board members and the few other curators, all of whom were uncertain about their own role in the Academy's future.⁶⁷

One way to understand the struggles Patrick faced during the mid-1950s is by analyzing the vicissitudes of her diatometer program. In 1953, Roberts tried to obtain a patent for Patrick's new instrument. The Academy's official policy stated that employees could only file for patents with the approval of the president, director and the board of trustees.⁶⁸ In 1953, Roberts, who approved of the department's work and convinced the board of the potential value of this instrument, initiated the process and helped to secure copyright for the name "Catherwood diatometer." There is no evidence, however, that a patent was ever issued. While the name was protected, the instrument was not. With no patent on the

⁶⁶ John E. Bowers, "Minutes, Academy Trustees," May 17, 1950, Box 2, Folder 7, Board of Trustees Records.

⁶⁷ John E. Bowers, "Minutes, Academy Trustees," March 16, 1949, Box 2, Folder 6, Board of Trustees Records.

⁶⁸ Henry S. Drinker, "Patent Policy for the Academy of Natural Sciences," July 10, 1950, G. Evelyn Hutchinson Papers, Box 1, Folder 12.

instrument, Patrick could not advertise it to interested parties like the US Public Health Service, where pollution experts were working on a nation-wide water monitoring program.⁶⁹

Although Patrick was uncertain how to expand the diatometer program, she envisioned three alternatives. She could wait for the patent and sell the instruments, train others to interpret them, or continue renting them out while maintaining control of their procedure. She thought that a training program would produce only half-qualified users, who might fail and then publicly criticize the method as useless. Even with a patent, she worried that sharing the diatometer would cut off the main revenue stream for her department. Patrick understood the great value and potential of her instrument, but she underestimated the difficulty of identifying 8,000 diatoms and the willingness of corporations to adopt her practices.

In the end, Patrick pursued all three options, but favored the third. She continued to pursue a patent for the diatometer, trained new diatometer slide readers and expanded the number of industrial contracts. With help from Reimer, she began writing a comprehensive reference work on the diatoms of the United States. She hoped it would not only serve the small community of expert diatom taxonomists in the United States and abroad, but also, more importantly, ease the burden of hands-on training of slide readers, who could use the text as they learned to distinguish different species on the diatometer slides. Once published, it could simplify the use of the diatometer and therefore promote the instrument to a broader audience. With a patented instrument, reference work and training program, Patrick hoped

⁶⁹ H. Radclyffe Roberts to Ruth Patrick, April 17, 1953, Box 32, Folder 9, Ruth Patrick Papers, Academy of Natural Sciences of Drexel University, Philadelphia.

her department would become a center of excellence for the study and monitoring of water pollution and, in the process, transform the Academy.⁷⁰

In 1956, Patrick won a small victory at the Academy that freed some of her time for basic research and removed some of the stress of managing her department. Since its beginning, the Limnology Department provided their own funding through industrial contracts, and paid toward the Academy's overhead. Any profit the department made was kept by the Academy. All that changed in January, when the board of trustees approved a motion that would give Patrick control over three-fourths of her profits, which she planned to use as a reserve fund "to meet unforeseen contingencies, such as a sudden falling off of their projects, or as a fund to meet some new program of research." Although this removed some financial stress, Patrick continued to search for ways to save money.⁷¹

In 1956, the Academy was again struggling to balance its budget. Systematic research across the institution had lost much of its funding, as private donations and local government appropriations were steadily diminishing. Although several senior curators, such as de Schauensee, were independently wealthy, other curators supplemented their meager salaries by teaching biology courses at nearby universities. Patrick, for instance, taught a course on systematics for years at the University of Pennsylvania. While Patrick's department supplemented the Academy's overhead costs, other departments brought in money from their public displays in the museum.

⁷⁰ Ruth Patrick, "Agenda Concerning the Diatometer," 1954, Ruth Patrick Papers, Box 27, Folder 44.

⁷¹ John E. Bowers, "Minutes, Academy Trustees," January 24, 1956, Box 2, Folder 9, Board of Trustees Records.

Roberts became increasingly dependent on the National Science Foundation to fund the Academy's systematic research. He went to Washington to speak with key NSF program managers, such as John Todd Wilson, assistant director of the Biological and Medical Sciences Division, and Rogers McVaugh, the director of systematic biology. They could not provide any immediate funds, but encouraged Roberts to submit a proposal that outlined the Academy's situation. Roberts sought Hutchinson's advice, as he had in the past. He worried about the future of systematics research in general, and wrote that "if nothing is done, some of our major centers in this field may quietly and unnoticed [sic] die on the vine or, perhaps more likely, seek richer pastures in other fields of science."⁷²

The National Science Foundation eventually came through for Roberts, providing over \$200,000 in six grants from 1956 to 1960. Some of the money went to Patrick, who had earlier received a grant for her reference work on diatoms—although the demands of running the Limnology Department prevented her from making any sustained progress. With the help of Reimer, who had been hired to help with the diatom manual, Patrick finished the first volume only in 1966, using four grants that totaled over \$90,000, and the second in 1975. NSF funding continued to pour into the Academy through the 1960s and 1970s and sustained its systematic research, as Roberts had hoped. After his plea, the National Science Foundation even began funding systematic research at other natural history museums, such as Harvard's Museum of Comparative Zoology.⁷³

⁷² H. Radclyffe Roberts to G. Evelyn Hutchinson, July 2, 1956, G. Evelyn Hutchinson Papers, Box 1, Folder 13.

⁷³ Funding from the National Science Foundation can be located using the NSF's Award search tool at <https://www.nsf.gov/awardsearch/>, using the keyword "Academy of Natural Sciences." See also Toby A Appel, *Shaping Biology: The National Science Foundation and American Biological Research, 1945-1975* (Baltimore: Johns Hopkins University Press, 2000), 90.

Patrick, who was caught in a cycle of managing the immediate needs of the department and who could not even find time to work on her own large NSF grant, continually adjusted her procedures. Starting around 1958, she more closely managed department personnel, especially for her diatometer program. Patrick thoroughly streamlined the process of analyzing diatometer slides. Some companies complained that her cursory surveys did not provide them with enough new information, so she replaced them with “semi-detailed readings” that cost more but met this new demand.⁷⁴ The new semi-detailed readings used prior knowledge from the most recent detailed reading to count fewer diatoms and determine whether any change had occurred. Hohn managed the program by training new department personnel, but he also trained corporate employees at the surveyed plants, obviating the need for Academy staff to travel out to different sites to collect slides or troubleshoot minor problems. These local employees helped lessen the burden on Patrick’s team: they installed diatometers at designated stations around the plant, monitored them, collected the slides and mailed them back to Philadelphia, where Patrick and her team interpreted the results. She also increased the annual price of diatometer stations. This new approach allowed Patrick to expand the diatometer program to more rivers and bring more money into the department. It did not, however, alleviate the stress of managing research for more than fifteen people with few sources of funding other than demanding industrial contracts.

It might be argued that Patrick’s work was just part of standard managerial practice at the time, but this would be mistaken. Patrick trained young scientists, juggled corporate

⁷⁴ “New Program for Reading the Diatometer,” 1958, Ruth Patrick Papers, Box 27, Folder 30.

contracts requiring her or her team to travel across the country and abroad, contributed to Academy affairs and finances and led research programs—all as curator at a natural history museum, which had no precedent for such work. And if we recall Patrick’s statements about Cadwalader and Stine, some people expected her to fail. Managing the basic and applied research of her department was no simple task under these institutional constraints. Although the department’s efficiency and funding increased by 1961, its place in the Academy remained uncertain, for at least two reasons. First, the department had financial difficulties of their own. The workload of its staff was unsustainable, Patrick argued, because of the dual requirements of basic and applied research:

Since the time of its inception, the aim of the Limnology Department has been to produce good research and yet be completely self-supporting and if possible turn in an additional amount to the Academy’s general income funds. This has been possible through work done for industry and state and federal governments. This requirement to do research and yet be self-supporting produced a great deal of strain on the people working in the department particularly in the early days. Most of the fundamental research had to be produced by the scientific staff on their own time, for the hours from 9 to 5 were spent in “making ends meet.”⁷⁵

Patrick asked the Academy’s board of trustees to alleviate this stress by raising funds and providing an independent budget for basic research. The board met these demands later that year, when it agreed to provide “some support to the operations of the Department on a temporary basis, if, as and when the need arises.” It also promised to return up to five thousand dollars per year in the department’s profits, which were being used to help pay the Academy overhead, for Patrick’s own use to conduct basic research.⁷⁶

⁷⁵ Ruth Patrick, “The Limnology Department,” 1961, Ruth Patrick Papers, Box 27, Folder 53.

