The “Cycle of Life” in Ecology:

Sergei Vinogradskii’s Soil Microbiology, 1885-1940

by

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Abstract

Historians of science have attributed the emergence of ecology as a discipline in the late nineteenth century to the synthesis of Humboldtian botanical geography and Darwinian evolution. In this essay, I begin to explore another, largely-neglected but very important dimension of this history. Using Sergei Vinogradskii's career and scientific research trajectory as a point of entry, I illustrate the manner in which microbiologists, chemists, botanists, and plant physiologists inscribed the concept of a "cycle of life" into their investigations. Their research transformed a longstanding notion into the fundamental approaches and concepts that underlay the new ecological disciplines that emerged in the 1920s. Pasteur thus joins Humboldt as a foundational figure in ecological thinking, and the broader picture that emerges of the history of ecology explains some otherwise puzzling features of that discipline—such as its fusion of experimental and natural historical methodologies. Vinogradskii's personal "cycle of life" is also interesting as an example of the interplay between Russian and Western European scientific networks and intellectual traditions. Trained in Russia to investigate nature as a super-organism comprised of circulating energy, matter, and life; over the course of five decades—in contact with scientists and scientific discourses in France, Germany, and Switzerland—he developed a series of research methods that translated the concept of a "cycle of life" into an ecologically-conceived soil science and microbiology in the 1920s and 1930s. These methods, bolstered by his authority as a founding father of microbiology, captured the attention of an international network of scientists. Vinogradskii's conceptualization of the "cycle of life" as chemosynthesis, autotrophy, and global nutrient cycles attracted the attention of ecosystem ecologists; and his methods appealed to practitioners at agricultural experiment stations and microbiological institutes in the United States, Western Europe, and the Soviet Union.

Key Words: autotrophism, chemosynthesis, cycle of life, ecology, nitrification, plant physiology, soil microbiology, Sergei Nikolaevich Vinogradskii (Winogradsky)

> *"Everything that the plants take from the air they give to animals,*
> *the animals return it to the air; this is the eternal circle*
> *in which life revolves but where matter only changes place."*
> Jean Baptiste Dumas, 1842[1]

Historians of science have attributed the emergence of ecology as a discipline in the late nineteenth century to the synthesis of Humboldtian botanical geography and Darwinian evolution.[2] In this essay, I begin to explore another, largely-neglected but very important dimension of this history. Using Sergei Vinogradskii's career and scientific research trajectory as a point of entry, I illustrate the manner in which microbiologists, chemists, botanists, and plant physiologists inscribed the concept of a "cycle of life" into their investigations.[3] Their research transformed a longstanding notion into the fundamental approaches and concepts that underlay the new ecological disciplines that emerged in the 1920s. Pasteur thus joins Humboldt as a foundational figure in ecological thinking, and the broader picture that emerges of the history of ecology explains some otherwise puzzling features of that discipline—such as its fusion of experimental and natural historical methodologies.

Vinogradskii's personal "cycle of life" is also interesting as an example of the interplay between Russian and Western European scientific networks and intellectual traditions. Trained in Russia to investigate nature as a super-organism comprised of circulating energy, matter, and life; over the course of five decades—in contact with scientists and scientific discourses in France, Germany, and Switzerland—he developed a series of research methods that translated the concept of a "cycle of life" into an ecologically-conceived soil science and microbiology in the 1920s and 1930s. These methods, bolstered by his authority as a founding father of microbiology, captured the attention of an international network of scientists. Vinogradskii's conceptualization of the "cycle of life" as chemosynthesis, autotrophy, and global nutrient cycles attracted the attention of ecosystem ecologists; and his methods appealed to practitioners at agricultural experiment stations and microbiological institutes in the United States, Western Europe, and the Soviet Union—inspiring developments in a wide variety of areas, ranging from Rene Dubos's ecological approach to health and disease to Vladimir Vernadsky's concept of the biosphere.

