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TOPICAL COLLECTION ARTICLE: WOMEN, GENDER AND SEXUALITY IN BIOLOGY

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Redefining Boundaries: Ruth Myrtle Patrick's Ecological Program at the Academy of Natural Sciences of Philadelphia, 1947–1975

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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. In 1947, an opportunity arose for Patrick to lead a new kind of river survey for the Pennsylvania Sanitary Water Board to study the effects of pollution on aquatic organisms. Patrick leveraged her already extensive scientific network, which included ecologist G. Evelyn Hutchinson, to overcome resistance within the Academy, establish a new Department of Limnology, and carry out the survey, which was a resounding success and brought much needed money to the Academy. As demand for her expertise grew among industrial companies, such as the chemical company DuPont, Patrick became more active in the world of applied science. She repurposed data and instruments from her river surveys to run new experiments, test ecological theories, and conduct long-term ecological studies. Through these studies, she advanced an argument that biologist Thomas Lovejoy dubbed the "Patrick principle," the idea that the ecological health of a body of water could be measured by the relative abundance and diversity of species living there. Patrick was elected to the National Academy of Sciences in 1970, became a board member of DuPont in 1975, and received two of the most prestigious awards in ecology: the Eminent Ecologist Award from the Ecological Society of America in 1972 and the Tyler Ecology Award in 1975. This article analyzes Patrick's unusual success in bridging the worlds of science and industry and her unusual ability to cross, and redefine, the perceived boundary between basic and applied fields in biology. It argues that Patrick's position at the Academy, an institution of natural history that was both willing and able to accept money from industrial corporations, is key to understanding her success in, and influence on, the field of river ecology.

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Introduction

In 1974, Yale ecologist George Evelyn Hutchinson nominated his long-time colleague, Ruth Myrtle Patrick, for the Tyler Ecology Award (now called the Tyler Prize for Environmental Achievement), which she received in 1975, along with $150,000. 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” (Miller 1975). Hutchinson had received the first Tyler Award in 1974, sharing it with Arie Haagen-Smit for his work on air pollution and Maurice Strong, the first executive director of the UN Environment Programme. Patrick received the second award in 1975, the sole recipient that year.

In his nomination letter, Hutchinson referred to Patrick’s “enthusiasm and seemingly limitless energy” in her meticulous studies of diatom taxonomy and described her as a “dynamic advocate of clear healthy rivers,” whether working on a government committee or company board.[1] Her fundamental studies of diatom flora of post-glacial lakes, Hutchinson explained, served as a “powerful approach to a standard natural sequence without which pollution studies are meaningless.” He added that, through “her energy, sincerity and knowledge,” Patrick had earned the respect of both scientists and industrialists to speak on matters of river pollution. Hutchinson made much the same point earlier when he and Frederick Herbert Bormann wrote the citation for the Eminent Ecologist Award, which Patrick received from the Ecological Society of America in 1972. Hutchinson and Bormann claimed that Patrick was “one of the very few Americans who are completely trusted by both the academic and industrial communities” (Hutchinson and Bormann 1972). In his Tyler Award nomination, Hutchinson noted how Patrick’s innovative experimental work relating the balance of species to water chemistry, especially to the trace element manganese, laid the basis for future efforts to improve the inland waters of the world. Patrick’s work, he predicted, would “appear as a major contribution providing the fundamental basis for what later can be done” to address problems of water pollution. That Patrick would be not only the second recipient of the Tyler Award, but also the sole recipient of an award commonly shared among two or three candidates, was a remarkable testimony, not only to her intelligence, energy, and hard work, but also to her ability to combine both basic and applied science in a way that matched the aims of the Tyler Award.

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” (Lovejoy 2000), which was the idea that the ecological health of a body of water could be measured by the relative abundance and diversity of species living there. Patrick specialized in the study of diatoms, single-celled planktonic algae with cell walls made of silica,

[1] G. Evelyn Hutchinson, “Tyler Award,” n.d., Hutchinson Papers, Box 25, Folder 405, Sterling Memorial Library, Yale University, New Haven; hereafter cited as the Hutchinson Papers.

and pioneered the use of these widespread organisms as measures of river pollution. Much of her work was done at the Academy, whose trustees in 1948 created a new Department of Limnology for Patrick and her research team. She specialized in a new kind of river survey that leveraged the expertise of several taxonomists, many more than was usual at the time, to measure the effects of pollution on the relative abundance and diversity of aquatic life. The research and river surveys carried out by her department expanded over two decades to embrace a wide range of both basic and applied problems relating to river ecology and water pollution. By 1975, Patrick had not only received the Tyler and Eminent Ecologist Awards; she had also been elected to the National Academy of Sciences in 1970 and was a board member for the E. I. Du Pont de Nemours & Company (hereafter, DuPont). Patrick continued to chair her department until 1973, when she became chair of the Academy's board of trustees. These basic facts about Patrick's scientific career are described in her biographical memoir for the National Academy of Sciences (Bott and Sweeney 2014).

By the time the Department of Limnology was created, Patrick had worked at the Academy, mostly unpaid, for fifteen years. After offering to volunteer with the Department of Microscopy in 1933 to gain access to the Academy's diatom collections for her PhD research, Patrick became a member of the Academy in 1935 while working to publish her dissertation on the distribution of freshwater diatoms of the Malay Peninsula. With her entomologist husband, Charles Hodge IV, on the faculty at Temple University, she remained in Philadelphia and continued to volunteer at the Academy, performing tasks such as organizing their vast diatom herbarium. It was only in 1945 that she was put on the Academy's payroll and in 1947 that an opportunity arose for her to bring in the funds that helped to support the creation her department.

Patrick's early career thus followed that of many other women in science in the United States during the 1930s and 1940s. As Margaret Rossiter has shown in three monumental volumes, gender has shaped women's careers in American science (1982, 1995, 2012). Rossiter argued that many of the women who led successful careers in the 1950s and 1960s typically found their scientific niche in nonprofit rather than academic institutions. Funded by private philanthropy and federal grants, these institutions were more likely to support scientific specialties such as biology, psychology, and biochemistry that featured higher proportions of women. Many of these women, Rossiter suggests, would have preferred academic positions, but with these closed to them, they instead chose careers in organizations with "short promotional ladders, flexible work styles, and admittedly often low (and in some cases nonexistent) salaries" (1995, pp. 235–245).

While Rossiter's framework is useful for understanding Patrick's early career path, it does not explain how Patrick's case differed from other "institution builders," as Rossiter referred to women who established themselves in non-academic institutions. Patrick certainly was an institution builder, as this article will demonstrate. Although she frequently taught courses throughout her career—first, at the Pennsylvania School of Horticulture for Women from 1935 to 1945 and later at the University of Pennsylvania from 1950 to 1970—Patrick did not persist in realizing an academic career. She viewed this as closed to her, not only because she was a woman, but also because she had earned her PhD in the middle of the Depression when jobs were scarce (Mandula 1997; Brown and Hartman 2004). For Patrick, a diatom ecologist, the Academy would have seemed a better fit from the start, given its enormous collection of diatoms and other resources for undertaking taxonomic research.

Unlike the other women Rossiter studied, Patrick was unique in raising most of her research resources from industry rather than from private philanthropy or federal grants. Her institutional niche afforded her the flexibility to receive funding for applied work that would have been more difficult to pursue in academic settings. Jean Langenheim, in a detailed review of the history of women in ecology, points out that Patrick seems to have avoided some of the problems that women in academia experienced (Langenheim 1996, p. 13). Langenheim's observation provides an important clue that requires deeper investigation. I argue that Patrick's position at the Academy, an institution of natural history, is crucial for understanding why her career was different from the pattern common to other women in ecology. The Academy was extremely strapped for money during the Great Depression and did not benefit from the increased funding available for science during the Second World War. This partly explains why Patrick was not paid over the period when the Academy hired no new curators and even cut employee salaries. When new funds for the study of pollution became available through Patrick's network of industrial managers, the Academy's trustees were anxious and able to accept the money. They were willing, if reluctant, to look past prejudices among the Academy's leadership against women as research leaders to accommodate the wishes of those who were supplying the research funds. When opportunity arose, Patrick was extremely well prepared. Her multidisciplinary river survey brought the vast taxonomic knowledge of the Academy to bear on problems of industrial water pollution. By leading hundreds of these surveys for polluting industries, Patrick not only funded her department but also generated a surplus, transforming her home institution. Moreover, she constantly repurposed data gathered during these surveys in ways that contributed to basic research in ecology and taxonomy, elevating her academic status.

The wartime and postwar context of the 1940s was a critical period for expanding the kind of freshwater ecology and taxonomy that was Patrick's specialty, since new sources of funding became available for studying the causes of pollution in the nation's waterways. The federal government, concerned about high levels of stream pollution, moved to regulate point sources of pollution through passage of the Federal Water Pollution Control Act of 1948. Prior to this legislation, in the mid-1940s industries were already being sued on the grounds that they were polluting waterways. These lawsuits pressured industry to find ways to evaluate the impact of industrial effluents on waterways and possibly fend off future regulation. This context helps explain how funding became available for Patrick's new Department of Limnology at the Academy in the mid-1940s.

Although the Academy's financial needs, met by newly available funds from industry, enabled Patrick to obtain and sustain a central position as department chair, three other factors also explain Patrick's scientific productivity over a period when few other women achieved similar success. First, there is the undoubted fact, as Hutchinson's citation suggests, that she was extraordinarily creative, intelligent, and energetic. This article describes some aspects of her creative intelligence, in particular the innovative ways in which she developed a robust research program, devised new graphical methods to represent her results, invented new instruments for gathering data, and devised what Hutchinson referred to as "a remarkable set of experiments using quasi-natural but chemically controlled streams" to test the effect of trace elements on species diversity and relative abundance.

Second, Patrick relied on her mentors and the vast scientific network she had assembled in the decade after her PhD, enabling her to expand beyond her disciplinary boundaries and break into new disciplines. Patrick had collaborated and co-authored scientific studies with Hutchinson and his students and had become active in the Limnological Society of America, presenting her work at scientific meetings. Patrick turned to her network as she enlarged her scientific projects by including areas of knowledge in which she lacked specific expertise. This enabled her to move from a narrow specialization in diatoms to a broader type of ecological river survey that required a team of researchers, each performing different tasks and with different areas of expertise. Patrick explicitly acknowledged Hutchinson, above all others, for his immense support of her work, and this article focuses on their relationship. It is crucial to understand how Patrick's success depended on more than clever ideas or hard work: it depended on building teams and drawing on a diverse range of experts so that projects could transcend biological specialties.

At the same time she was expanding beyond the boundaries of biological disciplines that focused on studies of specific classes of organisms, Patrick was also breaking through the boundaries of applied sciences, in which some researchers were approaching the study of pollution through the lenses of the public health and engineering professions. The methods they used to assess problems such as pollution were well established, but Patrick was not speaking their language. Patrick's fields were taxonomy and ecology, and she brought the perspectives of these disciplines into applied studies of water quality in a new way. As a result, she was viewed with suspicion by applied scientists, who thought she was really a "basic" biologist only masquerading as an applied scientist. Patrick's gender only heightened their perception of her as outsider, as she was often the only female presenter at pollution conferences. Her student John Cairns accompanied her to meetings with industrial managers who were "always male and were very interested in seeing and talking with a woman who worked near sewage and industrial waste" (Cairns 2013). She convinced many of these men that her ecological approach was a valid way to study an applied problem, demonstrated not only by her receiving the Tyler Award but also by Lovejoy's recognition of the "Patrick principle."

Third, Patrick benefited from the enormous federal investment in national laboratories after the Second World War. These were new institutions where the distinction between basic and applied research was less rigidly observed, and where many American ecologists found their niche (Bocking 1995). Patrick also managed to find a niche within this new setting: her work on the Savannah River over more than two decades funded her department and created opportunities for long-term ecological research.

As a result of this combination of circumstances and opportunities, Patrick, throughout her career, was able to navigate across the boundary of basic and applied science in a way that was unusual. Her scientific identity was not fixed in the first decade after her doctorate but was shaped later, when she had the experience and connections to seize and exploit new opportunities that emerged in the postwar environment. These enabled her to forge a career that differed from the typical museum taxonomist, academic, or applied scientist working in public health or engineering. It is this story of boundary-crossing that this article will tell. By understanding Patrick's unusual willingness and ability to step outside the boundary of what was expected and combine goals in a synergistic way that contributed equally to basic and applied science, we can better understand what led to her eventual success and eminence.