⁷⁶ Lewis H. Van Dusen, “Recommendation of the Departmental Program Committee Concerning the Policy and Program of the Limnology Department,” September 11, 1961, Ruth Patrick Papers, Box 27, Folder 49.

A second reason that Patrick's department's future remained uncertain was because of the complete lack of encouragement she and her staff received from the other departments. Patrick wrote to the board that although "intra-department morale has never been higher," her senior staff felt like second-rate members of the Academy. "They feel that they are off in 'left center' and the institution is really not backing them."⁷⁷ She asked the library to expand their meager collection of works on limnology and ecology. Also, the Academy's system of promotion through the curatorial ranks did not apply to many of her employees, including the slide readers, so she requested a new system for raises and promotions. By the early 1960s, Patrick worried that some of her senior staff would leave for more lucrative positions in academia. Her fears were justified, since Patrick lost two of her most senior staff by the mid-1960s. Hohn left in 1961 to become a professor at Carnegie Mellon University. John Cairns, one of the department's most productive biologists who had been with the department from its inception and occasionally helped Patrick with the diatometer program, left in 1966 for Virginia Polytechnic Institute.

Taken together, these episodes demonstrate the intense pressure placed on Patrick to simultaneously conduct basic and applied research, as well as the mixed support Patrick received from Academy leadership, who were often worried about their own future. The diatometer had freed some time for research, but did not address how that additional time could be used. One strategy that Patrick implemented by the middle of the 1950s was long-term research. Rather than expect dedicated time periods to conduct basic research that might resemble the old collecting expeditions of earlier years, or the work habits of an academic

⁷⁷ Ruth Patrick, "General Comments," 1961, Ruth Patrick Papers, Box 27, Folder 49.

biologist, Patrick spread research over several decades, collecting and tabulating data from every river survey and every diatometer slide.

Building Evidence from Long-Term Studies

By 1961, Patrick applied her river surveys more deliberately to long-term research. Since her team had extracted new taxonomic and environmental data from every survey, they acquired more evidence for her idea that the number and relative abundance of species indicated health, and showed that it applied over an extensive range from the Saint Lawrence River in Canada to the Guadalupe River in Texas. Her team also uncovered new taxa during the two months of specimen identification in the laboratory following a river survey.

Patrick analyzed the wealth of data from these river surveys and published her results, a kind of meta-survey, in the *Academy Proceedings*. She determined that the number of species remained relatively constant across all rivers and streams in ecologically similar regions; only the kinds of species varied. This result answered the criticism of Gaufin and Tarzwell, who argued that healthy rivers in Utah and Colorado had few species. Patrick denied this in the discussion, but at the time she lacked evidence to support her claim. Her results from 1961 showed that, across the different regions she had studied, “the numbers of species in the larger groups of organisms such as protozoa, insects, fish, and algae usually vary less than 33% from the mean” in unpolluted rivers. In 1963, she showed that Thienemann's theory about the diversity and abundance of species in unpolluted environments was consistent with the results from fifteen years of river surveys.⁷⁸ These

⁷⁸ Ruth Patrick, “The Structure of Diatom Communities Under Varying Ecological Conditions,” *Annals of the New York Academy of Sciences* 108, no. 2 (1963): 359–65.

results included ten years of diatometer data collected from healthy streams across the United States, notably on the Savannah River, which Patrick and the Limnology Department studied continuously for over fifty years.⁷⁹

The Savannah River surveys for DuPont demonstrate how Patrick leveraged the three kinds of survey simultaneously to manage a long-term research program. This program was the longest continuous survey Patrick conducted, which the Academy continued until 2007.⁸⁰ The site was part of a nuclear facility managed by DuPont for the Atomic Energy Commission (AEC). As a government laboratory, the land surrounding the facility was protected, forming a buffer zone that would become part of the Savannah River Ecology Laboratory led by Eugene P. Odum, an ecologist at the University of Georgia, Athens, who had worked there since the early 1950s.⁸¹ In 1972, the Department of Energy named the area the first National Environmental Research Park. The Savannah River Site became an early center of ecological activity in the United States, supporting projects on old-field succession, thermal ecology, radioecology, environmental chemistry and toxicology.

Patrick used the Savannah River Site as a long-term testing ground for her idea linking biodiversity and environmental health. Plans for a baseline survey started in 1950, before the nuclear plant began operations and disturbed the river. In a letter to Hutchinson sent in January, Patrick seemed uncertain about managing another river survey:

⁷⁹ Ruth Patrick, "A Study of the Numbers and Kinds of Species Found in Rivers in Eastern United States," *Proceedings of the Academy of Natural Sciences of Philadelphia* 113 (1961): 215.

⁸⁰ Potapova, "The ANSP Diatom Herbarium: An Important Resource for Diatom Research," 11.

⁸¹ Michael H. Smith, Eugene P. Odum, and Rebecca R. Sharitz, "Savannah River Ecology Laboratory: A Model for a Cooperative Partnership between a University and the Federal Government," in *Holistic Science: The Evolution of the Georgia Institute of Ecology (1940-2000)*, ed. Gary W. Barrett and Terry L. Barrett (New York: Taylor & Francis, 2001), 95–127.

Again I come to you with my problems. We will probably be asked to make a stream survey in the vicinity of the H-bomb plant which the Du Pont Company will build for the government. The purpose of this survey will be to establish conditions as [they] now are for comparison at a later date. I will call you Friday morning for your opinion as to the main factors we should take into account.⁸²

She then asked Hutchinson about the long-term effects of radiation on the metamorphoses of insects, or on the reproduction rates of fish, before posing a question to which diatoms would later be the answer: “are there certain aquatic organisms which are known to accumulate radioactive substances more quickly than others?” Patrick continued a strategy she had employed since 1948, viewing each river survey as an opportunity for taxonomic and ecological research. Throughout the 1950s, Patrick asked colleagues what they knew about the effects of radionuclides ingested or absorbed by various aquatic life. For the Savannah River surveys, however, the AEC left these questions to other scientists, and her task was only to monitor the effects of chemical and thermal pollution.⁸³

Patrick and her team monitored five stations across two main sections of the river, one upstream of the plant and one downstream. From 1951 to 1956, they visited the river twice per year to conduct comprehensive surveys, similar to the ones performed at stations in the Conestoga Basin in summer 1948. Their work was frequently interrupted by packs of feral dogs, the descendants of domestics left by farmers who were displaced by the AEC before 1950.⁸⁴ Beginning in 1953, Patrick installed diatometers at three of the five stations, and trained AEC personnel to maintain them; they replaced any missing diatometers,

⁸² Ruth Patrick to G. Evelyn Hutchinson, January 3, 1950, MS 649, Box 41, Folder 651, G. Evelyn Hutchinson Papers.

⁸³ Mary Beth Reed et al., *Savannah River Site at Fifty* (United States Department of Energy, 2001), 463. Ruth Patrick, “Statement on the Savannah River Surveys,” January 1983, Ruth Patrick Papers, Box 151, Folder 24.

⁸⁴ The history of the largely African American displaced population, see Kari Frederickson, *Cold War Dixie: Militarization and Modernization in the American South*. (Athens, GA: University of Georgia Press, 2013).

changed slides every four weeks and mailed them to the Academy so that Patrick and her team could track shifts in the diatom communities without having to travel to South Carolina. In 1957, Patrick began performing either four cursory surveys per year or, about every five years, two cursory and two full surveys per year. This pattern continued through 1977.⁸⁵

Patrick had amassed substantial evidence from the Savannah River supporting her idea about the relationship between biological diversity and water quality. In 1966, Cairns, Roback and Patrick published their results from over fifteen years of collecting on the river, which she called an “ecosystematic” study for the important roles played by ecology and by systematics and taxonomy. She argued that these surveys confirmed the results from her 1948 Conestoga Basin survey about the number and relative abundance of species and how they were affected by pollution. Patrick also confirmed the results of her recent studies of the number and kinds of species—namely, that over this period the number of species present in similarly healthy regions of the river remained the same, although the kinds of species changed. The study mentioned DuPont’s clean record, which made her ecosystematic study possible; “the Savannah River,” they noted, “has continued to be a ‘healthy’ river” near the plant.⁸⁶

Although the river was generally healthy, Patrick noted whenever there was some large disruption, such as in 1968 when Patrick summarized their findings in annual reports to DuPont. Often, the river’s health was affected either by agricultural runoff or some upstream source, such as a paper mill in Augusta, or the dredging and snag-removal operations of the

⁸⁵ Anderson, “Summary of Work Performed, 1950 Thru 1977.”