A Gentleman Turns to Science

Vinogradskii was born in 1856 in Podolia near Kiev, Ukraine, an area that also produced such outstanding scientific figures as the Nobel Prize-winning microbiologist Selman Waksman, soil scientist Jacob Lipman, evolutionist and pathologist Elie Metchnikov, and geneticist Theodosius Dobzhansky. His family's wealth, earned from his father's investment in beet sugar refineries, provided a comfortable life on a large country estate. [4] After completing gymnasium,

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[1] Dumas, 1842.

[2] Acot, 1988; Browne,1983; Cittadino, 1990; Coleman, 1986, pp. 181-196; Golley, 1993; McIntosh, 1985; Nicolson, 1996, pp. 289-310; Weiner, 1988.

[3] Although Vinogradskii is more recognizable in the West as 'Winogradsky,' I follow the trend in Russian History to transliterate his Russian name. I use 'Winogradsky' when I cite the works he published in German, French and English under that spelling.

[4] Biographical treatments of Vinogradskii include: Omelianskii, 1927, 11-33; and Waksman, 1953. I also draw on Vinogradskii's reminiscences *Itogi (In the End)*: Vinogradskii, 1949a. I acknowledge that Vinogradskii's

he traveled to St. Petersburg to study the forte piano with the German master Theodor Leschetizky, whose novel, “modern” methods of piano instruction were attracting students from around the world.[5] Vinogradskii worked zealously at his music, but “without that fire of the unconscious or subconscious inspiration that characterizes genuine artistic natures.”[6] That fall, he abandoned a career in music and entered St. Petersburg University, where he decided on a science career.[7]

Intending initially to study chemistry, he enrolled in Dmitri Mendeleev’s courses. The famous chemist’s stultifying, pedantic style, however, soon dulled his initial interest in chemistry.[8] In sharp contrast, the University’s youthful and charismatic plant physiologist, Andrei Famintsyn, offered an exciting combination of observational and experimental approaches to the study of nature that renewed Vinogradskii’s interest in science.[9] Recognizing Vinogradskii’s devotion to plant physiology (he regularly frequented the lab and had begun to

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portrayal of himself (his ‘life’s film’ as he called it) should not be accepted entirely at face value; his self-representation must be interpreted in light of its own particular context. Vinogradskii was nearing the end of his life, he felt abandoned by his daughter Helen Vinogradskii, and Waksman was persistently encouraging him to send autobiographical materials. Vinogradskii, who was more than a little embarrassed about having a biography written about him while he was still living, resisted Waksman’s requests. Ibid., pp. 3-4.

[5] Later Vinogradskii felt that music had prohibited him at this early stage to develop an attraction to the natural sciences and “in the end even paralyzed it.” Ibid., p. 15. That the family would protest is somewhat surprising, since an interest in music prevailed in the Vinogradskii home; the matriarch, Natalia V. Skoropadskaia, had taught her sons music at home. Perhaps the family was just concerned that he kept switching career paths. See Ibid., p. 4. There was also an O. Vinogradskii involved in the Russian Imperial Music Society of Kiev. Selman Waksman relates that Vinogradskii’s brother Alexander, while studying law at the University of Kiev, also “became intensely interested in music.” See Waksman, 1953, p. 7.

Leschetizky taught at the Conservatory between 1867 and 1879. Vinogradskii studied with him for one year and three days (16 September 1876 to 19 September 1877) not enough time to be considered his student, but long enough for music to become a steady companion in his life. Some of Leschetizky’s other students recalled that he considered a person his “student” only when that person had studied with him for at least two years. On Theodor Leschetizky at the St. Petersburg Conservatory see St. Petersburg Tsentral’nyi Gosudarstvennyi Istoricheskii Archive, Fond 361, Opis’ 9, Delo 10, No. 90, 3 lista—“Lichnoe delo Professora T. Leshetitskogo.” On Sergei N. Vinogradskii at the Conservatory, see idem. Fond 361, Opis’ 1, Delo 693, 5 listov—“Vinogradskii, Sergei, 16/9/1876 - 19/9/1877.” On Alexandr N. Vinogradskii time at the Conservatory see Fond 361, Opis’ 1, Delo 362, 1 list—“Vinogradskii, Alexandr 5/1/1879 - 20/1/1879.” Vinogradskii later recalled that one of the reasons he quit music and returned to study the natural sciences was that Leschetizky had left Russia. These dates, however, seem to tell another story.