Finding Opportunity

Patrick's success in the worlds of science and industry depended on the extensive knowledge of diatom taxonomy she had accumulated before entering the hallowed halls of the Academy. Her father, a lawyer who had wanted to become a scientist and studied diatoms in his spare time, encouraged his daughter to pursue a scientific career and financially supported her through graduate school. In 1931, after marrying Charles Hodge (1900–1985), Patrick chose to retain her maiden name out of honor to her father, who wanted to have a scientist in the Patrick family (Holden 1975). When Hodge joined the faculty of biology at Temple University the following year, Patrick worked remotely from Philadelphia to complete her PhD in botany from the University of Virginia, volunteering at the Academy in order to access its diatom collections for her research and receiving her degree in 1934 (Mandula 1997; Patrick 1997; Cairns 2014).[2]

According to several sources, Patrick continued to work as a volunteer at the Academy from 1933 to 1945. Later in life, Patrick explained why she continued in this unremunerated position for so long. First, her husband had family and professional ties in Philadelphia; second, academic positions were scarce during the Depression, especially for women and taxonomists; and, third, the Academy housed the largest diatom herbarium in the US, which was key to Patrick's further taxonomic research (Mandula 1997; Patrick 1997; Brown and Hartman 2004).

Historians have stressed the importance of marriage and family relationships on scientific work and creativity, and Patrick and Hodge certainly qualify as a form of collaborative, scientific couple (Abir-Am and Outram 1987; Pycior et al. 1995; Lykknes et al. 2015). The two first met at Cold Spring Harbor Laboratory while she was an undergraduate at Coker College for Women in the late 1920s and married in 1931. Hodge, who was from an established Philadelphia family tracing its lineage

[2] Sources are contradictory on the time Patrick spent between Philadelphia and Charlottesville in the early 1930s. Patrick stated that she completed doctoral coursework at the University of Pennsylvania, while Cairns pointed out that Patrick had become curator of the Academy's Department of Microscopy by 1933. These sources suggest that Patrick settled in Philadelphia by 1933, although by then she had likely made several trips to the Academy. The biological sketches by those who were less familiar with her early career, such as Bott and Sweeney (2014) and Lowe (2015), simply point out that she moved to Philadelphia after receiving her PhD.

back to Benjamin Franklin, got a teaching position in biology at Temple University in 1932 (Mandula 1997). We know little else about Hodge from available sources, but Patrick's own memoir suggests that, although her attention was divided between home and workplace, she felt fortunate that Hodge supported her career and read and discussed the biological literature with her (Patrick 1997).[3]

The Great Depression severely affected the academic job market, especially for someone who was a diatom taxonomist. By the time Patrick received her PhD in 1934, the venerable Academy of Natural Sciences of Philadelphia, with its century-old natural history museum, was financially unstable. It had passed what Peck called its "Golden Age of exploration" in the first third of the twentieth century, when wealthy patrons sponsored collecting trips abroad (2000, pp. 17–18). Charles Cadwalader, who had been the Academy's managing director since 1928, struggled to sustain revenue amid the depression.

Cadwalader came from an old and well-connected Philadelphia family, apparently never took a salary, and by the early 1930s had arranged for a few wealthy amateur naturalists, such as Clement Newbold and George Washington Vanderbilt III, to fund collecting trips. These trips helped to balance the Academy's budget, which for years had depended on dividends from stocks and other securities. Cadwalader also updated the museum's exhibits to attract the public and generate new sources of revenue. He installed several new and exotic dioramas under the guidance of Clarence Rosenkranz, who 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 Academy members criticized Cadwalader's plan. For example, entomologist Eleanor Carothers claimed that the new dioramas distracted curators from the Academy's goals in taxonomic study. Most members, however, went along with these changes. Yet despite his efforts to sustain the Academy through the depression by arranging expeditions and creating more public displays, Cadwalader's innovations could not guarantee the Academy'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 staff remained small and its future uncertain (Peck and Stroud 2012, pp. 270–286; Rader and Cain 2014, p. 71).

While serving as a volunteer staff member at the Academy through the late 1930s, Patrick began to apply her knowledge of diatoms to broader problems outside the field of botany. In a piece in *Frontiers*, she referred to diatoms as "the useful jewels of the sea" (1938), listing their many industrial uses, such as a stabilizer for dynamite, in fine polishes, and in purifying beer and sugar. The article also indicated that Patrick was expanding her research of diatoms to include their ecology—their relations with other organisms and with abiotic conditions. Since certain diatoms were

[3] At the time of Hodge's death in 1985, Patrick created a memorial scholarship in his name at Temple for a "graduating senior in the Biology Department who has been distinguished in the areas of research and scholarly achievements" (College of Science and Technology Awards 2020).

"very specific for the types of environment which they prefer," she wrote, "some species are valuable in water analyses as indicators of specific conditions."[4]

In the 1940s, Patrick increased her knowledge of how diatoms addressed different disciplinary concerns outside botany while also promoting a broader vision for diatom research at conferences. In 1940, she began collaborating with Hutchinson, who, with graduate students Edward Smith Deevey Jr. and Anne Wollack, was studying the biological history of Linsley Pond near the campus of Yale University. The team studied sediment cores from the pond to understand how changes in fossilized pollen, diatom communities, and chemical concentrations were related over centuries (Deevey 1939; Hutchinson and Wollack 1940; Patrick 1943). Contributions from Wollack, a water chemist, strengthened Patrick's ideas about the relationship between diatoms and their environment. 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 (Patrick 1948a). In March 1946, Patrick presented her research on diatoms at the American Association for the Advancement of Science meeting in St. Louis, Missouri, the first meeting of AAAS following a two-year wartime suspension. The gathering was enormous: forty-one other scientific societies participated, including the Limnological Society of America (Lauff 1963, p. 672).

Patrick's presentation at the conference 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 new method involving fish placed in test solutions of river water with varying concentrations of a given pollutant to determine its "median tolerance limit," or the concentration at which half the fish died and the other half survived. This became a widely accepted procedure in industry for evaluating the toxicity of wastewater (W. B. Hart et al. 1945).

Despite the positive reception of his method, Hart's company was involved in a lawsuit over the effluent from one of its refineries, and his method was proving unconvincing in court. Although many of the fish survived in his laboratory tanks filled with river water, some were weakened by fungal infection.[5] According to Patrick, Hart "cornered" her at the AAAS meeting and asked for her help. He intended to enlist not only Patrick but also other members of the Limnological Society and offer them financial support from his company. The money interested Patrick, who wrote to Hutchinson for advice in April: "[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

[4] Earlier naturalists had also promoted the taxa's valuable applications. For example, Mann, curator at the Smithsonian Institution, wrote that "there is no better illustration in science of the practical value of ecology than is afforded by the diatoms" (1921, p. 79). He contrasted the common conception of diatoms as "little more than the playthings of microscopists" with the more capacious vision he was proposing, in which knowledge of diatoms, the "great fundamental food-supply of the aquatic world," would greatly enhance the current work in the fishing industry under the guidance of the US Bureau of Fisheries.

[5] William B. Hart to Ruth Patrick, June 28, 1946, Hutchinson Papers, Box 41, Folder 651.

individuals involved or for the Society as a whole to have the support of the oil company for this work."[6]

Hutchinson failed to respond, but Hart was persistent, visiting Patrick several times in Philadelphia. In July 1946, Patrick again wrote to Hutchinson, who had recently been elected president of the Limnological Society:

> 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.[7]

Hutchinson balked at the proposal, finally responding 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."[8] But what were the dangers? Patrick needed to spell out the financial benefits of applied science for Hutchinson. Both scientists considered the Linsley Pond study as basic or "pure" research: it investigated ecological systems that were relatively unaffected by human activity and their results would mostly interest academic scientists. Both also agreed that Hart's work was "applied" because it assessed the effect of human activity on ecological systems; any work Patrick performed for Hart would benefit industry and be of little use or interest to academic scientists. While both acknowledged a boundary between pure research and applied science, only Patrick expressed a willingness to cross it. In the end, Hutchinson remained skeptical of Hart's "scheme," although nevertheless agreeing to meet with Hart and Patrick, suggesting that they discuss the matter at the next Society meeting in late December. Patrick was ill, however, and unable to attend, and it does not appear that the Society ever took up the offer of outside pay for stream pollution research.[9]

Hart's problem at Atlantic Refining was typical of a larger trend in the United States toward stricter government regulation of water quality and stream pollution. By the mid-1940s, government and industrial officials shared a growing concern over the effects of industrial waste on the nation's water quality. Two legislative changes indicate that greater regulations were considered necessary. First, in 1946, the American Water Works Association adopted recently revised Drinking Water Standards of the US Public Health Service, despite internal criticism that these new standards did not go far enough in protecting water quality. By that time, lawsuits over water pollution were common, especially in Pennsylvania, one of the nation's

[6] Ruth Patrick to G. Evelyn Hutchinson, April 12, 1946, Hutchinson Papers, Box 41, Folder 651.

[7] Ruth Patrick to G. Evelyn Hutchinson, July 8, 1946, Hutchinson Papers, Box 41, Folder 651.

[8] G. Evelyn Hutchinson to Ruth Patrick, October 28, 1946, Hutchinson Papers, Box 41, Folder 651.

[9] Ruth Patrick to G. Evelyn Hutchinson, December 27, 1946, Hutchinson Papers, Box 41, Folder 651. 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, although 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 (1963, p. 680).

largest industrial producers. Coal mines, steel mills, pulp and paper mills, tanneries, distilleries, canneries, milk plants, textile mills, dye houses, and petroleum industries like Hart's Atlantic Refining all dumped wastewater into local streams and rivers. Second, the Water Pollution Control Act of 1948, the first major federal legislation of its kind, regulated interstate water pollution. Although its statutes were difficult to enforce and it limited federal power by requiring the consent of the affected states, the Act represented growing national concern over pollution abatement (Melosi 2011, pp. 67–71).

Hart, a pollution expert eager to see his problems with oil refinery wastes resolved, was well connected to both the Philadelphia corporate world and Pennsylvania's state government. Besides managing pollution abatement at Atlantic Refining, he was also chair of the Stream Pollution Committee of Oil Industries of America and president of the Pennsylvania Chamber of Commerce. Hart generally supported government regulation of industry. In the mid-1940s, he helped develop water pollution standards for the Pennsylvania's Sanitary Water Board (Hart and Milligan 1948). Without the support of the Limnological Society, Hart approached Academy leadership for help. Using his connections, Hart raised $60,000 (about $700,000 today) for Patrick to design and lead a new kind of river survey for Pennsylvania's Water Board that might determine the effects of various pollutants on aquatic communities and become a standard for future water quality assessment. Patrick, with Hart's endorsement, only needed to convince Academy leadership that she could manage the project.

Leading a New Kind of Survey

The Academy needed Hart's money, but Cadwalader was not comfortable with a woman leading the survey. As Patrick recalled, he was "horrified" by the idea that Patrick would manage the funds and personnel involved in such a large-scale pollution study because he believed she "was a young woman and all young women waste money" (Patrick 1997). When Patrick later shared this story with her students and colleagues at the Academy, she credited Hart for threatening to withhold the money from the Academy unless Patrick led the survey (Hart 2014). Although at Hart's insistence Cadwalader eventually relented, he needed assurance that Patrick would not endanger the new relationship. He enlisted Charles Stine, a DuPont manager and Academy trustee since 1941, to supervise her work.

Although Stine knew little about limnology, Patrick remembered his perceptive questions, which encouraged her to convene 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, professor of limnology at the University of Wisconsin-Madison; 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 support of these scientists, Patrick convinced men like Cadwalader and Stine that she could manage the river survey. As their confidence in her abilities grew over the summer and fall of 1947, Patrick began preparations for the survey in early 1948 (Mandula 1997).

Patrick assembled a team of both young and experienced scientists from within and outside the Academy. With a map of major polluting industries in the region provided by the Sanitary Water Board, she and Jack Graham, a geologist with the US Geological Survey, identified 170 collection stations within the Conestoga Basin to the north and east of Lancaster, Pennsylvania. At each station, water chemists and bacteriologists analyzed stream samples using standard methods defined by the American Public Health Association, while Patrick's team of biologists, many of whom were graduate students hired for the summer, 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 (Patrick 1948b, p. 25). Patrick enlisted senior curators from the Academy, such as ichthyologist Henry Weed Fowler and malacologist Henry Augustus Pilsbry, to assist with the more difficult identifications. If neither her team in the field nor the curators back at the Academy could identify a specimen, Patrick mailed it to one of the consultants in her extended academic network, drawing on the expertise and connections of her advisory committee when necessary. Patrick's skill at building teams was an important reason for her success. With such efficient organization, Patrick completed the massive survey in less than a year, brought much needed revenue to the Academy, and published her results in the Academy's *Proceedings* by December (Patrick 1949).