⁸⁶ Ruth Patrick, John Cairns Jr., and Selwyn S. Roback, “An Ecosystematic Study of the Fauna and Flora of the Savannah River,” *Proceedings of the Academy of Natural Sciences of Philadelphia* 118 (1966): 192.

Army Corps of Engineers. Of the twenty-four summary reports submitted by the Limnology Department to DuPont between 1957 and 1980, most years reported no significant changes, and every report either explicitly stated that changes were not caused by DuPont operations or called for further checks and studies of plant effluent.⁸⁷

Given their long relationship, it is surprising that Patrick never seriously accused DuPont of polluting their waters. Did Patrick tolerate such polluting industries, just to protect her department's funding? Several factors explain why this conclusion is mistaken. First, Patrick was operating well before any consensus had formed on environmental best practices, such as the appropriate limits on thermal pollution. Her benchmark since 1948 had always been the integrity of the diversity and relative abundance of species across time—an idea she herself had developed—and her river surveys monitored such changes. During a lengthy debate in the early 1980s about whether to restart the plant's L Reactor, Patrick acknowledged that thermal pollution from the reactor had affected the aquatic life near its point of discharge, in a small tributary to the Savannah River called Steel Creek. The Limnology Department had not studied the creek directly, but Patrick viewed it as a necessary sacrifice and buffer zone to protect the Savannah River, where diatometers continuously monitored any disruption to biodiversity. At the closest stations, she found fluctuation in biodiversity caused by changes in temperature, but no clear trends over time. By the 1980s, however, environmental groups had determined that this sacrifice was unacceptable, and they called for temporary shutdown of the reactor until mitigations could be installed, such as an artificial lake to limit the rise in temperature in the creek. In

⁸⁷ Reports for E. I. Du Pont de Nemours and Company, 1957 to 1980, Box 140, Folder 18, Ruth Patrick Papers.

particular, they wanted the lake temperature to remain below 90° F during the summer months. This episode illustrates how ecologists and environmentalists provided different answers to the question of what constituted “acceptable” levels of pollution. Patrick’s answer, based on downstream biodiversity and species abundance, tended to support DuPont in favor of reactor operation, while environmental groups wanted stricter adherence to more general thermal requirements, which ultimately led to the reactor’s permanent shutdown.⁸⁸

There are at least three other reasons why Patrick did not speak out against DuPont as polluter. First, many DuPont managers had invested in sophisticated waste disposal systems beginning in the 1940s. They avoided the practice of dumping toxic effluent directly into rivers and instead buried pollutants in underground tanks or burned them after temporary storage in evaporation basins. These facilities protected the river, although they could pollute the groundwater—a problem that pollution experts, including Patrick herself, would not pursue until later in the twentieth century. Over the decades that DuPont managed the Savannah River Plant, they periodically updated their waste disposal procedures to conform with contemporary standards. Second, some rivers were so polluted in the 1950s that a single DuPont plant, such as their Chamber Works site on the Delaware River in New Jersey, barely contributed to already appalling upstream conditions. Third, she tended to view pollution as a distributed problem that involved the consumers of industrial products just as much as the manufacturers, like DuPont. “Of course, we are all polluters,” she told a journalist for *Smithsonian* magazine in 1970. “Man really is the cause of pollution. It’s his way of life.”

⁸⁸ Reed et al., *Savannah River Site at Fifty*, 501.

Later in life, she was outspoken about the nation's pollution problems, but did not blame any particular companies for having caused them.⁸⁹

By expanding her connections with new industries, Patrick not only increased department funding but also visited new rivers across the United States, which tested her ideas in ecologically diverse regions. From 1950 until the mid-1970s, Patrick led hundreds of river surveys and a large multidisciplinary team as curator and chair of the Limnology Department. Key actors in Patrick's network helped her manage this complexity: Hart and Roberts pursued new avenues of funding, Greenwalt provided new opportunities for long-term research and Hutchinson defended the department's work and advised Patrick on scientific matters. As she recruited more taxonomists to her own department, Patrick relied less on the help of senior curators at the Academy. By 1977, the Limnology Department had received over ninety corporate contracts and over fifty state and federal grants to conduct river surveys and toxicological research.

These river projects, conducted within the context both of a growing national crisis of river pollution and of Cold War military developments, illustrate the ways in which years of applied work could produce new ecological knowledge. They demonstrate that Patrick's ideas about the relationship between ecological health and species diversity and abundance did not begin and end with the 1948 Conestoga Basin survey but rather developed from her broader, persistent activity, most of which was funded by US corporations like DuPont.

⁸⁹ For more on DuPont's pollution abatement strategy, see Ross and Amter, *The Polluters*, 129–40; John K. Smith, "Turning Silk Purses into Sows' Ears: Environmental History and the Chemical Industry," *Enterprise and Society* 1, no. 4 (December 2000): 790–804; Michael J. Bandler, "Dr. Ruth Patrick, a Diagnostician of Water Pollution," *Smithsonian*, August 1970, 13; Ruth Patrick, "Energy and Our Environment," *Frontiers*, 1975; Ruth Patrick, *Surface Water Quality: Have the Laws Been Successful?* (Princeton University Press, 1992).

Above all, they constitute not only Patrick's unusual career trajectory but also, borrowing a metaphor from historian Frederic Holmes, her unique investigative pathway—one that helped create the new field of river ecology and led to important insights in a growing area of research.⁹⁰

Building Authority within an Expert Community

We gain insight into Patrick's unorthodox views by examining her reception at conferences organized by sanitary biologists, pollution experts with biological backgrounds who were largely funded by federal or state programs. One expert community, centered in Cincinnati, Ohio, revised its approach to studying pollution by the early 1960s, about a decade after many of its leading experts became aware of Patrick's work. This section explores how Patrick contributed to the significant shift in practices among some sanitary biologists.

In the decade after Patrick published and promoted the methods of her survey of the Conestoga Basin, some sanitary biologists and engineers began to question and criticize Patrick's approach to assessing environmental health. Water pollution experts, such as Tarzwell and Gauvin, defended their own methods, based on indicator species or physico-chemical analyses, which they thought worked well enough without needing to consider ecological complexity. They discussed Patrick in sanitary engineering journals and at conferences. One such center of debate was the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio, the nexus of environmental expertise for the Public Health Service. Tarzwell, chief scientist of the Aquatic Biology section at the Taft Center, hosted a series of

⁹⁰ Frederic Lawrence Holmes, *Investigative Pathways: Patterns and Stages in the Careers of Experimental Scientists* (New Haven: Yale University Press, 2004).

three conferences from April 1956 to August 1962 titled “Biological Problems in Water Pollution.” By the third conference, Patrick had convinced key biologists, including Tarzwell, of the merits of her ecological approach.

Some biologists at the first Cincinnati conference of April 1956 could not understand Patrick’s ecological approach to monitoring pollution. Although Patrick could not attend the first conference, she submitted a brief paper that described her diatometer method. Despite her absence, Patrick provoked vigorous debate. Two sanitary biologists in particular—Peter Doudoroff, an ichthyologist with the Public Health Service, and Charles Warren of the Department of Fish and Game Management at Oregon State College—criticized recent studies for their vague definitions of key terms, such as pollution and stream health, but singled out Patrick and her idea of linking water quality to biological diversity. “Because of certain novel features and the relatively wide scope of the studies, and the broad implications of some of the conclusions, the work of Patrick has attracted much attention in the United States and seems to deserve the closest scrutiny.”⁹¹

Doudoroff and Warren shared many of the same concerns as Tarzwell and Gaufin from 1952. They shared with Tarzwell and Gaufin, for instance, their rejection of Patrick’s envisioned relationship between species diversity and pollution. In one of her earlier articles, Patrick defined pollution as “anything which brings about a reduction in the diversity of

⁹¹ Peter Doudoroff and Charles E. Warren, “Biological Indices of Water Pollution, with Special Reference to Fish Populations,” in *Biological Problems in Water Pollution: Transactions of a Seminar on Biological Problems in Water Pollution Held at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, April 23-27, 1956*, ed. Clarence M. Tarzwell (U.S. Department of Health, Education and Welfare, Public Health Service, Division of Sanitary Engineering Services, 1957), 144.

aquatic life and eventually destroys the balance of life in a stream.”⁹² Few sanitary biologists, they argued, would accept such a definition. To Doudoroff and Warren, a reduction in diversity was neither necessary nor sufficient to indicate pollution. They claimed that rivers without any pollutant present might lose some of its diversity, and some forms of pollution would have little, if any, measurable effect on aquatic life. To define pollution and clean water, Doudoroff and Warren reverted to legal definitions that focused on some demonstrable injury to the plaintiff.