[6] Vinogradskii, 1949a, pp. 5-6.

[7] Ibid., p. 6.

[8] Mendeleev was enjoying great fame as the creator of the periodic system of elements and his lecture hall “was always full, yet Vinogradskii found the subject completely unfamiliar, alien, and fatiguing. After his experiences in the German University system (1885-1888), and through his daughter Elena’s experience at Cambridge in England, Vinogradskii would blame “not the professors, not even the mumbling of Mendeleev—and not the bluntness of the students, but rather the Russian lecture system itself.” “In Germany, he wrote, lecture courses were also delivered—or to be more exact, were delivered in my time—in all sciences, but the student was able to choose the courses that most interested him. [There were also] the secondary subjects for him, for example: botany and chemistry, zoology and chemistry, chemistry and physics etc.; and thus one had to attend not more than one or two lectures per day.” Ibid., pp. 7-8.

[9] Vinogradskii would later add that “since the experimental sciences are completely based on observations and experiments, the main method to introduce beginners in any of the sciences is . . . only by way of observations and experiments, which should be carried out in parallel with theory, and best of all if a little bit beforehand; this is in order that the participant can familiarize himself, if only a little, with the materials before hearing in detail the theory of a given field.” Ibid.

acquire his own library of essential literature), Famintsyn soon accepted him as a *stagiaire* or trainee.[10] Released from sitting through long hours of lectures, Vinogradskii spent all his time in the laboratory searching for an interesting theme for independent work.[11] By the time he graduated from the University in 1880, Vinogradskii had found his path—he would train for a professorship in botany. The next fall, he began an apprenticeship with Famintsyn. In Famintsyn's botany and plant physiology courses, Vinogradskii first encountered the cycle of life concept—a perspective that would provide the foundation of his long career in microbiology.

Figure 1. Sergei Vinogradskii in the 1880s (From Selman Waksman, *Sergei N. Winogradsky: His Life and Work* [New Brunswick, N.J.: Rutgers University Press, 1953], p. 49.)

A Synthesis of Thermodynamics and Pasteurian Microbiology

Vinogradskii developed his strong commitment to the cycle of life concept during his intensive investigation of microbial nutrition. Imbibing Famintsyn's approach to plant physiology, Vinogradskii learned to view nature as a complex exchange of matter and the transformation of energy. He also read widely in the foreign literature and found himself especially attracted to Louis Pasteur's fermentation research.[12] In this literature, he learned about the debates between Pasteur and Cohn on the nature of microbial life and its significance for the cycle of life. During his apprenticeship, he synthesized his training in plant physiology and his interests in microbiology, developing a theoretical commitment to the cycle of life and a

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[10] Ibid.

[11] Ibid.

[12] Ibid., pp. 10-11.Vinogradskii continued to expand his small library of scientific literature through regular visits to "Pikker's store on Nevsky where [he] looked over the news and in general subscribed to foreign literature." Pasteur's *Etudes sur la vinaigre, Etudes sur la vin,* and especially his *Etudes sur la biere*, in which he outlined his theory of fermentation, became Vinogradskii's primary reference books and it was there, perhaps, that he first encountered the notion of the cycle of life. Vinogradskii exercised his new knowledge within the structure of his apprenticeship, engaging Famintsyn's particular views on plant physiology. Through his courses and research interests, Famintsyn not only reinforced Vinogradskii's knowledge of Pasteur's ideas, but also offered Vinogradskii another interpretation of those ideas—as a nutritionally based "exchange of matter and transformation of energy."

repertoire of laboratory skills to study it.[13] This perspective animated the research for his Master's degree on the nutritional needs of a common microscopic fungus—*Mycoderma vini*.[14] Using a novel experimental design, the centerpiece of which were tiny glass bulbs known as Geissler chambers, Vinogradskii actualized under the microscope his vision of the cycle of life.