To legitimize her leading role in the survey, Patrick and Hart convinced H. Radclyffe Roberts, the Academy's managing director, to establish a new Department of Limnology in May 1948, with Patrick as chair.[10] Some of the graduate students who had assisted Patrick with the survey, such as John H. Wallace and John Cairns Jr., became the department's first full-time staff. Documents from the Academy's budget meetings reveal that Roberts and Cadwalader expected Patrick to conduct more surveys and bring in more revenue.[11] The new department provided Patrick with an institutional base and an opportunity to manage research programs, as long as she continued to generate surplus revenue for the Academy.

Patrick articulated the more theoretical aspects of the survey in her *Proceedings* report (Patrick 1949). Her approach was based on a biological measure of a stream's health, namely, the diversity and abundance of species. She attributed this idea to the German limnologist August Thienemann, who in 1939 argued that optimum environments supported large numbers of species with relatively small populations (Thienemann 1939). Hutchinson had collaborated with Thienemann in the 1930s

[10] John E. Bowers, "Minutes, Academy Trustees," May 19, 1948, Board of Trustees Records, Box 2, Folder 6, Academy of Natural Sciences of Drexel University, Philadelphia; hereafter cited as the Board of Trustees Records.

[11] John E. Bowers, "Minutes, Academy Trustees," October 5, 1948, Board of Trustees Records, Box 2, Folder 6.

and again soon after the Second World War, when Hutchinson sent CARE packages to Thienemann and his wife in Plön.[12] Throughout the first half of the twentieth century, Thienemann applied his taxonomic and theoretical knowledge to problems of wastewater as director of the KWI for Hydrobiological Research, established in 1911 by the Kaiser Wilhelm Gesellschaft as one of the new German research institutions financed by industry and government (Nyhart 2009, p. 321; Kaldewey and Schauz 2018, pp. 68–69). While Thienemann provided Patrick with a scientific basis and support for her ecological theory, she also acknowledged Robert Earl Richardson, who had studied river pollution from 1913 to 1928 for the Illinois Natural History Survey and 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 (Richardson 1921).[13]

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 pesticide- and nutrient-rich runoff from farms, while others were weakened by the presence of such chemicals. In natural streams, 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. The 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 also 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 ichthyology, malacology, and entomology, was uniquely capable of providing (Patrick 1948a, p. 500; Patrick et al. 1954).

In her Academy publication, Patrick devised a graphical representation of the survey results that would allow her broad audience to distinguish quickly between relatively polluted and healthy stream sections within the basin. Patrick understood from Hart that government officials and industrial managers would be interested in adopting her river survey approach, but only if it yielded a simplified measure, or "yardstick," of relative pollution levels. 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 (Fig. 1). She divided all species of aquatic organisms found across stations into seven groups based on their similar sensitivities to certain ecological

[12] August Thienemann to G. Evelyn Hutchinson, March 20, 1947, Hutchinson Papers, Box 49, Folder 822.

[13] To contrast Patrick's survey to one from the same period that used far fewer taxa, see Gaufin and Tarzwell (1952).

conditions, such as change in temperature or dissolved oxygen level. These groups represented the seven columns along the horizontal axes.

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.[14] 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" (Patrick 1949, p. 289). Even without understanding the meaning behind the plot's construction, one could quickly recognize the condition of a stream by simply comparing the relative heights of these seven columns.

Patrick's 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. 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 her 1949 article on the Conestoga Basin survey, Patrick explained why her method improved upon each of the three most common measures of stream pollution at the time. 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. For each station Patrick surveyed, her chemist, John M. Ward, measured these properties, which he found either to differ significantly across two healthy stations or match closely between a healthy and polluted station. These physical and chemical properties also changed over time, and their measurement would not detect a temporary wave of pollutants that had earlier wiped out aquatic life. Second, sanitary engineers measured the biochemical oxygen demand and counted coliform bacteria in effluent before it entered a stream. Patrick argued that this approach, though valuable for sanitary wastes, failed to measure the effects of toxic chemicals on aquatic life. A third standard method, and the one favored by most applied 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 could 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.

Hart's method for evaluating toxicity was based on the indicator species approach. Patrick thought this approach had one major flaw: the organisms might tolerate some

[14] 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 found within each group.

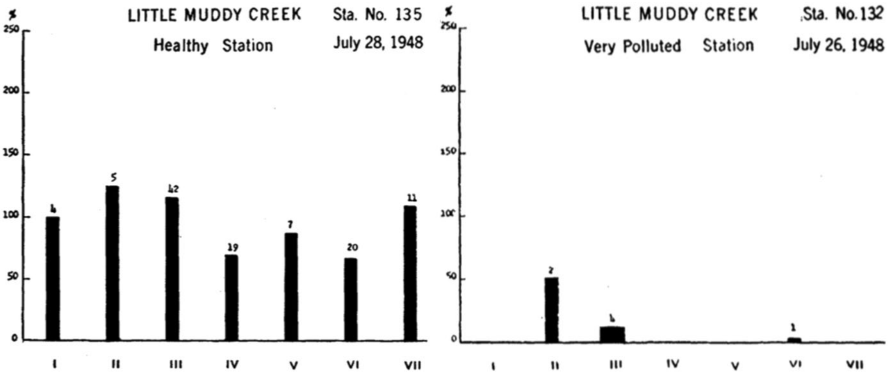

Fig. 1 In her 1949 article in the Academy *Proceedings*, Patrick used histograms to represent graphically what she referred to as the "balance of life." The x-axis shows seven groups of species (I to VII), each group consisting of species that responded similarly to the same ecological conditions. The 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 represent 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

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 pollution would ripple through the aquatic community and show up on the histogram. By promoting her river survey as a comprehensive method, Patrick wanted to supplement the standard practices of the day rather than replace them (Hart et al. 1945; Patrick 1949).

Patrick explained her method in terms of the biodynamic cycle, an expression of the interdependence of all life in an aquatic community. For 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. This 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. (Patrick 1953a, pp. 210–211)

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.

Patrick's survey was the first extensive study that linked a river's species diversity and relative abundance to its health. Patrick also demonstrated that an interdisciplinary team of biologists with different specialties could be coordinated and contribute to a new measure of pollution. The survey marked the beginning of Patrick's decades-long connection with industries that would fund her new department. Some scientists, including Hutchinson, described this work as "applied" limnology, implying the boundary that existed between the Academy's taxonomic studies and Patrick's survey work for the Sanitary Water Board. Patrick had a different perspective: the two kinds of work could be made compatible. In her letter to Hutchinson, she said she expected the applied work to support the Academy's basic research at a time when there were few other sources of funding. From another perspective, one that would eventually become more common, Patrick's idea to link diversity with water quality was valuable as both basic and applied knowledge: the two were synergistic. It uncovered fundamental ecological relationships in rivers that few scientists had explored before. Pollution could be understood ecologically as a stress on the aquatic community, and Patrick's concept of a river's health suggested a relationship between that stress and the community structure. Neither of these perspectives, however, received strong support at the Academy, where Patrick's survey was viewed as a mixed blessing.

Assembling Networks Across the Basic-Applied Boundary

Even before the Conestoga Basin survey had ended, Patrick leveraged her network of supporters to supply the young Department of Limnology with new laboratory space, new contracts, and, ultimately, new staff. Her success demonstrates that Academy leaders were, overall, supportive of the applied work she brought to the museum. In October 1948, Patrick outlined her vision for a new laboratory to the Academy's board of trustees, who agreed unanimously to begin raising the required funds. This achievement was significant, given that the board and Academy leadership 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 the wealthy 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. By the end of 1949, with some small donations and a large contribution from R. R. M. Carpenter, a DuPont executive and trustee of the Academy, Roberts converted rooms from the former Department of Mineralogy into a state-of-the-art laboratory for Patrick's department. Several new contracts justified this investment. For example, the Sanitary Water Board was so impressed by Patrick's survey that they renewed their contract in 1949.[15] Hart used his connections within the oil industry to convince the American Petroleum Institute to fund Patrick's studies for the next five years. Roberts summarized the department's broad and growing array of work at the Academy's annual meeting in February 1950:

> As a result of these new facilities and more especially the competence of Dr. Ruth Patrick and her staff, many problems bearing on water and aquatic life have been brought to us. To mention a few of these, we completed a study for the State of Pennsylvania on stream conditions in Lancaster County; we studied the effect of certain sulphur wastes on the food of oysters for the Freeport Sulphur Company in Louisiana; we are studying methods for controlling the carrier, an aquatic snail, of the tropical disease called schistosomiasis, for the Pennsylvania Salt Manufacturing Company [Pennsalt]; we are studying the poisoning effect of certain chemical wastes on our streams for a number of gas and electric companies. We studied the aquatic life and conditions of the Guadalupe River in Texas for E. I. du Pont de Nemours & Company last fall, sending a team of six of our staff to Texas. More such activities completed or being planned could be enumerated. (Roberts 1950)

The list of companies that sponsored the department was growing so fast that there was hardly any reason to name each one. Many of these companies 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 at both annual and board meetings.

Evidence of criticisms against Patrick's department is difficult to locate in archival sources, but there are signs that Academy leaders were ambivalent about expanding their associations with industry. For example, Roberts wrote to Hutchinson asking him to endorse the Academy's new line of work and thereby help to legitimate the Limnology Department within academic circles. Hutchinson responded that he was already doing so and had written to the American Philosophical Society to request funds for Patrick's new laboratory.[16] Hutchinson, who was "enormously impressed" by the young department, reassured Roberts that he felt any implied criticism of Patrick's work was "quite unjustified in principle and absurd in practice."[17]

Although Hart, Roberts, and Hutchinson helped establish the young Limnology Department, Patrick was ultimately responsible for building and sustaining its corporate relationships. She was extremely skilled at translating her department's expertise to fit the needs of potential clients and advertised three kinds of services to industries. 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

[15] John E. Bowers, "Minutes, Academy Trustees," January 19, 1949, Board of Trustees Records, Box 2, Folder 6.

[16] H. Radclyffe Roberts to G. Evelyn Hutchinson, November 16, 1948, Hutchinson Papers, Box 1, Folder 12. See also the handwritten note by Hutchinson, dated November 17, 1948, Hutchinson Papers, Box 41, Folder 651.

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

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 sold this kind of method as "insurance against further accusations."[18] Second, a river survey could assess new waste disposal systems that some companies were installing. For example, DuPont designed a new facility at their plastics plant on the Guadalupe River and cited the Academy survey that convinced them of its efficacy (Murdock 1951). Third, a pair of surveys, one upstream and one downstream of an industrial plant, could isolate its effluent from other effects in the river and identify both short- and long-term changes in water quality. Patrick and her team conducted many surveys of this kind for DuPont throughout the 1950s and 1960s.

Although Patrick sought many of her own clients, industrial managers also wrote to her, as word of her department's services spread through corporate circles. The assumptions these men made about the department's purpose sometimes revealed their simplistic understanding of the institutional basis for applied work at the time. For example, when F. J. Giffen of the Canadian International Paper Company in Montreal wrote to Patrick in 1954, he mistakenly assumed that Patrick was a full-time pollution specialist and that the Academy was an institution dedicated to pollution abatement—an association that some Academy members likely feared. Rather than correct the error, Patrick merely enclosed a list of the department's services and invited Giffen to visit the Academy to view their laboratory firsthand.[19]

While this strategy of advertising services to polluting industries brought money to the Academy, Patrick established the Limnology Department not simply to conduct river surveys for corporations, but also to study the "fundamental" ecological relationships in rivers across the United States. She revealed this more basic purpose of her work not, understandably, in her discussions with industrial managers but rather in other, more academic contexts. For example, in 1953, Patrick described 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.[20]

[18] Ruth Patrick to Eugene D. Crittenden, March 12, 1953, Ruth Patrick Papers, Box 3, Folder 15, Academy of Natural Sciences of Drexel University, Philadelphia; hereafter cited as Ruth Patrick Papers.

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

[20] Patrick, Ruth. Letter to Paul Bigelow Sears, November 16, 1953. Hutchinson Papers, Box 41, Folder 651.

Patrick displays in this passage a highly flexible conception of scientific research. She articulated an early version of an idea that would later become prominent: the organisms that form ecosystems provided humans with services, such as drinkable water, and that preserving biological diversity and the balance of life in ecosystems ensured that these services would also be preserved. Sears would have recognized in Patrick's letter her willingness to integrate basic and applied knowledge in ecology, an ideal he himself had promoted earlier in *Deserts on the March* (1935). The letters to Crittenden, Giffen, and Sears demonstrate how Patrick could translate her broad conception of scientific research into different contexts, and thus maintain good rapport with a diverse set of potential clients and collaborators.