Their criticism of Patrick went deeper, however, since they also questioned her motivation for encroaching on the sanitary biologist’s domain. Tarzwell and Gaufin had earlier criticized Patrick’s method as unnecessarily complex and costly, but confined their criticism to methodological issues. Doudoroff and Warren broadened this criticism by questioning her motivation and funding. Was Patrick an applied scientist, like them and other sanitary biologists, or was she a limnologist, devoted to basic research? They asked:

Are broad limnological investigations being undertaken where intensive study and appraisal of supposedly damaged natural resources of obvious value to man would be more profitable? Is immediate practical value of research results being claimed improperly in an effort to justify fundamental limnological studies for which no such justification should be necessary?⁹³

Doudoroff might have thought Patrick was really doing basic science under the guise of applied science. These categories of “basic” and “applied” science were significant in the 1950s, and Patrick herself sometimes referred to them and worried about her scientific

⁹² They quoted this definition from Ruth Patrick, “Biological Phases of Stream Pollution,” *Proceedings of the Pennsylvania Academy of Science* 27 (1953): 33. Note how, in this case, Patrick mentioned only diversity and left out relative abundance of species, a crucial component of her method.

⁹³ Doudoroff and Warren, “Biological Indices of Water Pollution,” 145.

identity. Patrick and the scientists in her department fit neither category. They developed an ecological approach that not only had implications for pollution abatement but also generated new scientific knowledge.

The second Cincinnati conference of April 1959 was, by contrast, uneventful. Neither Patrick nor her colleagues from the Academy attended, and no contributor cited her paper from the previous conference. In fact, she was only mentioned in a brief paper on the graphical representation of biological data, which praised her histogram method. It appeared as if the controversy were over, and Doudoroff and Warren had the last word.⁹⁴

The third conference in August 1962 marked an important shift within the research program of Tarzwell's Aquatic Biology section. The shift is clear when we compare the conference's participants and session titles between the first and third conference. Several members of the Limnology Department presented at the third conference. Cairns, Roback and Reimer each presented on the ecology of protozoa, insects and diatoms. Patrick described recent improvements to her diatometer method, argued that the indicator species approach had become untenable since 1957 because of the growing number of new chemical substances found in rivers, and re-emphasized the importance of community structure as a measure of pollution. Whereas the 1956 conference was relatively unorganized, being divided broadly into three sections on bioassays, indicator organisms and the different regional approaches to pollution, from Oregon to Great Britain, the third conference was

⁹⁴ William M. Ingram and Alfred F. Bartsch, "Graphic Presentation of Biological Data for Water Pollution Survey Reports," in *Biological Problems in Water Pollution: Transactions of a Seminar on Biological Problems on Water Pollution, Held at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, April 20-24, 1959*, ed. Clarence M. Tarzwell (Cincinnati, Ohio, U.S.: U.S. Department of Health, Education and Welfare, Public Health Service, Division of Water Supply and Pollution Control, 1960), 260–63.

organized more deliberately around all of the aquatic taxa Patrick had collected in her 1948 river survey: algae and diatoms, bacteria, invertebrates, insects, fish and protozoa. Tarzwell titled all sessions along the theme of “environmental requirements,” a phrase he strongly promoted. Taxonomic complexity, once rejected by Tarzwell, had become the organizing principle of the third conference.

One reason why the conference articles were so different, and so uniformly titled, was that Tarzwell orchestrated this shift in the months leading up to the conference. Patrick continued to seek common ground with Tarzwell, despite their differences. She wrote to him in July 1961, expressing interest in the third conference and offering the support of her entire staff.⁹⁵ In response, Tarzwell invited Patrick, as well as several senior scientists in her Limnology Department, to present their research, but dictated titles for their papers, such as Cairns’s “Environmental Requirements of Fresh-Water Protozoa.”⁹⁶ He later wrote to Reimer expecting a paper on the “Environmental Requirements of Diatoms.”⁹⁷

Reimer’s reaction to Tarzwell’s directive is revealing of the difference between Tarzwell’s desired program on “environmental requirements” and the research pursued by the Limnology Department. Reimer balked at Tarzwell’s suggestion that precise environmental requirements, including temperature, turbidity, pH, dissolved oxygen and carbon dioxide, could be extracted from Reimer’s wealth of data on diatoms, even with the aid of a computer the department had started using around this time. Reimer did not have

⁹⁵ Ruth Patrick to Clarence M. Tarzwell, July 31, 1961, Ruth Patrick Papers, Box 3, Folder 14.

⁹⁶ Clarence M. Tarzwell to Ruth Patrick, September 6, 1961, Ruth Patrick Papers, Box 3, Folder 14.

⁹⁷ Clarence M. Tarzwell to Charles W. Reimer, February 15, 1962, Ruth Patrick Papers, Box 3, Folder 14.

“much faith in either the data or the machine,” and suggested to Patrick that, in pursuit of precise answers to Tarzwell’s questions,

it is quite possible that we will get no such an answer. Given, that there will be some positive "correlation" found, it would not seem right to assume that A causes B. This will only show that the organism or group of organisms are found at least in this range of pH, CO₂, etc. This does not appear to me to show any requirements or effects.

Given his disagreement with Tarzwell, he told Patrick he planned to decline Tarzwell’s offer to participate. We do not have Patrick’s response, but she likely brokered the compromise between Tarzwell and Reimer, who eventually published a paper with a different title, “Diatoms and their Physico-Chemical Environment.”

Criticism of Patrick’s work disappeared from the third conference. Her former detractors, Doudoroff and Warren, were present at the conference, but their tune had changed. In their presentation on recent laboratory experiments on fish, they called for further research into the ecology of their favored species. Gaufin, who had criticized Patrick with Tarzwell in 1952, contributed a paper on stoneflies that complemented Roback’s own paper on caddisflies. Unlike the first conference, no one challenged Patrick’s definitions of pollution or questioned her methods. Instead, a survey of conference papers reveals that laboratory studies in the style of Doudoroff and Warren increasingly generated questions and concerns, whereas field studies like Patrick’s were flourishing.

The shift from lab to field among water pollution experts at the Taft Center was one of two changes captured in the opening and closing remarks of the conference. The other was a “turning toward an ecological approach.” James M. Quigley, assistant secretary of the Department of Health, Education and Welfare, and head of the Federal Water Pollution

Control Program, opened by presenting a new conception of the aquatic biologist. “For too long, problems of water pollution in this country have been approached in much too narrow, much too parochial ways.” He blamed the sanitary engineering community and its conservatism. “The boldness and imagination that have characterized engineering efforts in such varied fields as rocketry and saline-water conversion have all too often been lacking in their approach to water pollution control.” According to Quigley, sanitary biologists needed an infusion of ecological thinking. They needed to discard the “costly, wasteful, and senseless procedure” of the laboratory test in order to “work with natural laws rather than against them.”⁹⁸ Most of the methods developed by sanitary biologists were not producing useful results because they had not taken adequate notice of ecological relationships, such as Patrick’s discussion of the biodynamic cycle and food chain. The conference’s purpose was to begin a new research program with a broader understanding of the relationships among aquatic communities.

Richard H. Stroud and Charles H. Callison, who had witnessed many of the presentations of the conference, analyzed the common themes of the conference and confirmed Quigley’s conclusions. In their closing remarks, they criticized earlier biologists for their “unveiled contempt” for fieldwork and their emphasis on toxicity methods that were of limited use outside the laboratory. They called upon sanitary biologists at the conference to join national debates and inform the public of the implications of their research, just as Rachel Carson had done earlier that summer when she serialized “Silent Spring” in *The New*

⁹⁸ James M. Quigley, “The Role of the Aquatic Biologist in the Federal Water Pollution Control Program,” in *Biological Problems in Water Pollution, Third Seminar: Held at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, August 13-17, 1962*, ed. Clarence M Tarzwell (Cincinnati, Ohio: U.S. Department of Health, Education and Welfare, Public Health Service, Division of Water Supply and Pollution Control, 1962), 1–3.