At the time of Vinogradskii's apprenticeship, Famintsyn was setting a new direction for plant physiology.[15] Outlining his grand vision in *Obmen Veshchestv i Prevrashchenii Energii* (*The Exchange of Matter and Transformation of Energy)* (1883), Famintsyn drew on Felix Hoppe-Seyler and Claude Bernard's ideas in general physiology, calling for the unification of animal and plant physiology through investigations of organisms' "two principal vital functions: respiration and nutrition."[16] Famintsyn attached "primary meaning to the processes of nutrition" and, although he concentrated on plant physiology, he offered what he considered powerful analogies to the animal world. [17] Through the study of nutrition, Famintsyn hoped to unite the entire organic world into one global economy of matter and energy. He envisioned a world in which "animals live on organic compounds prepared by plants or on animals that live on plant food . . . plants themselves transformed inorganic matter into the "organic compounds for constructing their cells, tissues and organs."[18] Through the study of microorganismal nutrition,

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[13] Vinogradskii's exploration of fungi nutrition placed his investigation within plant physiology, an emergent field that strove to synthesize the taxonomic and morphological aspects of botany with a laboratory-based physiological approach. By the last quarter of the nineteenth century, the practices and ideals of physiology—featuring the "quantitative delineation of organic phenomena, experimental control over those phenomena, and aspiration toward prediction of phenomena"—were being extended to many domains of biology, including botanical research. These developments were informed substantially by diverse conceptualizations of the conservation of forces and energy and the rise of thermodynamics in the mid-nineteenth century. Thermodynamics at this time was an integral part of physiology, especially in the investigations of heat and the transformation of energy (metabolism) in animals. By the 1870s, however, experimental physiologists recognized that they had reached a methodological impasse. By the 1850s, Justus Liebig, Hermann Helmholtz, and Robert Mayer conceptually had transformed the static chemical methods of Jean-Baptiste Dumas and Jean-Baptiste Boussingault into a thermo- "dynamic" method. The principle of the conservation of energy as conceived by Liebig, Helmholtz, and Mayer, however, "black boxed" the physiological processes occurring in living organisms, measuring only input (food) and output (changes in heat). By the 1880s, the application of the conservation of energy to physiology had raised a new set of theoretical and experimental issues that required a new methodology. To investigate the vital processes occurring within organisms at the molecular and cellular level—inside the "black box" of life—physiologists drew on the new chemical approach known as "bioenergetics." For them this was a departure from the thermodynamics of life, which studied the energy exchanges at the level of the whole organism. On the impact of thermodynamics on biology and physiology see Kremer, 1990), pp. 453-455; and Lenoir, 1982, pp. 197-215, 229.

[14] In 1826, Dezmaziéres, a botanist in Lille divided the genus *Mycoderma* (coined by C. J. Persoon in 1822) into several species, including *M. vini*. In 1836-37, three scientists (Baron Charles Cagniard-Latour, Theodor Schwann, and Friederich Traugott Kutzing) independently discovered the biological "fermentatitve" nature of these "yeast" cells. Three chemists (J. J. Berzelius, F. Wohler, and Justus Liebig) challenged this biological definition of fermentation, offering their own chemical definition. As influential as Pasteur's works on fermentation in the 1860s and 1870s were, they failed to convince many of the biological nature of fermentation, including Liebig, Oscar Brefeld, and Moritz Traube. See Bulloch, 1938), pp. 47-63; and Fruton, 1972, pp. 42-66.