To realize the capacious vision outlined in her letters, Patrick needed to attract scientists with PhDs who were willing to forego some of their taxonomic research and prioritize applied work for corporate clients. 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, in 1951, three students joined the department, under a grant from the Public Health Service, to study the toxicity of several industrial chemicals (Roberts 1951). Although Patrick could fill such part-time positions, it was more difficult to recruit and keep full-time staff. For example, Patrick wrote to Hutchinson about his student, W. Thomas Edmondson, to whom she had offered a position in the new Limnology Department with a starting salary of $4200 per year. The job required someone "willing to do practical work such as running toxicity tests for industries, as well as pursue the problems of theoretical research."[21] But Hutchinson responded a few days later indicating that Edmondson had another offer from the University of Washington in Seattle that came with "a rank and salary considerably better than anything you would be able to offer him."[22]

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, such as John Cairns and John Wallace, became full-time staff in the department. Cairns, who was working on his PhD at the University of Pennsylvania, studied toxicology and identified protozoa and fish for subsequent river surveys. Other staff members 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 lead entomologist for most river surveys and remained at the Academy until his death in 1988. In 1952, Patrick hired Matthew H. Hohn, who had 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.[23] With Cairns, Wallace, Roback, Hohn, and Reimer, Patrick had amassed a committed team of specialists to

[21] Ruth Patrick to G. Evelyn Hutchinson, March 9, 1950, Hutchinson Papers, Box 41, Folder 651.

[22] G. Evelyn Hutchinson to Ruth Patrick, March 13, 1950, Hutchinson Papers, Box 41, Folder 651.

[23] 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* (Patrick and Reimer 1966, 1975).

help with the river surveys; by 1953, the department had twenty full- and part-time staff.

Of all her new sources of funding, DuPont would become Patrick's most dependable support through the 1950s and early 1960s, a period when her department's future was unstable. Several DuPont executives, including Carpenter and Stine, were trustees of the Academy when Patrick began her survey in 1948. 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. Greenewalt (Patrick 1997). Upon Roberts's request, Hutchinson also wrote to Greenewalt in November 1948 and "endorsed Dr. Patrick's scheme in the strongest possible terms."[24] By 1949, DuPont enlisted Patrick's department for a survey of the Guadalupe River near Victoria, Texas, where the company had recently built a new chemical plant for producing nylon. Greenewalt funded Patrick's department for over a decade, and succeeding presidents of DuPont continued this support. This connection to DuPont would prove critical: by 1975, the company had provided Patrick 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.[25]

Companies like DuPont partnered with Patrick for various reasons, but above all they sought to maintain a favorable public image and avoid lawsuits and government 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. (E. I. Du Pont de Nemours & Company 1952)

To demonstrate its responsible policies, DuPont included three photographs from the Academy surveys of the Guadalupe River from 1949 and 1950. 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 a proactive 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

24 Handwritten note by Hutchinson dated November 17, 1948, Hutchinson Papers, Box 41, Folder 651.

25 These include 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 paid the Academy about twice as much money as DuPont, but only during the later period 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, Ruth Patrick Papers, Box 27, Folder 50.

establishing new and lasting corporate connections. Despite these successes, Patrick was inundated with work. The demands of the river surveys left few opportunities to conduct basic research. Patrick solved this labor issue by inventing a new instrument, the diatometer.

The diatometer was a shoebox-sized device that floated in a river and collected the live diatoms that gathered on microscope slides mounted near its center (Fig. 2). Patrick (or, as time went on, increasingly her assistants) could leave the diatometer tethered in a river, retrieve it after two weeks to remove the slides, scrape off and clean the diatoms, and identify and count them back at her laboratory. 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 was developed in the wake of Patrick's Conestoga Basin survey of 1948. 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 a river's health and its biological diversity. Likely due to the Korean War, by 1950 they abandoned their plans for an international expedition. As an alternative, Patrick suggested they fund her development of an instrument for measuring pollution. Patrick described this plan to 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.[26]

It took Patrick and her team three years to design and test the diatometer. With two young scientists in her department, Hohn and Wallace, Patrick ran tests to determine how long to leave the instrument floating in place at a collection site. They settled on two weeks: any shorter and rare but important species would fail to colonize the slide; any longer was unnecessary, since either the same distribution persisted or it would be harder to identify when a disturbance to the community had occurred. Patrick 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 thirty individuals. In a polluted stream, there were often a few diatom species with over a thousand individuals (Patrick et al. 1954). After the Catherwood Foundation funded the prototype design, the American Petroleum Institute (API) supported further development at locations around Delaware, Maryland, and Galveston Bay in Texas. These were important locations for the oil industry, and Patrick suggested that her diatometer could determine how refineries had polluted local rivers. The significant funding from the API ($41,000) allowed Patrick and

[26] Ruth Patrick to G. Evelyn Hutchinson, November 21, 1950, Hutchinson Papers, Box 41, Folder 651.

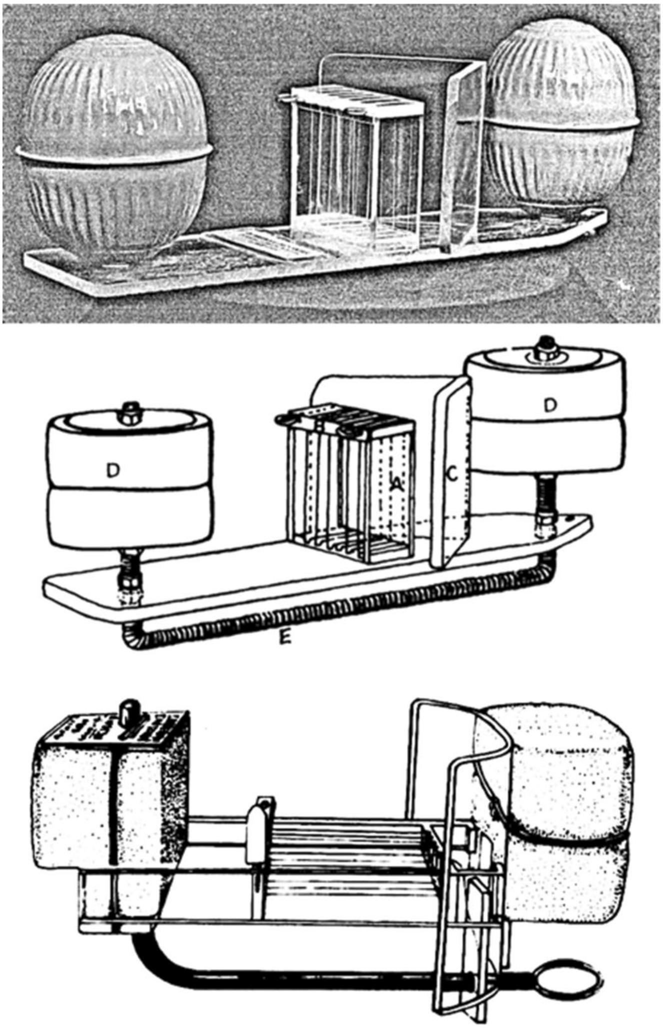

Fig. 2 The three versions of the diatometer from roughly 1954, 1957, and 1965 (Patrick et al. 1954; Patrick 1957, 1965)

her team to calibrate the diatometer over a wider geographical range and refine their methods (Patrick and Hohn 1956).

Patrick also developed a new graphical method for plotting results read from the diatometer. This new method preserved the histogram's ability to capture a snapshot of the balance of life. Her audience could then quickly infer the presence of pollutants from the diatom community alone. Rather than another histogram, however, Patrick used a curve that fit a statistical distribution. This approach was based on a method developed by Frank W. Preston, an engineer who applied his experience with mathematical models to problems in population ecology. Preston graphically

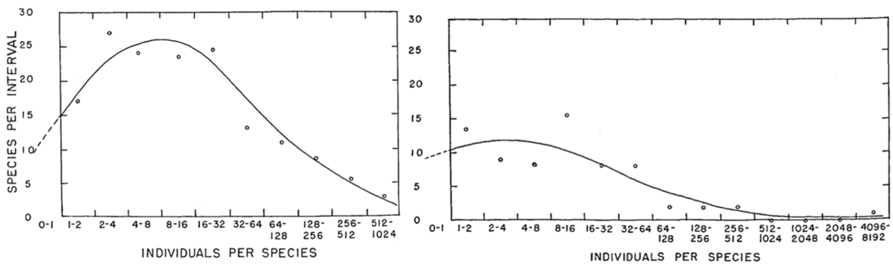

Fig. 3 Patrick's graphical method for the diatometer was based on a curve, rather than a histogram. The plot on the left shows a diatom population from Ridley Creek, a healthy stream. The plot on the right shows a diatom population from Lititz Creek, a polluted stream in the Conestoga Basin. These plots represent the two extremes that resulted from diatometer readings; note the "long tail" in the right plot of a handful of dominating species that characterized polluted streams. Like the histograms, these plots provided a quick snapshot of the balance of life. (Patrick and Hohn 1956)

represented a community using a log-normal distribution of the number of species containing a certain range of individuals in the community (Preston 1948). 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 applied Preston's method to the diatometer readings, interpreting large shifts in the mode and height of the distribution as an indicator of pollution (Fig. 3). 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.

The diatometer became a key time-saving device, allowing Patrick to replace the interdisciplinary team of the full survey with a much smaller team that installed and retrieved the diatometer, which could then be processed in the department's laboratory in Philadelphia. At some sites, she trained local technicians to do this work and mail the diatometer slides back to the Academy, saving even more time and money. In 1957, she designed a new "cursory survey," a faster, more targeted survey that relied on data collected from previous surveys. An appreciation of how valuable the diatometer was for sustaining Patrick's applied work can be gauged by plotting the three kinds of surveys that Patrick used to monitor over seventy rivers and streams for ninety different clients from the late 1940s to the mid-1970s (Fig. 4).

The labor of counting and identifying 8000 diatoms per slide was a significant hurdle for Patrick, who hired a team of slide readers but lacked sufficient time to train these staff herself. She appointed Hohn to lead her diatometer program. Between 1958 and 1960, they hired six slide readers, four women and two men. These slide readers were at first paid $75 per detailed reading of a slide ($90 if the slide reader also produced a report with graphs).[27] It took the inexperienced slide

[27] Matthew H. Hohn to Ruth Patrick, February 3, 1959, Ruth Patrick Papers, Box 27, Folder 30.

reader almost a full week to count the diatoms on a single slide, and each diatometer often was equipped with six slides. One worker, Joan Hellerman, was paid more, at the rate of $2.75 an hour; according to Hohn, who managed the diatometer program for Patrick, this was due to her advanced ability and speed; Hellerman was often selected from among the six workers for overtime work, and her salary of about $5,000 in 1958 (about $45,000 today) was significantly higher than other workers, who earned closer to $4,000 ($36,000 today). Patrick and Hohn charged companies like DuPont $1200 for two detailed readings per year per diatometer.[28] Slide readers therefore received $900 of every $1200, or three-fourths of their income, from industries.

The repetitive task of identifying diatoms caused many slide readers to leave, and Hohn struggled with high turnover rates. Hohn complained to Patrick that out of four workers reviewed in 1959, Hellerman was the only one competent for working the most important contracts.[29] By the early 1960s, most of the slide readers had left: one woman told Hohn that she expected to leave once her husband finished medical school. Hohn and Hellerman both eventually left the Academy for academic positions, although they continued to build their scientific career on their work from the diatometer program (Hohn and Hellerman 1963, 1966). Patrick and her diatom specialist, Charles Reimer, hoped that the publication of their diatom manual would allow them to train diatom taxonomists more quickly, but the first volume was not published until 1966 (Patrick and Reimer 1966).

Despite the limited success of the diatometer in saving time, Patrick did not completely abandon the full river survey, which provided much more information than the diatometer slide readings. Each kind of survey had strengths and limitations. Although the full survey provided a more comprehensive inventory of life in the stream, the diatometer continuously monitored the condition of a river, integrating changes over a two-week period. Together with its graphical method for representing pollution, the diatometer was also a concrete tool that interested diverse actors across disciplinary boundaries. The next section illustrates why this instrument became useful to applied scientists.

Building Authority Among Applied Scientists

By the late 1950s, Patrick's influence expanded beyond corporate circles and her own institution, which was traditionally oriented toward natural history collections and taxonomic research, into other institutions dedicated to applied or "sanitary" biology.[30] One such institution was the Public Health Service's Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio. Established in 1954, the Taft Center

28 Matthew H. Hohn to Ruth Patrick, July 1, 1958, Ruth Patrick Papers, Box 27, Folder 30.

29 Matthew H. Hohn to Ruth Patrick, January 7, 1959, Ruth Patrick Papers, Box 27, Folder 30.

30 Although the term "sanitary biologist" was not commonly used in the 1950s, it was prevalent at the Taft Center, where government scientists, such as Clarence Tarzwell, promoted the application of zoological and botanical knowledge to the problem of pollution; see Newcombe (1957) and Renn (1957).