Yorker. Patrick set the example when, in an article from *Reader's Digest* published days before the conference, she promoted the “intelligent use, not blind abuse” of streams and rivers.⁹⁹

The analysis by Stroud and Callison identified several factors that explain the shift from lab to field and toward an ecological approach, and Patrick was intimately involved in all of them. First, prejudices against field research diminished; since 1949, Patrick had been promoting her river survey, a field-based, taxonomically rich approach to studying pollution. Second, conclusions from laboratory results often did not match what was observed in the field; Patrick had identified problems and published her concerns about laboratory approaches as useful, but limited, throughout the previous decade, including at the first conference. Third, conference participants repeatedly noted that no single approach sufficed, and different approaches were needed that, together, formed what Stroud and Callison called a “kit of tools” for understanding pollution; Patrick’s method was criticized as vague and imprecise, but it emphasized early on that no single approach sufficed. Fourth, by 1962 there were simply more trained personnel to conduct ecological studies; Patrick had been training graduate students in her department for over a decade. Fifth, communication between disciplines, as well as the public understanding of science, had both improved; Patrick was committed mostly to improving the former, but Stroud and Callison also praised Patrick for the latter when they compared her to Carson. Sixth, chief scientists and administrators had a more favorable attitude toward ecological studies and helped direct policies and practices;

⁹⁹ James Poling, “She Takes the River’s Pulse,” *Reader's Digest*, August 1962, 172.

Patrick had allied with Tarzwell, who encouraged these two themes during the third conference.

Why had Tarzwell, who strongly influenced and enabled these shifts within the expert community of sanitary biologists at the Taft Center, warmed to Patrick's approach by 1962? Two developments suggest that it might have been the diatometer that swayed some of Patrick's critics, including Tarzwell. First, senior scientists at the Taft Center had seriously considered sending their staff to the Academy so they would learn how to use the diatometer in the field throughout the United States. In 1958, Patrick and Hohn trained Charles Mervin Palmer, a senior algologist in Tarzwell's Aquatic Biology Section and another organizer of the third conference, on their diatometer methods. Palmer was impressed by Patrick's 1956 conference article, and became interested in using the diatometer in a Taft center program called "Interference Organisms Studies." He spent about a month at the Academy in two separate trips. Three years later, Palmer and his successor, Louis Williams, merged this program into the much larger National Water Quality Network, which had just established over one hundred stations across the United States for water quality sampling and analysis. If Palmer and Williams had continued their training with Patrick and the Limnology Department, the diatometer might have become a standard instrument of water quality. But Williams decided not to adopt the full diatometer method. Instead, he selected parts of the method to incorporate into the nationwide water quality survey, using diatoms as indicator species, and discarded the rest—including the use of the diatometer. He may have found the process of slide reading too time consuming and complicated, especially without diatom experts like Patrick and Reimer available to manage the effort. Other than in helping the program identify certain diatoms, there is no evidence the Academy participated any further

in the national program.¹⁰⁰ But the episode does reveal the kind of attention the diatometer received in Tarzwell's Aquatic Biology Section.

Second, after 1962, some sanitary biologists, including Tarzwell, wrote favorably about the diatometer and shared its methods through their publications. These scientists often praised and promoted the diatometer while at the same time denigrating Patrick's more general claim about the relationship between pollution and species diversity and abundance. Tarzwell demonstrates this simultaneous acceptance and rejection in a chapter on "Sanitational Limnology" from 1963. Some scientists, he wrote, "maintain that pollution is any interference with the balance of nature or any change in the quantitative relationship of the biota. None of these definitions is entirely correct." He continued to promote strict definitions, in terms of some viable human use or hazard. In the same chapter, however, he dedicates a full paragraph to the merits of the diatometer method. Of all Patrick's work, including her impact on the 1962 conference, what really stood out to Tarzwell was her diatometer method. Other sanitary biologists, such as Jerome E. Stein and John G. Denison, later praised the graphical method in particular: "Patrick and co-workers (1963) vastly improved the presentation of indicator data by the application of log normal curves." They were less direct in crediting her with the "central idea" that "in nonpolluted environments there is a diversity in the qualitative and quantitative structure of the community."¹⁰¹

¹⁰⁰ Charles Mervin Palmer to Ruth Patrick, January 24, 1958, Ruth Patrick Papers, Box 27, Folder 35; Louis Gressett Williams and Carol Scott, "Principal Diatoms of Major Waterways of the United States," *Limnology and Oceanography* 7, no. 3 (April 1, 1962): 363–79.

¹⁰¹ Clarence M. Tarzwell, "Sanitational Limnology," in *Limnology in North America*, ed. David G. Frey (University of Wisconsin Press, 1963), 653--666; Jerome E. Stein and John G. Denison, "Limitations of Indicator Organisms," in *Pollution and Marine Ecology*, ed. Theodore A. Olson and Fredrick J. Burgess (Wiley Interscience, 1967), 323–49.

Patrick may have eventually swayed critics because the usual arguments leveled against her river surveys—that they were too complicated, expensive and qualitative—applied less to the diatometer. Other than the laborious process of slide reading, the diatometer was relatively straightforward to use and cost little to manufacture, install and maintain. Most importantly, perhaps, it relied upon a quantitative, graphical method. Historian Thomas Hankins has shown how graphical methods tend to become adopted more readily than metaphysical claims. As I have shown, Patrick was committed to, and praised for, her clarity and efficacy in the presentation of her results, both from her river survey and diatometer studies. Her graphs rendered quantifiable and concrete that which had been criticized as qualitative and vague. As a method, rather than a metaphysics, the diatometer results were much less controversial, and therefore easier to discuss, explain and accept, than her claim that pollution disrupted the balance of life in a stream.¹⁰²

The Taft Center conferences demonstrate how Patrick impacted water quality experts, who slowly became convinced of her ecological approach to pollution. Sanitary biologists and engineers who at first balked at Patrick's reference to the biodynamic cycle, her attention to whole diatom communities, and her way of bringing what they perceived as the complex methods of basic science to bear on applied problems, now understood that laboratory tests were insufficient, and that the indicator species approach needed to extend its domain of study beyond a select group of organisms. Not all of this change was due to Patrick, but she did significantly contribute to several factors involved in the shift. Although she convinced some of her critics that field studies were necessary, mounting evidence of the toxic effects

¹⁰² Thomas L. Hankins, "A 'Large and Graceful Sinuosity': John Herschel's Graphical Method," *Isis* 97, no. 4 (2006): 605–33.

of a growing number of chemicals also overwhelmed pollution experts, who in their conference papers called for greater attention to ecological studies. By the third conference, Patrick was viewed against the backdrop of a growing national debate on the use of chemical pesticides, sparked by Rachel Carson in June 1962.

Designing Experiments and Testing Theories

By 1963, Patrick had more time and resources to devote to taxonomic and experimental studies. In 1961, the Academy board permitted Patrick to use three-quarters of her department's profits—up to a limit of \$5,000 per year—for basic research projects, whereas previously all profits had gone to the museum. From July 1962 to July 1963, they granted her a leave of absence to work on her diatom manual, which would contain the vast taxonomic knowledge Patrick had compiled over three decades.¹⁰³ *The Diatoms of the United States*, published in two volumes in 1966 and 1975, was the first publication of its kind and changed diatom research in the United States. One reviewer praised Patrick and Reimer for their exceptionally clear and comprehensive treatment of diatom taxonomy, “one of the most difficult areas of systematic phycology.”¹⁰⁴ The work ended over a century of dependence on the European diatom literature.¹⁰⁵ It also stimulated diatom research in the United States, turning the Academy and its vast herbarium into a “diatomist's Mecca.”¹⁰⁶ Patrick also expected this manual to popularize her diatometer method. By the early 1960s, her

¹⁰³ Lewis H. Van Dusen, “Recommendation of the Departmental Program Committee Concerning the Policy and Program of the Limnology Department,” September 11, 1961, Box 27, Folder 49, Ruth Patrick Papers.