[15] On Famintsyn, see Kursanov et al, eds., 1981.

[16] Famintsyn, 1883, pp. 13. For a discussion of Hoppe-Seyler and Bernard's influence on Famintsyn see Manoilenko, in Kursanov et al., pp. 131-149; esp. 140.

[17] Famintsyn, 1883, 13.

[18] Ibid. Since his earliest work in plant physiology, he had come to see that "plants" and "animals" were merely subjective morphological categories for very similar organisms. The proper way to understand the relationships between organisms was through the exchanges of matter and transformations of energy that occurred between them and their surrounding environments.

the researcher would confront a crucial juncture in the circulation of matter and energy in nature—that between the inorganic and organic realms.[19]

Microscopic fungi (including bacteria) played an especially significant role, Famintsyn insisted, in the exchange of matter and the transformation of energy in nature. Drawing heavily on Ferdinand Cohn and Pasteur's investigations of microorganismal nutrition, Famintsyn incorporated their conceptualizations of the cycle of life into his own notion of the exchange of matter and transformation of energy.[20] Inspired by Jean Baptiste Dumas' lectures, Pasteur had attempted to understand the role of oxidation in fermentation, combustion, and putrefaction; and the means by which those processes fueled the cycle of life.[21] Pasteur based his vision of a cycle of life on the tenet that "it is a law of the universe that all that has lived disappears."[22] He described the cycle of life as an "absolutely necessary" exchange of "mineral and gaseous substances"—such as water vapor, carbonic gas, ammonia gas, and nitrogen gas—between living beings and the soil and atmosphere they inhabited.[23] He thought of these substances as "simple and mobile principles" that were moved to all locations on the planet by the movement of the atmosphere.[24] For him, life drew on these materials in order to maintain its "indefinite perpetuity." What process, he asked, would cause living beings to relinquish their "simple

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[19] Ibid. 496-7. Mayer might have died in obscurity had it not been for the intervention of the English natural philosopher and microbiologist John Tyndall (1820-1894). Tyndall championed Mayer's work, and it was largely through his efforts that Mayer received research funding and eventually fame. These were not new ideas in the 1880s. Building on the late-eighteenth century ideas of Joseph Priestley (that plants restore the air used in animal respiration) and Antoine Lavoisier (who gave chemical interpretations of the reciprocal processes of respiration and vegetation) Jean Baptiste Dumas had proposed that plants possessed reduction apparatuses, and animals combustion apparatuses. At the end of the eighteenth century, Lavoisier had introduced the quantitative method into chemistry and established that matter neither arises nor perishes, but that it exists in the same quantities throughout all of its alterations. Other writers such as Priestley, Ingenhouss, Senibier, and Saussure had discovered the "principal laws of the transformation of matter in plants and animals, and thereby established the great doctrine of the circulation of matter in Nature, which portrays the organic and inorganic worlds in close reciprocal action." By extending the law of the preservation of energy, as formulated by Huygens and Leibniz, and Lavoisier's law of the conservation of matter, Robert Mayer applied their work to his physiological investigations in the mid-nineteenth century. Mayer's experiments on the relationship between heat and motion, on which he founded his law of the conservation of energy, demonstrated to him that in the course of vital processes forces were only transformed and never created. It is probable that his ideas, as well as those of Hermann Helmholtz, strongly influenced biologists to consider the notions of the circulation of matter in nature and to study energy transformations in living organisms. The conservation of energy at first attracted little recognition between 1842 and 1860, but finally became established in the scientific literature because it could be profitably applied to develop novel investigations.

[20] Strogonov, 1996, 144; on the plant physiology courses see Idem, 28-29. For a discussion of the rise of thermodynamics and the concept of energy as it applied to these changes in physiology in the mid-nineteenth century see: Glas, 1979; Holmes, 1974, pp. 445-455; Rosen, 1959, pp. 243-263; and Teich, 1970, pp. 171-191.