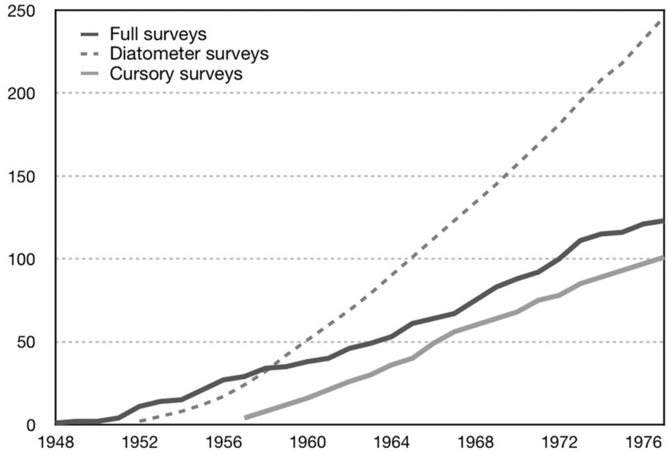

Fig. 4 The cumulative number of river surveys conducted by the Department of Limnology from 1948 to 1977. Patrick's diatometer reduced the complexity and cost of the full survey and was supported by several companies, especially DuPont. (E. L. Anderson, "The Academy of Natural Sciences of Philadelphia, Division of Limnology and Ecology, Summary of Work Performed, 1950 Thru 1977," September 1, 1978, Ruth Patrick Papers, Box 27, Folder 50)

prioritized research on applied problems, such as maintaining water quality, reducing air pollution, and tracing the effects of radiation on human health. Center officials hosted interdisciplinary conferences devoted to these applied problems. For example, Clarence Tarzwell, chief scientist of the Aquatic Biology section, hosted three conferences on "Biological Problems in Water Pollution." Patrick engaged this community of applied scientists by promoting her ecological approach to monitoring pollution, especially with the diatometer. Patrick contributed to, but did not attend, the first conference in 1956, and the ideas she presented there were criticized by some leading biologists. Although Patrick did not participate in the second conference in 1959, she and her department were critical contributors to the third in 1962.

Patrick's ambiguous identity as a basic and applied scientist shaped her interaction with participants in the Taft Center conferences, as suggested by two forms of criticism and of support. Whereas criticism was directed at Patrick's identity, motivation, and theoretical approach to pollution, some applied biologists supported specific tools that Patrick had developed—namely, her graphical and instrumental methods. These methods explain why Patrick was able to overcome criticism at the Taft Center, although the publication of Rachel Carson's *Silent Spring* just prior to the third conference also pushed the applied scientists to review and revise their traditional approaches to studying pollution. This section analyzes Patrick's relationship with the applied biologists at the three Taft Center conferences of 1956, 1959, and 1962 and demonstrates her contribution to two key shifts in Taft Center priorities by the summer of 1962: increased emphasis on field studies and an acknowledgement of the role of ecologists in the study of water pollution.

Tarzwell, who organized the three conferences on water pollution and was perhaps the most influential applied biologist at the Taft Center, knew of Patrick well before the first conference of 1956, and his criticism of the Conestoga Basin survey reveals how applied scientists understood her work. At a conference of the Federation of Sewage and Industrial Wastes Associations held in October 1952, Tarzwell and another pollution expert, Arden Gaufin, were invited to comment on Patrick's novel approach to monitoring pollution. Gaufin and Tarzwell had just conducted an extensive river survey of their own near Cincinnati in October 1949 (just as Patrick was compiling her results for publication) but had collected far fewer taxa than Patrick, consistent with standard approaches based on indicator species. While Patrick measured most major taxa present at each station, Tarzwell and Gaufin 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" (Gaufin and Tarzwell 1952, p. 63). These applied scientists not only viewed her approach as too complicated and expensive, but also saw little value in the ecological method she was advocating. They argued that most biologists can tell whether a stream was polluted without collecting all the species present. To contradict Patrick's claim that the number of species could indicate stream health, they 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 could show definite, quantitative trends over time. She also noted that, 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: that is, pollution affected the biodynamic cycle similarly within each region (Patrick 1953a, pp. 214–217). At the first Taft Center conference of 1956, Tarzwell did not explicitly challenge Patrick's work, but the indicator species method he and Gaufin promoted was still the dominant one.

Applied biologists at the first conference on Biological Problems in Water Pollutions, held in Cincinnati in April 1956, extended this critique of Patrick's ecological approach and questioned the need for her participation, not only at the conference but in the water pollution field more generally. These biologists were Charles Warren of the Department of Fish and Game Management at Oregon State College and Peter Doudoroff, a fisheries expert with the Public Health Service who had collaborated with Hart in the early 1940s to develop bio-assay methods using fish as test organisms; he had also worked with Patrick in 1951 (Hart et al. 1945; Doudoroff et al. 1951). Doudoroff and Warren criticized Patrick for vaguely defining key terms, such as pollution and stream health. Like Tarzwell and Gaufin, Doudoroff and Warren focused on the way Patrick linked species diversity to stream pollution. In one of her earlier articles, Patrick defined pollution as "anything which brings about a reduction in the diversity of aquatic life and eventually destroys the balance of life in a stream."[31] Few sanitary biologists,

[31] They quoted this definition from (Patrick 1953b, p. 33). Note how, in this case, Patrick mentioned only diversity and left out relative abundance of species, a crucial component of her method.

Doudoroff and Warrren argued, would accept such a definition. Instead, they preferred legal definitions of pollution that focused on some demonstrable economic harm. Their criticism of Patrick went deeper, however, since they claimed she was encroaching on the sanitary biologist's domain. Whereas Tarzwell and Gaufin had confined their criticism to Patrick's theoretical approach, Doudoroff and Warren questioned the role of limnologists—considered basic scientists—in water pollution research, which they viewed as the proper domain of applied scientists and engineers:

> 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? (Doudoroff and Warren 1957, p. 145)

Although Doudoroff criticized her work as an unjustified encroachment of a limnologist on the domain of the applied fisheries researcher, Patrick's conception of scientific research was not based on a rigid distinction between basic and applied research, as demonstrated by her earlier correspondence with Crittenden, Giffen, and Sears. She developed an ecological approach that not only had implications for pollution abatement but also generated new scientific knowledge.

Doudoroff and Warren did not share Patrick's capacious view of ecological research and instead preferred a strictly disciplinary approach to pollution abatement. The goal of national pollution research, as they saw it, was to protect and sustain fish populations. Some biologists, they wrote, clearly referring to Patrick, "seem to have curiously attached at least as much importance to the elimination of any species of diatom, protozoan, rotifer, or insect as to the disappearance of the most valuable food or game fish species" (Doudoroff and Warren 1957, p. 149). Fish, and not diatoms, had commercial and recreational value, so study of their response to pollution should command the attention of Taft Center scientists: "if detection and evaluation of pollutional damage to fisheries is the only or primary objective of a biological investigation, an enumeration of the species of organisms of all taxonomic groups … cannot be deemed a direct approach to the problem at hand. Judged only by its practical utility, it may be a waste of time, effort, and money, which perhaps could be far better expended on more directly pertinent studies" (Doudoroff and Warren 1957, p. 156). The approach taken by Doudoroff and Warren is a clear example of how rigidly some applied scientists understood the boundary between basic and applied science.

Not everyone at the Taft Center criticized Patrick. By examining which aspects of her approach were adopted with little resistance, we see that some aspects of her creative strategy worked better than others. Patrick's histogram, for example, was viewed as a valuable contribution to the water quality field. At the second conference, in a brief paper on the graphical representation of biological data, two Taft Center officials praised her histogram method (Ingram and Bartsch 1960). They spoke of the need for biologists to develop clear representations of pollution to communicate with broader audiences.

Perhaps the clearest form of support from Taft Center managers came from an initiative to adopt the diatometer into their standard operating procedures used throughout the United States. Patrick had written about the diatometer for the first Taft conference of 1956 (Patrick 1957). Her paper impressed Charles Mervin Palmer, a senior algologist in Tarzwell's Aquatic Biology Section and co-organizer of the third Taft conference of 1962. In 1957, Patrick and Hohn began training Palmer to use the diatometer in a Taft Center program called "Interference Organisms Studies."[32] He spent about a month at the Academy in two separate trips. Tarzwell also approved of the instrument. In his 1963 textbook *Limnology in North America*, he promoted the diatometer method even while continuing to dismiss some of the more theoretical aspects of Patrick's work as too broad and detached from economic value (Tarzwell 1963).

By the late 1960s, a more diffuse group of pollution researchers used Patrick's diatometer method. For example, at an interdisciplinary conference on Pollution and Marin Ecology held at Texas A&M Marine Laboratory in Galveston, Texas in March 1966, Jerome Stein, director of Research and Control at the Metropolitan Sanitary District of Chicago, and John Denison, Stein's former colleague at the paper and pulp company Rayonier, praised Patrick's diatometer method for its measurement of the community structure of aquatic organisms, which the indicator species approach failed to capture. For example, they emphasized the inconclusive results of one researcher, who "would have probably obtained different results had he used epiphytic plankton sampled with a diatometer as suggested by Patrick et al. (1954)." Stein and Denison also praised Patrick's graphical representation of the diatometer data: "Patrick et al. (1963) vastly improved the presentation of indicator data by the application of log normal curves." They indirectly credited her with the "central idea" that "in nonpolluted environments there is a diversity in the qualitative and quantitative structure of the community" (Patrick et al. 1954; Patrick and Strawbridge 1963; Stein and Denison 1967).

The diatometer attracted these experts, which included some of Patrick's earlier critics, because the usual arguments leveled against her river surveys—that they were too complicated, expensive, and qualitative—applied less to Patrick's instrumental method. 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 on a quantitative, graphical method. Thomas Hankins has suggested that graphical methods tend to become adopted more readily than metaphysical claims (2006). 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.

[32] Charles Mervin Palmer to Ruth Patrick, January 24, 1958, Ruth Patrick Papers, Box 27, Folder 35.

The third Taft conference, held 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 (Tarzwell 1962). Cairns, Roback, and Reimer each presented papers on the ecology of protozoa, insects, and diatoms. Patrick not only described recent improvements to her diatometer method, but she also argued that the indicator species approach had become untenable since 1957 because of the growing number of new chemical substances found in rivers. She re-emphasized the importance of community structure as a measure of pollution.

Whereas the first conference in 1956 was relatively unorganized—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 more deliberately organized around all of the aquatic taxa Patrick had collected in her 1948 river survey: algae and diatoms, bacteria, invertebrates, insects, fish, and protozoa. Taxonomic complexity, once rejected by Tarzwell, had become the organizing principle of the third conference. Criticism of Patrick's work also disappeared. 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, Doudoroff and Warren called for further research into the ecology of key species. 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 were beset with unanswered questions, whereas field studies like Patrick's were flourishing. Yet by fitting their work to Tarzwell's conferences, Patrick and her colleagues acknowledged that detailed toxicity studies were also valuable in understanding the effects of various pollutants on the river biota; Patrick herself had conducted much of this work in her laboratory back in Philadelphia. The difference was that many Taft Center participants were now more open to broad, ecologically oriented field surveys.

The change in standard practices that occurred between 1956 and 1962, the years of the first and third Taft conferences, were the central topics of the opening and closing remarks of the third conference. James M. Quigley, assistant secretary of the US Department of Health, Education and Welfare and head of the Federal Water Pollution Control Program, opened by presenting a new conception of the sanitary biologist. "For too long, problems of water pollution in this country have been approached in much too narrow, much too parochial ways" (Quigley 1962). He primarily blamed the sanitary engineering community for lacking the "boldness and imagination that have characterized [other] engineering efforts in such varied fields as rocketry and saline-water conversion." According to Quigley, sanitary biologists, like engineers, needed an infusion of ecological thinking: "it is in the field of ecology that the aquatic biologist may make some of his most important contributions." Taft Center biologists, he argued, 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. This was reflected in the third conference's purpose: to begin a new research program with a broader understanding of the relationships among aquatic communities.