¹⁰⁴ Richard E. Norris, “Review: The Diatoms of the United States,” *Science* 153, no. 3742 (1966): 1369.

¹⁰⁵ G. W. Prescott, review of *The Diatoms of the United States*, by Ruth Patrick and Charles W Reimer, *Transactions of the American Microscopical Society* 85, no. 4 (1966): 582; Daniel E. Wujek, review of *The Diatoms of the United States*, by Ruth Patrick and Charles W Reimer, *Economic Botany* 21, no. 2 (1967): 193.

¹⁰⁶ Lowe, “Ruth Patrick,” 110.

experience from past river surveys streamlined the planning of later ones, and the diatometer program supplemented the full surveys. Her full-time, senior taxonomists—especially Cairns, Roback and Reimer—simplified the task of managing of the Limnology Department.¹⁰⁷

These developments, therefore, provided Patrick the opportunity to ask a broader range of fundamental questions in ecology. A series of experiments used the diatometer and a newly acquired creek on private land to create what Patrick called “semilaboratory” conditions that explored the causes and limits of structural change in diatom communities. This section examines Patrick’s creative experiments in the 1960s, which tested ecological theories and led to her election to the National Academy of Sciences in 1970. It also describes a new controversy caused by Patrick’s applied work and how she resolved it, and covers Patrick’s awards from the 1970s. These awards recognized Patrick’s basic and applied work in ecology, with particular emphasis on these later experiments.

Patrick continued to leverage connections with industrialists associated with the Academy to find opportunities to conduct basic research. In 1955, Patrick received \$80,000 from the Manufacturing Chemists’ Association of Washington to study how aquatic organisms colonize new areas of a stream.¹⁰⁸ Patrick needed a relatively stable experimental setting to conduct this study, and found one in 1958 when Samuel B. Eckert and his wife donated part of their property near Paoli, Pennsylvania, to the Limnology Department.¹⁰⁹

¹⁰⁷ For example, Cairns served as acting chairman of the Limnology Department from 1962 to 1963, when Patrick was given a leave of absence to complete her diatom manual. See Van Dusen, “Recommendation of the Departmental Program Committee Concerning the Policy and Program of the Limnology Department”; John Cairns Jr. to John C. Ragin, February 25, 1963, Box 11, Folder 8, Division of Environmental Research Records, Academy of Natural Sciences of Drexel University, Philadelphia.

¹⁰⁸ Anderson, “Summary of Work Performed, 1950 Thru 1977.”

¹⁰⁹ “Abstract of Minutes of the Annual Meeting of the Academy of Natural Sciences of Philadelphia,” *Proceedings of the Academy of Natural Sciences of Philadelphia* 111 (1959): 273–85.

Eckert had been a member of the Academy since 1927 and director and vice president of marketing for Sun Oil Company. Ridley Creek crossed their suburban estate as it meandered through townships southwest of Philadelphia before emptying into the Delaware.

Patrick created an artificial channel that linked two parts of the creek in order to observe the succession of aquatic organisms that entered the channel from upstream. She told a Baltimore journalist that she and the Eckerts “bulldozed what has been called the first ‘woman-made river,’ between two bends of the creek.”¹¹⁰ To Patrick, the creek served as a “semilaboratory” where she could test theories by running long-term, semi-controlled experiments.

The evidence from the Ridley Creek studies not only supplemented her applied work—she told one journalist that the creek helped her understand “how to reclaim a river that has been completely ‘burnt over’ by pollution”—but also helped Patrick advance recent ecological theories, including one that Hutchinson had promoted. In 1967, Robert H. MacArthur, a former doctoral student of Hutchinson, and Edward O. Wilson published their new and controversial theory of island biogeography. According to this theory, an island’s biological diversity is governed by a dynamic process of colonization and extinction, and correlates with various physical features of the island, such as its degree of isolation, area, elevation and complexity. MacArthur and Wilson’s theory set out a number of plausible scenarios, but these possibilities needed to be tested in experimental settings, with the idea that the experimental results could then be used to fine-tune the theory.¹¹¹

¹¹⁰ Frank Henry, “First Woman-Made River,” *The Baltimore Sun*, June 26, 1960.

¹¹¹ For Patrick’s comment to the journalist, see Poling, “She Takes the River’s Pulse,” 172. For MacArthur and Wilson’s theory, see Robert H. MacArthur and Edward O. Wilson, *The Theory of Island Biogeography*

Patrick's experiments contributed to the testing of MacArthur and Wilson's hypotheses and her results refined their conclusions by showing that, in the case of diatoms, some variables had larger effects on community structure than others. Using diatometer slides to simulate islands within Ridley Creek and a nearby spring, Patrick tested the relative effects of three variables from their theory: the island area, the rate of invasion and the "species pool" available to invade the area. She discovered that varying either the invasion rate or species pool changed the number and relative abundance of diatom species, whereas area had a relatively minor effect. Larger areas contained more species than smaller ones after a few days, but this effect did not continue and leveled off after a couple of weeks. Patrick varied the invasion rate by controlling the rate of water flowing toward the slide and varied the species pool by placing slides in two different creeks near Philadelphia that she knew had a different number of diatom species present.¹¹²

Patrick used the diatometer, an instrument born out of the demands of applied work, to isolate the effect of a single variable on the structure of aquatic communities. She focused on two variables in particular, water temperature and manganese concentration, and how they changed the relative abundance of diatoms, green algae and blue-green algae, or cyanobacteria. Algologists knew that blue-green algae tolerated higher temperatures and lower manganese concentrations than other algae, but the ranges of these variables that

(Princeton, NJ: Princeton University Press, 1967). Their theory was criticized by Daniel Simberloff in the mid-1970s for its tendency to oversimplify and ignore historical processes. See Sharon E. Kingsland, *Modeling Nature: Episodes in the History of Population Ecology* (University of Chicago Press, 1985), 192–97.

¹¹² Ruth Patrick, "The Effect of Invasion Rate, Species Pool, and Size of Area on the Structure of the Diatom Community," *Proceedings of the National Academy of Sciences* 58, no. 4 (October 1, 1967): 1335–42. For Patrick's assessment of these experiments, see Ruth Patrick, "Identifying Integrity through Ecosystem Study," in *The Integrity of Water: Proceedings of a Symposium, March 10-12, 1975, Washington, D.C.* (Environmental Protection Agency Office of Water and Hazardous Materials, 1977), 157.

constituted a shift from a more diverse flora to one consisting mostly of blue-green algae had not been studied. The experiment depended on her results from 1967, which demonstrated that a controlled set of diatometers under similar ecological conditions would contain diatom communities that were 95 to 98 per cent similar in their species composition.¹¹³ The experiment began with eight modified diatometers placed in a children's swimming pool continuously filled with water from a nearby creek. Pumps at the center of the pool directed water in one direction into the boxes. This experimental design served as a starting point for studying one parameter at a time in isolation. She first varied the temperature and then the manganese concentration in each of the eight boxes to determine the point at which the community transitioned from diatoms to green algae, then to blue-green algae. Patrick published her results in the *Proceedings of the National Academy of Sciences*, and was elected to the National Academy the following year.¹¹⁴

Forming New Institutions

In the 1960s, Patrick established two institutions that served as field sites for Limnology Department research. The first was the Stroud Water Research Center, set up to study streams under more controlled environmental conditions. The second was the Benedict Estuarine Laboratory, which studied the effects of power plants along the Chesapeake Bay on aquatic life. These two research sites—the first dedicated to basic research, the other to applied, but each one blending ideas, evidence and other resources from across the

¹¹³ Ruth Patrick, "The Structure of Diatom Communities in Similar Ecological Conditions," *The American Naturalist* 102, no. 924 (1968): 173–83.

¹¹⁴ Ruth Patrick, Bowman Crum, and John Coles, "Temperature and Manganese as Determining Factors in the Presence of Diatom or Blue-Green Algal Floras in Streams," *Proceedings of the National Academy of Sciences* 64, no. 2 (October 1, 1969): 472–78.

department's diverse activities—add to our sense of Patrick as an institution builder who created opportunities for a new generation of freshwater ecologists to flourish within Patrick's larger research program.