[21] When these ideas were flourishing in the work of Liebig and other physiologically minded chemists, Dumas was interested in elucidating the chemical transformations that took place within animals. Considering these transformations to be combustions driven by the action of oxygen on organic compounds, he envisioned a program that would study the "complex partial oxidation reactions of organic compounds" using the new tools and achievements of organic chemists. He presented these ideas in his last lecture at the Sorbonne entitled *Essay on the Chemical Statics of Organic Beings*. The work of Dumas and Liebig during the 1840s, by redefining life in terms of chemical events, encouraged both animal and plant physiologists to transform their field into a strictly mechanical science.

[22] Vallery-Radot, ed., 1939, Vol. III, pp. 84-85. Andrew Mendelsohn identifies and discusses this key passage in Mendelsohn, 1996, pp. 41-56.

[23] Ibid.

[24] Ibid.

principles?" He concluded that life was formed only in the process of death and decay [*la dissolution*].[25]

While Pasteur envisioned the cycle of life as a series of chemical transformations, Cohn developed his vision from a botanical perspective. Emphasizing the morphology and physiology of single-celled organisms rather than the general flow of chemical elements (Pasteur's "simple principles"), Cohn imagined the cycle of life as a taxonomic classification of organisms.[26] He derived this perspective in part from his mentor Christian G. Ehrenberg, who had attempted to classify the lowest animals and plants.[27] In 1872, Cohn described the 'cycle of life' as the "entire arrangement of nature" in which the dissolution of dead organic bodies provided the materials necessary for new life.[28] The amount of material that could be molded into living beings was limited, he reasoned, so there must exist an "eternal circulation" [*ewigem kreislauf*] that constantly converts the same particle of matter from dead bodies into living bodies. Due to the limited amount of material that could be molded into living beings, he conjectured that there must be a conversion of the same particles of matter from dead bodies into living bodies. For Cohn, bacteria released the matter bound up in each generation of plants and animals, breaking down organic bodies, and so provided "body material" for the next generation of life. "Bacteria cause dead bodies to come to the earth in rapid putrefaction," he wrote, and so "they alone cause the springing forth of new life, and therefore make the continuance of living creatures possible."[29]

In his Master's research of 1881-1883, Vinogradskii synthesized the views of Pasteur and Cohn, along with Famintsyn's concept of the exchange of matter and transformation of energy.

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[25] Vallery-Radot, ed., 1939, Vol. II, pp. 648-653, esp. 653. This is a review written by Mr. Danicourt of an address present by Pasteur at the *Soirées scientifiques de la Sorbonne*, originally published in *Revue des cours scientifiques*, No. 18, February 1865; and cross-referenced under "*Vie*" in *Oeuvres*, Vol. VII, 657.

[26] F. Cohn, 1870, pp. 203-204. On Cohn, see Geison, Vol. III, 336-341; and Cohn and Rosen, 1901. Pauline Cohn (Ferdinand Cohn's wife) edited together a collection of Cohn's diaries and correspondence. Both of these biographical works provide extensive bibliographies.

[27] Ibid. Christian G. Ehrenberg (1795-1876), Geheimer Medicinalrath and professor at the University of Berlin, at the time of instructing Cohn (in 1849) was using polarized light to determine the nature of microscopic objects. He did not arrive at any conclusions concerning their molecular structure, but this shows that Cohn may have been familiar with and possibly trained in the study of molecular structure. See Sachs, 354. Cohn recounted that he was driven to study "these organisms that stand at the border between plants and animals" when it had come to light, "that the cell, in the clearest and most complete scientific investigations, was accessible in those simplest, lowest, microscopic plants, in which, as single-celled beings, their entire development and complete life process took place in the same cell."

[28] F. Cohn, 1872, p. 18.