In their closing remarks, two conservationists, ecologist Richard H. Stroud of the Sport Fishing Institute and journalist Charles H. Callison of the National Audubon Society, synthesized the speakers' common themes and elaborated on Quigley's remarks. Having attended nearly every presentation of the third Taft Center conference, they identified six factors that explained two main shifts—from lab to field and from the narrow to the ecological—that they perceived in the Taft conferences on the Biological Problems in Water Pollution since the first in 1956. Patrick's contributions can be detected in each of the six factors identified by Stroud and Callison. 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 may have been 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, chief scientists and administrators had a more favorable attitude toward ecological studies and helped direct policies and practices. (Patrick had allied with Tarzwell, who encouraged these two themes during the third conference.) Sixth, communication between disciplines, as well as the public understanding of science, had both improved. (Patrick was committed mostly to improving the former, but recently also contributed to public science.) To emphasize this point, Stroud and Callison praised Rachel Carson, whose *Silent Spring* (1962) had just been serialized in *The New Yorker* a month before the third conference. "Not every biologist can be a gifted writer like Rachel Carson," they wrote, "but any one of you can take the time and trouble to make friends with the public relations specialist in your agency or company and to help him get your story to the press." They then explicitly singled out Patrick, who had recently been interviewed by journalist James Poling about her work in a story published in *Readers Digest* (Poling 1962). Stroud and Callison said this publicity would "do more to assure continued public and financial support for the work of the Philadelphia Academy of Natural Sciences than all the papers presented at this seminar by members of the Academy staff" (Stroud and Callison 1962).

The Taft Center conferences demonstrate how Patrick impacted water quality experts, who eventually came around to her ecological perspective on 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 overly complex methods of basic science to bear on applied problems, now understood that laboratory tests and surveys based on indicator species were only part of the solution. Not all this change was due to Patrick, even though she was certainly the outlier at the first Taft conference. At the same time Patrick promoted ecologically oriented field research, mounting evidence of the toxic effects of a growing number of chemicals was already overwhelming pollution experts. This intensifying concern can be understood against the backdrop of a growing concern among experts over the use of chemical pesticides, captured and popularized by Carson in June 1962. But interacting with pollution experts at the Taft Center was not Patrick's chief concern at the time. She was also engaged in long-term ecological studies that would build evidence for her claim about the link between pollution and species diversity and abundance.

Merging Basic and Applied Research at a New Kind of Institution

One of Patrick's contracts with DuPont was different from the others, both in its institutional setting and its scale. The Savannah River 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, professor of ecology at University of Georgia, Athens, who had worked there since the early 1950s (Smith et al. 2001). 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. In 1972, the Department of Energy named the area the first National Environmental Research Park. Patrick began work on the Savannah River in 1951, but the results of her fifteen years of surveys were only published in 1966. She continued to publish even after she formally retired as chair of the Department of Limnology in 1973 (Patrick et al. 1966; Patrick 1977a). The Academy continued to survey the river until 2007 (Potapova 2010, p. 11).

The rise of the national laboratories in the postwar period marked an important change in the institutional terrain of basic and applied research. Whereas the Academy and the Taft Center involved relatively rigid conceptions of what constituted basic and applied research, the Savannah River Site integrated different disciplines around common applied problems, such as nuclear processes, radiation detection and safety, environmental monitoring, and ecosystem ecology. As Steven Bocking has argued in the case of Oak Ridge, the postwar national laboratories became sites where ecological work flourished (Bocking 1995). Bocking showed how ecologists established a foothold at Oak Ridge because they were deemed relevant to the study of radiation.

By 1960, Odum's concept of the ecosystem served as an organizing principle for ecologists, who used it to distinguish their discipline from closely related ones at the laboratory, such as biology and health physics. Moreover, ecologists at Oak Ridge preferred the ecosystem concept because it offered them a quantitative, physicochemical perspective valued by AEC scientists, who tended to view field studies in ecology as "soft" and lacking in rigor. For this reason, ecologists at Oak Ridge abandoned some early efforts to study species populations and communities, including the 1948 study by fisheries biologist Louis Krumholz (Bocking 1995, pp. 4–9).

The Oak Ridge case differs from Patrick's study for three reasons. First, she continued to prioritize taxonomic studies at the Savannah River Site, emphasizing the quantitative changes in community structure over the physicochemical perspective of ecosystem ecology. Second, her contract with DuPont confined Academy studies to the river itself, whereas most of the ecosystem ecology research at the Savannah River Site was conducted inland, by affiliates of the University of Georgia. Third, unlike Krumholz's work at Oak Ridge, Patrick's monitoring of aquatic organisms thrived at the Savannah River Site, partly because she was based at a different institution, and therefore did not need to compete as vigorously with health physicists and biologists as the ecologists at Oak Ridge. Despite these minor differences with the ecologists at Oak Ridge, Patrick was yet another ecologist supported by the national laboratories in the early postwar decades. The Savannah River Site brought her the opportunity to engage in long-term ecological research under relatively controlled conditions.

Patrick continued a strategy she had employed since 1948, viewing each river survey as an opportunity for basic research. She used the Savannah River Site as a long-term testing ground for her idea linking biodiversity and ecological 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 ambivalent about this new kind of survey:

> 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 in such a survey.[33]

Patrick expected she would investigate the effects of radionuclides on the aquatic community. In the same letter, she asked Hutchinson about the long-term effects of radiation on the metamorphoses of insects or 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?" Throughout the 1950s, Patrick asked colleagues what they knew about the effects of radionuclides ingested or absorbed by various aquatic organisms. For the Savannah River surveys, however, the AEC generally left these questions to other scientists, and her task was only to monitor the effects of chemical and thermal pollution and generate annual reports for DuPont (Reed et al. 2001, p. 463).

Patrick developed a strict regimen of surveying any changes to the Savannah River caused by the nuclear facility. She and her team monitored five stations across two main sections of the river, one upstream of the plant and one downstream (Patrick et al. 1966). From 1951 to 1956, they visited the river twice a year to conduct comprehensive surveys, like the ones performed at stations in the Conestoga Basin in 1948. In 1953, Patrick installed diatometers at three of the five stations and trained AEC personnel to maintain them; they replaced any missing diatometers, changed slides every four weeks, and mailed them to the Academy so that Patrick

[33] Ruth Patrick to G. Evelyn Hutchinson, January 3, 1950, Hutchinson Papers, Box 41, Folder 651.

and her team could track shifts in the diatom communities without having to travel to South Carolina. Beginning in 1957, Patrick began performing four cursory surveys per year or, about every five years, two cursory and two full surveys each year. This pattern continued through 1977.[34]

Patrick amassed substantial evidence from the Savannah River supporting her idea about the relationship between biological diversity and ecological health. In 1966, Cairns, Roback, and Patrick published their results of 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 (Patrick et al. 1966). She and her colleagues 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. They 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.

In their annual reports to DuPont, Patrick's team focused on large disruptions. Often, the river's health was affected by agricultural runoff, upstream factories such as a paper mill in Augusta, or the dredging and snag-removal operations of the 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.[35] Yet Patrick's method focused on the effects of pollutants on river lifeforms, ignoring other, less visible pathways of pollution such as through groundwater.

Patrick's work for DuPont on the Savannah River was not her only continuous, long-term study of structural change within a river's aquatic community. By expanding her connections with new industries, Patrick not only increased department funding but also created opportunities to visit 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. 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. As described in the next section, these long-term, labor-intensive river projects—applied work conducted within the context both of a growing national crisis of river pollution and of Cold War military developments—enabled Patrick to develop key theoretical insights in ecology and thus contribute to basic scientific knowledge. They demonstrate that

[34] 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.

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

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 diverse and persistent activity for industries like DuPont. Above all, they constitute not only Patrick's unusual accomplishments, 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 (Holmes 2004).

Designing Experiments, Testing Theories, and Achieving Distinction

In the 1960s, due to her increased funding and the new tools she had developed, 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.[36] From July 1962 to July 1963, they granted her a leave of absence to work on the publication of a comprehensive diatom manual, which encompassed the vast taxonomic knowledge Patrick had compiled over three decades. *The Diatoms of the United States*, published in two volumes in 1966 and 1975, revitalized diatom research in the United States (Patrick and Reimer 1966, 1975). 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" (Norris 1966, p. 1369). Others noted that the work ended over a century of dependence on the European diatom literature (Prescott 1966, p. 582; Wujek 1967, p. 193). It also transformed the Academy and its vast herbarium into a "diatomist's Mecca" (Lowe 2015, p. 110). Most importantly, however, Patrick expected the manual to supplement her diatometer program by simplifying the task of training slide readers and on-site technicians.

By the early 1960s, Patrick's 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—shared the task of managing of the Limnology Department.[37] These labor-saving developments enabled Patrick to investigate 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. As we will see, Patrick's creative experiments in the 1960s tested ecological theories and led to her election to the National Academy of Sciences in 1970. But Patrick's applied work also introduced a new controversy that she had to resolve.

[36] 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.

[37] 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.

In the early 1960s, Patrick began to compile over a decade of results into meta-surveys, supporting her claim that the number and relative abundance of species indicated a river's health. She determined that the number of species remained relatively constant in rivers across ecologically similar regions and that only the kinds of species varied. This result answered the earlier criticism of Gaufin and Tarzwell, who had argued that healthy rivers in Utah and Colorado had few species, ignoring differences across ecologically distinct regions, such as deserts and temperate regions. At the time, although Patrick lacked evidence to challenge their assertion, her results from 1961 showed that, across ecologically similar rivers of the eastern United States, "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 (Patrick 1961). In 1963, she showed that August Thienemann's theory about the diversity and abundance of species in unpolluted environments was consistent with the results from fifteen years of river surveys (Thienemann 1939; Patrick 1963). These results included ten years of diatometer data collected from healthy streams across the United States, notably on the Savannah River.

Patrick continued to leverage connections with corporations associated with the Academy to create opportunities for basic research. For example, in 1955, she received $80,000 from the Manufacturing Chemists' Association of Washington to study how aquatic organisms colonize new areas of a stream. Patrick first needed a relatively stable experimental setting to conduct this study. She found one in 1958 when Samuel B. Eckert and his wife donated part of their property near Paoli, Pennsylvania, to the Limnology Department. 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 River. In 1960, Patrick created an artificial channel that linked two parts of the creek 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" (Henry 1960).

To Patrick, the artificial channel on Ridley Creek served as a "semilaboratory" to run long-term, semi-controlled experiments and test ecological theories, including one that Hutchinson had promoted. In 1967, Robert H. MacArthur, Hutchinson's former doctoral student, and Edward O. Wilson published a new and controversial theory of island biogeography (MacArthur and Wilson 1967). 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.[38] 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. Patrick's experiments contributed to the testing of MacArthur and Wilson's hypotheses. Her results refined their conclusions by

[38] MacArthur and Wilson's theory was criticized by Daniel Simberloff in the mid-1970s for its tendency to oversimplify and ignore historical processes; see Kingsland (1985, pp. 192–197).

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. After a few days, larger areas contained more species than smaller ones, 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 (Patrick 1967, 1977b, p. 157). The semilaboratory of the artificial channel was crucial since, as Patrick noted in a subsequent article, "no one has been able to grow diatom communities of a hundred or more species in strict laboratory conditions" (Patrick 1968).

While running her experiments on Ridley Creek, Patrick sought other opportunities to create semilaboratories for testing ecological theories. One important example was the Stroud Water Research Center, established in 1966 when two longstanding patrons and members of the Academy, Joan and William Stroud, approached Patrick and offered her their financial support. Patrick suggested that the White Clay Creek running through their property could be used to study the nearby watershed. The Strouds liked the idea and purchased adjacent land to expand the study area. By summer 1966, they converted their garage into a makeshift research laboratory and started planning the construction of a new building on their property. Work began in February 1967 and was completed by the end of the year; the new Stroud Center had a diverted creek water running through the bottom floor and an upstairs library designed by Joan Stroud. Its goal 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 and White Clay Creeks, two relatively unpolluted streams, provided more control over ecological factors and, therefore, a deeper understanding of ecological relationships than what she could learn from surveys. Patrick believed that this deeper understanding of how ecosystems function would show ecologists how to restore polluted streams to their original conditions (Peck and Stroud 2012, pp. 335–338; Stroud Water Research Center 2018).

As demonstrated by the semilaboratories at Ridley Creek and the Stroud Center, Patrick contributed to basic research in the 1960s by repurposing tools from her river surveys. In another set of experiments, Patrick used the diatometer to isolate the effect of a single variable on the structure of aquatic communities. She focused on two variables—water temperature and manganese concentration—and how they changed the relative abundance of diatoms, green algae, and blue-green algae (cyanobacteria). Algologists knew that blue-green algae tolerated higher temperatures and lower manganese concentrations than other algae, but the ranges of these variables that constituted a shift from a more diverse flora to one consisting mostly of blue-green algae had not been studied. The experiment depended on Patrick's results from 1967, which demonstrated that a controlled set of diatometers under similar ecological conditions would contain diatom communities that were 95 to 98 percent similar in their species composition (Patrick 1968).

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 and then to blue-green algae. Patrick published her results in *Proceedings of the National Academy of Sciences* in 1969 and was elected to the National Academy the following year, in 1970 (Patrick et al. 1969).