Patrick's idea for the Stroud Center further developed the ideas from her Ridley Creek studies. The land donated by the Eckert family near Ridley Creek had provided an opportunity to study invasion rates of different organisms, in what Patrick called "semi-laboratory" conditions. While Patrick was completing these studies, she was approached by Academy members William B. Dixon Stroud and his wife, Joan, who offered their help and financial support. Patrick suggested that White Clay Creek, part of which ran through their property, could be used to study the entire watershed. The Strouds also purchased adjacent land to expand the study area. By summer 1966, they converted their garage into a makeshift research laboratory and started planning a new building on their property. Work began in February of 1967 and was completed by the end of the year, with an upstairs library designed by Joan Stroud and water diverted from White Clay Creek running through the bottom floor of the new building.¹¹⁵

The goal at the Stroud Center was to understand every aspect of how the aquatic ecosystem functioned. Patrick had amassed a wealth of data on streams across the United States, some of which were healthy and others severely polluted, but her semi-laboratory experiments at Ridley Creek and White Clay Creek, two relatively unpolluted streams, provided more control over ecological factors and, therefore, a deeper understanding of

¹¹⁵ Peck and Stroud, *A Glorious Enterprise*, 335–38; "Stroud Water Research Center," *Stroud Water Research Center* (blog), accessed June 15, 2018, <https://stroudcenter.org/history/>.

ecological relationships than what she could learn from surveys. Patrick thought this deeper understanding of how ecosystems function would show ecologists how to restore polluted streams to their original conditions.

Patrick's work at the Stroud Center quickly expanded and helped train a new generation of ecologists in these semi-laboratory practices. In 1969, she received a five-year grant from the Rockefeller Foundation to pursue her research program on ecosystem function. She hired Bernard Sweeney and Robin Vannote, two ecologists who would significantly influence the Stroud Center's research. Sweeney arrived in 1972 as a first-year graduate student at the University of Pennsylvania and would become director at the Stroud Center in 1988. While researching at the Stroud Center in the 1970s, Vannote developed his River Continuum Concept, which explained variation in the structure of aquatic communities according to ecological factors that changed along the river. "From headwaters to mouth," he and his collaborators wrote in an influential article from 1980, "the physical variables within a river system present a continuous gradient of physical conditions." By securing land along the banks near the headwaters of the east branch of White Clay Creek, the Strouds had enabled Vannote and his team to study gradual changes along the length of the stream. Their continuum concept built upon Patrick's own ideas about how the changing structure of aquatic communities could indicate changes in the environment. "We reason that producer and consumer communities characteristic of a given river reach become established in harmony with the dynamic physical conditions of the channel."¹¹⁶

¹¹⁶ Robin L. Vannote et al., "The River Continuum Concept," *Canadian Journal of Fisheries and Aquatic Sciences* 37, no. 1 (January 1, 1980): 130–37.

The support Patrick received from the Strouds illustrates how significantly the nature and scope of Academy philanthropy had changed between the 1930s and 1960s. It contrasts, for example, with the support of Clement Newbold, a wealthy Philadelphian and family friend of Cadwalader who helped in fundraising campaigns of the early Depression. Newbold sponsored a large collecting expedition to South America in 1930, and three others by 1934, that funded the Department of Ornithology. On his international adventures he shot mountain goats and two grizzly bears and donated their skins to the Academy for Cadwalader's public displays. But there is little evidence that Newbold remained associated with the Academy after 1940. The Stroud family, on the other hand, donated their own land for environmental research, and have since remained active members of the Academy. They were also prominent in Philadelphia society, and William Stroud was equally engaged in traditional exploration; he had collected snails in New Guinea with an Academy expedition in 1956. These expeditions were fundamental to the Academy since its beginnings. But the Strouds understood that Patrick led the museum in new directions and wanted to support her vision. The stark difference between these two examples adds to our sense of how profoundly the Academy had changed through Patrick's strong influence.¹¹⁷

If the Stroud Center was built through a new kind of local philanthropy, one that tracked Patrick's environmental research, funding for the Academy's Benedict Estuarine Research Laboratory emerged from Patrick's expansive network of government and corporate contacts. The laboratory was established in 1967 along the Patuxent River in

¹¹⁷ Peck and Stroud, *A Glorious Enterprise*, 271–73; “Clement B. Newbold (1905–1984),” Academy of Natural Sciences of Drexel University, accessed May 27, 2019, <http://ansp.org/research/systematics-evolution/ornithology/ornithology-history/clement-b-newbold/>.

Benedict, Maryland, with the goal of preserving the aquatic communities of the Chesapeake watershed in light of the enormous economic development of the region. Patrick had studied that part of the Chesapeake before, first near Baltimore Harbor for the American Petroleum Institute in 1954 and again along the Potomac River for Potomac Electric and Power Company in the mid-1960s. The Benedict Laboratory drew funding from the state of Maryland, the US Navy, Baltimore Gas and Electric and the Maryland Oceanic and Atmospheric Administration. At first, it operated out of an old converted motel, but Patrick planned to build a state-of-the-art facility. Louis Sage, who directed the laboratory after 1973, tried to raise funds for the new building, but the plans never materialized. Despite this setback, the makeshift space served as a local base of operations for highly lucrative contracts the Academy secured near the Chesapeake Bay, outside power plants at Calvert Cliffs, Dickerson and Morgantown.¹¹⁸

The successful Stroud Center, founded for basic research, and the less successful Benedict Laboratory, which extended some of Patrick's more traditional applied work, demonstrate Patrick's track record as institution builder. By 1975, Patrick's department had a staff of over 20 scientists with PhDs and about 80 support staff, working across its three research sites. Although each site took on different questions, all of them featured ideas, evidence and other resources that were developed by Patrick through over thirty years of research, in which she blended and merged results from different studies. The diatometer, for example, inspired Patrick's studies of Ridley Creek, which in turn inspired questions pursued at the Stroud Center. Patrick's study of pollution encouraged this blending, since it yielded

¹¹⁸ Peck and Stroud, *A Glorious Enterprise*, 336–38.

both new and practical knowledge, and Patrick was one of the only ecologists willing to work with industries to understand pollution. This may have created new research opportunities, but it also elicited some criticism from academic scientists who had advanced their careers by different paths and who were independent of polluting industries like DuPont or national laboratories like the Savannah River Site.

Dealing with Criticism and Achieving Distinction

The synergistic relationship between basic and applied science that Patrick sustained for decades gained her admittance to the National Academy, but it also alarmed some academic biologists, who questioned the motives of an ecologist funded by chemical manufacturers and power companies. The late 1960s saw the emergence of this new kind of criticism of Patrick's work that, although rooted in the earlier criticism Patrick had faced, took on a different form within the environmental movement. While earlier arguments in the United States over the relative merits of pure and applied science tended to focus more on intellectual ideals—and the value of disinterested versus practical knowledge—Patrick's new critics questioned her motives and vested interests, and saw her as a scientific consultant whose ideas and publications were paid for by industries.

Patrick convinced some of her most outspoken critics that she was not a biased consultant by leveraging key allies in her vast network. In one episode, Eugene Cronin, a research professor and director of the Natural Resources Institute at the University of Maryland, criticized Patrick for conducting a baseline survey of the Potomac River near Morgantown, Maryland, for the Potomac Electric Power Company. Referring to Patrick as a

“company-hired consultant,” Cronin, the only biologist who publicly condemned Patrick’s work, criticized her method for its tendency to support industry’s view:

Dr. Patrick’s report on Morgantown observations in 1966 and 1967 contained some useful data, but includes many mistakes, and involves a theory that would permit her to say that there is no real evidence that pollution has occurred even when up to 40 per cent of the species disappear. This theory, used in combination with poor sampling, is dangerous.¹¹⁹

According to Kent Mountford, who worked for Patrick at the Academy in 1971 and was aware of this ongoing controversy, Cronin eventually changed his opinion of Patrick and her team when one of the biologists working for him at the Institute, David Flemer, invited Mountford and some of his assistants from the Limnology Department to conduct a survey of the Patuxent River. Flemer had completed his PhD at Rutgers University under Francesco Trama, who worked for Patrick as a graduate student in the 1950s under the grant she received from the US Public Health Service. As a student of Patrick’s student, Flemer took a more sympathetic view of her methods than Cronin. When Mountford conducted their “round-the-clock” survey, Cronin was able to observe Patrick’s methods first-hand and, according to Mountford, this “helped change Gene Cronin’s attitude and barriers slowly fell away.”¹²⁰

By the early 1970s, Patrick was recognized as a leading ecologist by government, academic scientists, and industrial managers and scientists. Over the next decade, Patrick received numerous awards and honorary positions from various institutions. In 1972, she was

¹¹⁹ James MacNees, “PEPCO Study Held Unsound: Marine Biologist Alleges Dangerous Errors,” *The Baltimore Sun*, March 16, 1969.