The synergistic relationship between basic and applied science that Patrick sustained for decades led to her election 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 brand of criticism of Patrick's work, which, although rooted in the earlier criticism she had faced, took on a different form during the modern environmental movement. While earlier arguments in the US over the relative merits of pure and applied science tended to focus more on the social status, prestige, and intellectual capabilities of their practitioners, Patrick's new critics detected in her work a conflict of interest between the proper environmental ideals of an ecologist and the motivations of polluting industries. These critics challenged the scientific reputation of anyone with a vested interest in a sustained relationship with such industries.

Patrick upheld her scientific reputation by leveraging key allies from her 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 (Holden 1975). Referring to Patrick as a "company-hired consultant," Cronin, one of the most outspoken critics of Patrick's work, claimed that her methods favored 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. (MacNees 1969)

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 completed his doctorate at Rutgers University under Francesco Trama, who had 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 own student, Flemer took a more sympathetic view of her methods than Cronin. When Mountford conducted the survey, Cronin was able to observe Patrick's methods firsthand and, according to Mountford, this "helped change Gene Cronin's attitude and barriers slowly fell away" (Mountford 2012).

Despite episodes of criticism, in the early 1970s Patrick received two prestigious awards following the endorsement of her friend and supporter, G. Evelyn Hutchinson. In 1972, she was named Eminent Ecologist by the Ecological Society of America. The citation, written by Hutchinson and F. Herbert Bormann, ESA president in 1970, credited Patrick's successes in ecology to her strong foundation in diatom taxonomy at the Academy and her connections with industry. Both the basic and the applied aspects of her research were, they noted, why Patrick was "one of the very few Americans who are completely trusted by both the academic and industrial communities" (Hutchinson and Bormann 1972, p. 7). Three years later, Patrick became the first ecologist to be appointed to 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.

Conclusion

This study explains Patrick's success at four levels: (1) her personal qualities of intelligence, creativity, and energy, which led her to disregard established boundaries between "basic" and "applied" science; (2) the exigencies of her home institution and the flexibility this institution provided as she sought to expand her research program; (3) the postwar context of pollution, anti-industry lawsuits, and government moves toward regulation, which caused industry to step up its patronage of scientific studies of pollution; and, finally, (4) the ability of Patrick to draw on a wide network of experts who helped her expand into multidisciplinary research projects that lay beyond the scope of any one individual.

Evaluating his experience working under Patrick from her first river survey in 1948 until he left the department to pursue an academic career in the early 1960s, Cairns wrote that Patrick's most important scientific contribution was to demonstrate that "theoretical and applied science cannot only co-exist, but are commonly synergistic" (1992). This synergistic relationship between basic and applied science was evident in Patrick's 1948 Conestoga Basin survey, which helped Pennsylvania's Sanitary Water Board establish standard measures of pollution while also testing her idea that would later be christened the "Patrick principle." With her new Department of Limnology housed in the Academy of Natural Sciences of Philadelphia, she offered an array of services to industrial managers while also generating new knowledge of fundamental ecological relationships and the balance of life in a river. 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 had 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 applied those surveys to her meta-analyses of the number and kinds of aquatic species in diverse regions across the United States. She invented the diatometer to meet the growing demands for river surveys and then repurposed the instrument to devise innovative experiments and test ecological theories.

The key to Patrick's successes in the early 1970s was the degree to which she sustained this synergistic relationship at every turn and consistently sought ways to make the most of the connections, resources, and evidence she had assembled over the years she spent at the Academy. Yet several other factors created the conditions for Patrick's program. Especially critical was the Academy's dire financial situation in the 1940s, but also important were its pool of taxonomic expertise and the network of collaborators, mentors, and friends who contributed to Patrick's program at key moments. More broadly, however, it was the growing public and private concern over pollution that welcomed methods and data Patrick produced.

Patrick's ambiguous identity as both a pure and applied scientist tended to elicit gendered reactions from those who tried to make sense of her work. She was criticized by Academy members who disapproved of the corporate money brought into her department; by the (overwhelmingly male) applied scientists and pollution experts, who rejected her methods as too complex and expensive; and by other biologists like Cronin, who perceived her as a company scientist who allowed her corporate ties to influence her scientific results. These critics struggled to fit Patrick into categories they understood, and their criticism can be viewed as deeply gendered. Patrick herself suggested this when, interviewed later in life, she recalled how she "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" (Peck and Stroud 2012, p. 324). Patrick, the only female department chair at the Academy between 1948 and 1975, pursued an unorthodox research program at a time when there were few ecologists studying pollution and extremely limited funding to support such research. Patrick was one of the only American ecologists willing to work with industrial managers on the problem of pollution. She therefore needed to overcome both the gendered perceptions of her scientific activity and the rigid institutional and conceptual boundary between basic and applied science. In crossing these boundaries, Patrick also redefined them, enabling younger men and women to work on research problems that were less strictly demarcated as either basic or applied.

Patrick and the other scientists in the Department of Limnology advanced the field of river ecology in the United States, a field that has received far less attention from historians than other areas of ecology. This article suggests that the field was born out of applied problems in water pollution, as Patrick assembled interdisciplinary teams to conduct her river surveys, visited hundreds of rivers across the United States to serve the needs of polluting industries, synthesized these surveys into long-term studies and meta-analyses, and mentored graduate students who later sustained the field (Langenheim 1996). Patrick promoted a view that would later become important in ecology: that biodiversity was essential for assessing an ecosystem's health. We often think this idea came out of basic ecosystem studies, but, as this study shows, it had much earlier roots in an applied context. In her early work for DuPont, Patrick drew on the earlier example of August Thienemann, on whose ideas she based her 1948 Conestoga Basin survey. River ecology was also shaped by G. Evelyn Hutchinson, one of the most accomplished and respected ecologists of the mid-twentieth century. As historian Nancy Slack has demonstrated, Hutchinson played a central role in establishing limnology through his own work and that of the younger ecologists he mentored, including Patrick (2011). In her memoir, Patrick singled out Hutchinson as the one who, more than anyone else, helped her achieve distinction, noting his "profound effect" on her scientific career and that "his encouragement was a great factor" in her success (Patrick 1997, p. 8). Patrick felt that, without Hutchinson's support, her research program at the Academy would have failed. In 1950, when she had just been granted her new laboratory by supportive board members and was growing her corporate connections and scientific 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."[39]

This article has demonstrated several moments when Hutchinson's insight or influence shaped Patrick's investigative pathway: in their collaboration on Linsley Pond, which gave Patrick a new appreciation for ecological theory; after the AAAS meeting in 1946, when Hart first approached her for help with his refining company; and during the Conestoga Basin survey, when Hutchinson helped Patrick answer Stine's questions about how to organize such a project and to prepare the survey results for the Sanitary Water Board. After the success of her initial survey, Hutchinson influenced the expansion of her program by assuring Roberts and Greenewalt that Patrick was capable of critical limnological research and by helping Patrick find young and able limnologists to fill positions in her growing department. Once 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, of course, was not all one-sided. Hutchinson also benefited from his collaboration with Patrick. For example, in 1952 the Academy awarded him their Joseph Leidy Award in recognition for his research and as an expression of gratitude for helping Patrick establish her profitable department. In his acceptance speech the award ceremony, Hutchinson elaborated a theory of the concepts of order and pattern in ecology and credited Patrick's diatometer for providing some evidence for it (Hutchinson 1953). Hutchinson was no doubt pleased when Patrick's experiments provided evidence to support the controversial theory of island biogeography proposed by his former doctoral student, Robert MacArthur. But, overall, Patrick relied upon Hutchinson's academic prestige, which legitimized the applied work of her department. His support of her program demonstrates that Patrick's success was not just the product of hard work but was also the product of her large support network.

This analysis suggests that it may be useful to think of Patrick as a kind of entrepreneur, although that term usually implies a connection to profit-seeking and commercial enterprise. While she was not interested in personal profit and her salary was not significantly augmented by her work with industry, Patrick did explore new ways to increase funding for basic science and expand the research performed at the Academy. Recent work on academic entrepreneurs, such as that by R. Daniel Wadhwani

[39] Ruth Patrick to G. Evelyn Hutchinson, November 21, 1950. Hutchinson Papers, Box 41, Folder 651.

and colleagues, has sought to correct historians' tendency to equate entrepreneurship with commercial practices and helps us place Patrick's case in a broader perspective. These entrepreneurs, including Patrick, "often shaped or reshaped institutions, by defining strategies and mobilizing various resources" (Wadhwani et al. 2017).

We might further consider Patrick not only as an entrepreneur, with all its connotations of profit-making and innovation, but also as an institution builder. Historians have shown interest in how natural history museums adapted to changing conditions over the second half of the twentieth century (Sunderland 2013). They have also explored how women have shaped late nineteenth- and early twentieth-century North American natural history museums—for example, through their role as educators (Kohlstedt 2013). Patrick's impact on the Academy after 1948 was transformative. Without the funding she brought into the museum throughout the 1950s and 1960s, it would not have survived or, at the least, would have become a very different kind of 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. The important role it plays today in environmental protection suggests how deeply Patrick had transformed the centuries-old Academy since she entered its halls in the final years of its golden age of expeditions.

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References

Archival Sources

Board of Trustees Records. Academy of Natural Sciences of Drexel University, Philadelphia.

G. Evelyn Hutchinson Papers. Sterling Memorial Library, Yale University, New Haven.

Division of Environmental Research Records. Academy of Natural Sciences of Drexel University, Philadelphia.

Ruth Patrick Papers. Academy of Natural Sciences of Drexel University, Philadelphia.

Published Sources

Abir-Am, Pnina G., and Dorinda Outram, ed. 1987. *Uneasy Careers and Intimate Lives: Women in Science, 1789–1979*. New Brunswick, NJ: Rutgers University Press.

Bocking, Stephen. 1995. Ecosystems, Ecologists, and the Atom: Environmental Research at Oak Ridge National Laboratory. *Journal of the History of Biology* 28: 1–47.

Bott, Thomas L., and Bernard W. Sweeney. 2014. Biographical Memoirs: Ruth Patrick 1907–2013. *National Academy of Sciences*.

Brown, Trudi, and Patty Hartman. 2004. Ruth Patrick. Hometown Legends. Philadelphia: WHYY-TV.

Cairns, John, Jr. 1992. Dedication. In *Predicting Ecosystem Risk*, ed. John Cairns Jr., Barbara R. Niederlehner, and David Robert Orvos. Vol. 20. Advances in Modern Environmental Toxicology. Princeton, NJ: Princeton Scientific.

Cairns, John, Jr. 2013. Ruth Patrick: A Pioneering Environmental Biologist. SETAC Globe 14.

Cairns, John, Jr. 2014. Ruth Patrick 1907–2013. *Bulletin of the Ecological Society of America* 95: 11–13.

Carson, Rachel. 1962. *Silent Spring*. Boston: Houghton Mifflin.

College of Science and Technology Awards. 2020. Temple University. https://cst.temple.edu/academics/scholarships-and-awards/cst-awards. Accessed October 29.

Deevey, Edward S. 1939. Studies on Connecticut Lake Sediments, Part I: A Postglacial Climatic Chronology for Southern New England. *American Journal of Science* 237: 691–724.

Doudoroff, Peter, B. G. Anderson, G. E. Burdick, P. S. Galtsoff, William B. Hart, Ruth Patrick, E. R. Strong, E. W. Surber, and W. M. Van Horn. 1951. Bio-Assay Methods for the Evaluation of Acute Toxicity of Industrial Wastes to Fish. *Sewage and Industrial Wastes* 23: 1380–1397.

Doudoroff, Peter, and Charles E. Warren. 1957. Biological Indices of Water Pollution, with Special Reference to Fish Populations. In *Biological Problems in Water Pollution*, ed. Clarence M. Tarzwell, 144–63. Cincinnati: U.S. Public Health Service.

E. I. Du Pont de Nemours & Company. 1952. Pollution Abatement—A Problem in Community Responsibility. *Journal of Southern Research*: 23–27.

Gaufin, Arden R., and Clarence M. Tarzwell. 1952. Aquatic Invertebrates as Indicators of Stream Pollution. *Public Health Reports* 67: 57–64.

Hankins, Thomas L. 2006. A "large and Graceful Sinuosity": John Herschel's Graphical Method. *Isis* 97: 605–633.

Hart, David. 2014. Ruth Patrick, 1907–2013. *Limnology and Oceanography Bulletin* 23: 54–54.

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

Hart, William B., and F. B. Milligan. 1948. Waste Treatment Problems from the Viewpoint of Industry. Sewage Works Journal 20: 273–281.

Henry, Frank. 1960. First Woman-made River. *Baltimore Sun*, June 26.

Hohn, Matthew H., and Joan Hellerman. 1963. The Taxonomy and Structure of Diatom Populations from Three Eastern North American Rivers Using Three Sampling Methods. *Transactions of the American Microscopical Society* 82: 250–329.

Hohn, Matthew H., and Joan Hellerman. 1966. New Diatoms from the Lewes-Rehoboth Canal, Delaware and Chesapeake Bay Area of Baltimore, Maryland. *Transactions of the American Microscopical Society* 85: 115–130.

Holden, Constance. 1975. Ruth Patrick: Hard Work Brings Its Own (and Tyler) Reward. *Science* 188: 997–999.

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

Hutchinson, George Evelyn. 1953. The Concept of Pattern in Ecology. *Proceedings of the Academy of Natural Sciences of Philadelphia* 105: 1–12.

Hutchinson, George Evelyn, and Anne Wollack. 1940. Studies on Connecticut Lake Sediments, Part II: Chemical Analyses of a Core from Linsley Pond, North Branford. *American Journal of Science* 238. Studies on Connecticut Lake Sediments: 493–517.

Hutchinson, George Evelyn, and Frederick Herbert Bormann. 1972. Eminent Ecologist, 1972, Ruth Patrick. *Bulletin of the Ecological Society of America* 53: 7.

Ingram, William Marcus, and Alfred Frank Bartsch. 1960. Graphic Presentation of Biological Data for Water Pollution Survey Reports. In *Biological Problems in Water Pollution*, ed. Clarence M. Tarzwell, 260–63. Cincinnati: U.S. Public Health Service.

Kaldewey, David, and Désirée Schauz. 2018. *Basic and Applied Research: The Language of Science Policy in the Twentieth Century*. New York: Berghahn Books.

Kingsland, Sharon E. 1985. *Modeling Nature: Episodes in the History of Population Ecology*. University of Chicago Press.

Kohlstedt, Sally Gregory. 2013. Innovative Niche Scientists: Women's Role in Reframing North American Museums, 1880–1930. *Centaurus* 55: 153–174.

Langenheim, Jean H. 1996. Early History and Progress of Women Ecologists: Emphasis Upon Research Contributions. *Annual Review of Ecology and Systematics* 27: 1–53.

Lauff, George H. 1963. A History of the American Society of Limnology and Oceanography. In *Limnology in North America*, ed. David G. Frey, 667–82. University of Wisconsin Press.
Lovejoy, Thomas E. 2000. Biodiversity. Respect for the Earth: 2000, Reith Lectures. BBC.
Lowe, Rex. 2015. Ruth Patrick: The River Doctor. *Limnology and Oceanography Bulletin* 24: 108–111.
Lykknes, Annette, Donald L Opitz, and Brigitte Van Tiggelen. 2015. *For Better or for Worse? Collaborative Couples in the Sciences*. Basel: Springer Verlag.
MacArthur, Robert H., and Edward O. Wilson. 1967. *The Theory of Island Biogeography*. Princeton, NJ: Princeton University Press.
MacNees, James. 1969. PEPCO Study Held Unsound: Marine Biologist Alleges Dangerous Errors. *Baltimore Sun*, March 16.
Mandula, Barbara. 1997. Ruth Patrick. In *Women in the Biological Sciences: A Biobibliographic Sourcebook,* ed. Louise S. Grinstein, Carol A. Biermann, and Rose K. Rose. Westport, CT: Greenwood.
Mann, Albert. 1921. The Dependence of the Fishes on the Diatoms. *Ecology* 2: 79–83.
Melosi, Martin V. 2011. *Precious Commodity: Providing Water for America's Cities*. Pittsburgh: University of Pittsburgh Press.
Miller, Richard S. 1975. The Tyler Award. *Bulletin of the Ecological Society of America* 56: 2–3.
Mountford, Kent. 2012. David Flemer, in Studying Tiny Plankton, Was Able to See Bay's Big Picture. *Bay Journal,* March 13.
Murdock, Harold R. 1951. Du Pont Uses the Biodynamic Method of Stream Evaluation in Evaluating River Pollution. *Industrial & Engineering Chemistry* 43: 129A–132A.
Newcombe, Curtis L. 1957. The Training of Aquatic Sanitary Biologists. In *Biological Problems in Water Pollution*, ed. Clarence M. Tarzwell, 225–229. Cincinnati: U.S. Public Health Service.
Norris, Richard E. 1966. The Diatoms of the United States. *Science* 153: 1369–1370.
Nyhart, Lynn K. 2009. *Modern Nature: The Rise of the Biological Perspective in Germany*. Chicago: University of Chicago Press.
Patrick, Ruth. 1938. Diatoms – The Useful Jewels of the Sea. *Frontiers*, February.
Patrick, Ruth. 1943. The Diatoms of Linsley Pond, Connecticut. *Proceedings of the Academy of Natural Sciences of Philadelphia* 95: 53–110.
Patrick, Ruth. 1948a. Factors Effecting [sic] the Distribution of Diatoms. *Botanical Review* 14: 473–524.
Patrick, Ruth. 1948b. Why Study a Stream? *Frontiers*, October.
Patrick, Ruth. 1949. 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: 277–341.
Patrick, Ruth. 1953a. Aquatic Organisms as an Aid in Solving Waste Disposal Problems [with Discussion]. *Sewage and Industrial Wastes* 25: 210–217.
Patrick, Ruth. 1953b. Biological Phases of Stream Pollution. *Proceedings of the Pennsylvania Academy of Science* 27: 33–36.
Patrick, Ruth. 1957. Diatoms as Indicators of Changes in Environmental Conditions. In *Biological Problems in Water Pollution*, ed. Clarence M. Tarzwell, 71–83. Cincinnati: U.S. Public Health Service.
Patrick, Ruth. 1961. 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: 215–258.
Patrick, Ruth. 1963. The Structure of Diatom Communities Under Varying Ecological Conditions. *Annals of the New York Academy of Sciences* 108: 359–365.
Patrick, Ruth. 1965. Use Without Abuse: Protecting Our Water Resources. *Frontiers*, June.
Patrick, Ruth. 1967. 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: 1335–1342.
Patrick, Ruth. 1968. The Structure of Diatom Communities in Similar Ecological Conditions. *American Naturalist* 102: 173–183.
Patrick, Ruth. 1977a. The Importance of Monitoring Change. In *Biological Monitoring of Water and Effluent Quality, ASTM STP 607*, ed. John Cairns Jr., Kenneth L. Dickson, and G. F. Westlake, 156–189. American Society for Testing and Materials.
Patrick, Ruth. 1977b. Identifying Integrity Through Ecosystem Study. In *The Integrity of Water: Proceedings of a Symposium, March 10–12, 1975, Washington, DC*, 155–162. Washington, DC: Environmental Protection Agency Office of Water and Hazardous Materials.
Patrick, Ruth. 1997. The Development of the Science of Aquatic Ecosystems. *Annual Review of Energy and the Environment* 22: 1–11.

Patrick, Ruth, John Cairns Jr., and Selwyn S. Roback. 1966. An Ecosystematic Study of the Fauna and Flora of the Savannah River. *Proceedings of the Academy of Natural Sciences of Philadelphia* 118: 109–407.

Patrick, Ruth, Bowman Crum, and John Coles. 1969. 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: 472–478.

Patrick, Ruth, and Matthew H. Hohn. 1956. The Diatometer—A Method for Indicating the Conditions of Aquatic Life. *Proceedings of the American Petroleum Institute* 36: 332–339.

Patrick, Ruth, Matthew H. Hohn, and John H. Wallace. 1954. A New Method for Determining the Pattern of the Diatom Flora. *Notulae Naturae of the Academy of Natural Sciences of Philadelphia.*

Patrick, Ruth, and Charles W. Reimer. 1966. *The Diatoms of the United States, Exclusive of Alaska and Hawaii*. Vol. 1. Philadelphia: Academy of Natural Sciences of Philadelphia.

Patrick, Ruth, and Charles W. Reimer. 1975. *The Diatoms of the United States, exclusive of Alaska and Hawaii.* Vol. 2. Philadelphia: Academy of Natural Sciences of Philadelphia.

Patrick, Ruth, and Dennis Strawbridge. 1963. Methods of Studying Diatom Populations. *Journal (Water Pollution Control Federation)* 35: 151–161.

Peck, Robert McCracken. 2000. 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: 15–46.

Peck, Robert McCracken, and Patricia Tyson Stroud. 2012. *A Glorious Enterprise: The Academy of Natural Sciences of Philadelphia and the Making of American Science*. Philadelphia: University of Pennsylvania Press.

Poling, James. 1962. She Takes the River's Pulse. *Reader's Digest*, August.

Potapova, Marina. 2010. The ANSP Diatom Herbarium: An Important Resource for Diatom Research. *Proceedings of the Academy of Natural Sciences of Philadelphia* 160: 3–12.

Prescott, G. W. 1966. The Diatoms of the United States. *Transactions of the American Microscopical Society* 85: 582.

Preston, Frank W. 1948. The Commonness, and Rarity, of Species. *Ecology* 29: 254–283.

Pycior, Helena M., Nancy G. Slack, and Pnina G. Abir-Am, ed. 1995. *Creative Couples in the Science*s. New Brunswick, NJ: Rutgers University Press.

Quigley, James M. 1962. The Role of the Aquatic Biologist in the Federal Water Pollution Control Program. In *Biological Problems in Water Pollution*, ed. Clarence M. Tarzwell, 1–3. Cincinnati: U.S. Public Health Service.

Rader, Karen A., and Victoria E. M. Cain. 2014. *Life on Display: Revolutionizing U.S. Museums of Science and Natural History in the Twentieth Century*. Chicago: University of Chicago Press.

Reed, Mary Beth, Mark T. Swanson, Steven Gaither, J. W. Joseph, and William R. Henry. 2001. *Savannah River Site at Fifty.* Washington, DC: United States Department of Energy.

Renn, Charles E. 1957. The Training of Aquatic Sanitary Biologists—A Letter. In *Biological Problems in Water Pollution,* ed. Clarence M. Tarzwell, 230–233. Cincinnati: U.S. Public Health Service.

Richardson, Robert E. 1921. 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: 33–75.

Roberts, H. Radclyffe. 1950. Abstract of Minutes of the Annual Meeting of the Academy of Natural Sciences of Philadelphia. *Proceedings of the Academy of Natural Sciences of Philadelphia* 102: 167–170.

Roberts, H. Radclyffe. 1951. Abstract of Minutes of the Annual Meeting of the Academy of Natural Sciences of Philadelphia. *Proceedings of the Academy of Natural Sciences of Philadelphia* 103: 237–240.

Rossiter, Margaret W. 1982. *Women Scientists in America: Struggles and Strategies to 1940*. Baltimore: Johns Hopkins University Press.

Rossiter, Margaret W. 1995. *Women Scientists in America: Before Affirmative Action, 1940–1972*. Baltimore: Johns Hopkins University Press.

Rossiter, Margaret W. 2012. *Women Scientists in America: Forging a New World since 1972*. Baltimore: Johns Hopkins University Press.

Sears, Paul Bigelow. 1935. *Deserts on the March.* Norman: University of Oklahoma Press.

Slack, Nancy G. 2011. *G. Evelyn Hutchinson and the Invention of Modern Ecology*. New Haven: Yale University Press.

Smith, Michael H., Eugene P. Odum, and Rebecca R. Sharitz. 2001. 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, 95–127. New York: Taylor & Francis.

Stein, Jerome E., and John G. Denison. 1967. Limitations of Indicator Organisms. In *Pollution and Marine Ecology*, ed. Theodore A. Olson and Fredrick J. Burgess, 323–49. New York: Wiley Interscience.

Stroud, Richard H., and Charles H. Callison. 1962. Summary of Third Seminar. In *Biological Problems in Water Pollution*, ed. Clarence M. Tarzwell, 371–76. Cincinnati: U.S. Public Health Service.

Sunderland, Mary E. 2013. Modernizing Natural History: Berkeley's Museum of Vertebrate Zoology in Transition. *Journal of the History of Biology* 46: 369–400.

Tarzwell, Clarence M., ed. 1962. *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, August 13–17, 1962*. Cincinnati: U.S. Public Health Service.

Tarzwell, Clarence M. 1963. Sanitational Limnology. In *Limnology in North America*, ed. David G. Frey, 653–666. Madison: University of Wisconsin Press.

Thienemann, August. 1939. Grundzüge einer allgemeinen Ökologie. *Archiv für Hydrobiologie* 35: 267–285.

Wadhwani, R. Daniel, Gabriel Galvez-Behar, Joris Mercelis, and Anna Guagnini. 2017. Academic Entrepreneurship and Institutional Change in Historical Perspective. *Management & Organizational History* 12: 175–198.

Wujek, Daniel E. 1967. The Diatoms of the United States. *Economic Botany* 21: 193–194.

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