¹²⁰ Kent Mountford, “David Flemer, in Studying Tiny Plankton, Was Able to See Bay’s Big Picture,” *Bay Journal*, March 13, 2012; Constance Holden, “Ruth Patrick: Hard Work Brings Its Own (and Tyler) Reward,” *Science* 188, no. 4192 (June 1975): 997–99.

named Eminent Ecologist by the Ecological Society of America. The citation by Hutchinson and F. Herbert Bormann, the ESA president in 1970, credited Patrick's strong foundation in diatom taxonomy at the Academy and her connections with industry as largely responsible for her successes in ecology. Both the basic and the applied aspects of her research were, to Hutchinson and Bormann, why Patrick was "one of the very few Americans who are completely trusted by both the academic and industrial communities."¹²¹ Patrick became the first ecologist on the board of a major US company when DuPont elected her to that position in 1975. That same year, she received the second annual Tyler Award. Funded by the insurance magnate John C. Tyler and his wife, Alice, this award recognized those who have made "the greatest contribution to mankind in the field of ecology and improvement of the environment."¹²² Patrick was nominated by Hutchinson, who had received the award the previous year.¹²³

It is worth reflecting on the support that Patrick received from Hutchinson, one of the most accomplished and respected ecologists of the mid-twentieth century. Patrick brought her expertise in diatom taxonomy to bear on Hutchinson's research program at Linsley Pond, and she emerged with a new appreciation for ecological theory. When Patrick met with Hart for the first time, she solicited Hutchinson's advice, hoping to secure the support of the Limnological Society. When Stine beset her with challenging questions, Hutchinson helped her answer them, and he also helped Patrick prepare the survey results for the Sanitary Water Board. When the Catherwood Foundation offered Patrick research funds, Hutchinson

¹²¹ G. Evelyn Hutchinson and F. Herbert Bormann, "Eminent Ecologist, 1972, Ruth Patrick," *Bulletin of the Ecological Society of America* 53, no. 3 (September 1972): 7.

¹²² Richard S. Miller, "The Tyler Award," *Bulletin of the Ecological Society of America* 56, no. 1 (1975): 2-3.

¹²³ G. Evelyn Hutchinson to George C. Bates, August 27, 1974, G. Evelyn Hutchinson Papers, Box 25, Folder 405.

encouraged her idea for the diatometer. He assured Roberts that Patrick's new department was capable of important limnological research, and helped Patrick find young and able limnologists to fill positions in her growing department. Decades later, after Patrick had managed to stabilize the Limnology Department and secure time to design new experiments and test ecological theories, Hutchinson nominated her for prestigious awards that brought her and the Academy national distinction.

Their relationship, however, was not at all one sided; Hutchinson also benefited from his interactions with Patrick. In 1952, the Academy awarded him their Joseph Leidy Award, in recognition for his research but also as an expression of gratitude for helping Patrick establish her profitable department. In his speech for the award ceremony, he elaborated a theory of the concepts of order and pattern in ecology to an audience that most certainly would have included the young graduates in Patrick's growing department, and credited the diatometer for providing some evidence for his theories. Also, Hutchinson was likely pleased that Patrick's experiments provided evidence for the controversial theory of island biogeography, proposed by his former doctoral student, Robert MacArthur.¹²⁴

In her memoir, Patrick singled out Hutchinson as the one who, more than anyone else, helped her achieve distinction. "Hutchinson," she wrote, "had a profound effect on my scientific career, and his encouragement was a great factor in my success."¹²⁵ But Patrick also felt that, without his support, her research program at the Academy would have failed. Decades earlier, when she had just been granted her new laboratory by several supportive

¹²⁴ G. Evelyn Hutchinson, "The Concept of Pattern in Ecology," *Proceedings of the Academy of Natural Sciences of Philadelphia* 105 (1953): 1–12; Patrick, "The Development of the Science of Aquatic Ecosystems," 8.

¹²⁵ Patrick, "The Development of the Science of Aquatic Ecosystems," 8.

board members and was growing her corporate connections and staff, she expressed this sentiment in a letter to Hutchinson: “Let me say again how deeply grateful I am for all you have done to help our Limnology Department. We would have no department if it had not been for you.”¹²⁶

Conclusion

Woven through this essay, I have shown several ways in which Patrick created a synergistic relationship between basic and applied research in the postwar period. Starting with the 1948 Conestoga Basin survey, she helped the Sanitary Water Board understand the complex effects of pollution within Pennsylvania’s industrial landscape, but also tested her idea that would later be dubbed the “Patrick Principle.” With her new department, she offered an array of services to industrial managers, as exemplified by her 1953 letter to Crittenden, but she also generated new knowledge of fundamental ecological relationships and the balance of life in a river, as she expressed to Sears that same year. For her work on the Savannah River for DuPont, she both assessed the environmental impact of a nuclear facility and organized the ecosystematic study of the river’s flora and fauna, based on data she compiled from over fifteen years of seasonal surveys. She promoted her river surveys as insurance policies to nearly one hundred corporate clients, but she also directed them toward a kind of meta-survey of the number and kinds of species in rivers across the United States. She invented the diatometer to meet the growing demands for river surveys, but the instrument also led Patrick to design innovative experiments and test ecological theories. The key to Patrick’s success was the degree to which she sustained this synergistic relationship at every turn and

¹²⁶ Patrick to Hutchinson, November 21, 1950.

consistently sought ways to make the most of the connections, resources and evidence she had assembled over the years at the Academy.

To promote her ecological approach to environmental health, Patrick needed to overcome three different kinds of criticism: from members of the Academy who disapproved of the work performed by the Limnology Department, from biologists at the Public Health Service who rejected her methods as too complex and expensive, and from other biologists who viewed her willingness to work with polluting industries as disloyalty to the ideals of conservation and ecology. Much of this criticism is entangled with the significant discrimination she faced as a woman scientist in a male-dominated world, and the extent to which this discrimination affected her career requires further historical research. Patrick was the first woman curator at the Academy, the first woman to publish in *Sewage and Industrial Wastes*, the only woman presenter at the Taft Conferences, the first woman on the Academy board of trustees, the first woman to be elected to the board of trustees of DuPont and one of few women in the National Academy of Sciences. Although I acknowledge that Patrick benefitted from the support of several influential men, especially Hutchinson, their support does not explain how Patrick was able to achieve her success at a time when women were considered incapable of conducting scientific research and managing multidisciplinary teams. She developed her own ideas, skillfully managed her department and persevered amidst such criticism.

By bringing in years of funding for Academy overhead and work for other departments, by training new generations of Academy scientists, by pulling more potential Academy donors into her environmental orbit, and by setting trends on environmental monitoring during a period in which this became increasingly important in American society,

Patrick fundamentally transformed the Academy. She at first benefitted from its wealth of taxonomic resources and expertise, which helped Patrick test a complex, labor-intensive idea with extraordinary efficiency. Its diatom herbarium earned Patrick an international reputation as a diatom expert, helped her train the slide readers for her diatometer program and contributed to her diatom manual. At the same time, some members of the Academy resisted the applied work Patrick's department would pursue in the 1950s. This same department, however, expanded the Academy, first through the profits it earned from its corporate clientele, then through the way Patrick led the Academy in new directions that intersected with national environmental concerns. Patrick built many things—expansive academic and corporate networks, a unique instrument to collect diatoms, a flourishing department that housed several PhDs and trained dozens of graduate students, and an extensive research program. Most importantly, however, she rebuilt the Academy into a new institution. In 1983, the Academy honored her legacy by renaming the Limnology Department the Patrick Center for Environmental Research, which continues to pursue the synergistic relationship Patrick envisioned between basic and applied research.

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Curriculum Vitae

Ryan James Hearty holds undergraduate degrees from Peabody Conservatory and Johns Hopkins University in Baltimore, Maryland. He received a master's degree in electrical and computer engineering at Johns Hopkins University in 2011, with a focus on software-defined radio. From 2011 to 2017, he worked at the Johns Hopkins University Applied Physics Laboratory (APL), where he helped design, assemble and test the software-defined radio for NASA's Parker Solar Probe. After working at APL, he began his PhD in history of science and technology at Johns Hopkins University in 2017.