[29] Ibid. The concepts of a life cycle described above had much in common, yet the differences reveal the varied theoretical and methodological commitments of their authors. For example, Pasteur's concept revolved around the movement of simple principles in chemical processes while Cohn's centered on the life cycles of organisms. Pasteur envisioned a circulation of matter that included all the chemicals, which provided living organisms their vital energy. He viewed bacteria as chemical agents that operated through the process of combustion to release all chemical elements into the atmosphere. Life could then draw on this reserve as needed in order to maintain itself. He did not think the "circle of transformations" was complete until the microscopic beings had returned all organic material back into the atmosphere. Cohn, on the other hand, emphasized the morphology and physiology of single celled organisms rather than the general flow of chemical elements (Pasteur's simple principles). For Cohn's "eternal circulation" of matter in nature to function, living beings would have to gain access somehow to the material stored in other organic beings. The action of microbes, Cohn believed, would accomplish this exchange of matter.

His goal—to determine how fungi life cycles were related to the organic and mineral contents of its environment—flowed from Famintsyn's approach to the study of plant nutrition. Famintsyn considered plant nutrition to be only one dimension of the much grander process of the exchange of matter and the transformation of energy. This process not only provided the organizing theme of *The Exchange of Matter*, but also, he believed, of all of nature. "The exchange of matter and the transformation of energy," he wrote, "are among the main functions of every living being; inseparably connected to them are all life functions, not only in the animal, but also in the plant organism."[30]

It was difficult, Famintsyn admitted, to show any analogy between the vital functions—such as nutrition, respiration, and reproduction—in the higher representatives of the two kingdoms."[31] Yet the idea "that animals and plants share a common fundamental beginning of life and that a deeper and more attentive study of their most central vital functions will present much that is analogous" was gaining increasing respect in science.[32] Vinogradskii chose an experimental organism that was strategically located for Famintsyn's agenda. *Mycoderma vini* existed at the border between animals and plants, and its nutritional demands made it a viable organism for studying the exchange of matter and energy between the organic and inorganic realms.[33]

On December 15, 1883, Vinogradskii presented the results of his investigation to the botanical section of the St. Petersburg Society of Naturalists.[34] His report "On the influence of external conditions on the development of *Mycoderma vini*," addressed two problems: "1) To find an exact method for studying the influence of external conditions on the development of lower fungi" and "2) To investigate to what extent the form of cells of some type of lower fungus remains constant in various conditions of nourishment."[35] Vinogradskii investigated these questions using Famintsyn's physiological approach. He first grew "normal appearing" *Mycoderma* cultures in "nutritive liquids, the chemical make-up of which were precisely known."[36] Then, varying these liquids by only one nutritive component, while keeping the remaining conditions of the culture strictly uniform, he observed the organisms for deviations in

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[30] Famintsyn, 1883, p. 10.

[31] Ibid.

[32] Ibid. Famintsyn, 1860, pp. 18-62. By choosing the "fermenting fungi" *Mycoderma vini Desm.*, Vinogradskii was, in part, satisfying Famintsyn's concern that, although a large number of investigations had been carried out on fungi nutrition, this work provided only a "scanty amount of information." It was also possible that Vinogradskii saw some practical application for studying this fermenting fungus, which also had been found to play a role in beet sugar production. Vinogradskii's family owned a presiding interest in a Kiev beet sugar plant, in which his father had invested.

[33] Vinogradskii's *Mycoderma vini* was suffering an identity crisis in the nineteenth century. Researchers' choices of species and genus names were telltale signs of their taxonomic preferences and the theoretical views that underlay them. Opposing schools of thought had produced various systems for classifying microorganisms. For example, Pasteur had also used the name *Mycoderma vini*, while Ferdinand Cohn termed it *Sacchyromyces Mycoderma* and Nägeli included the organism in a broad class under the name *hefepilze* (yeast plants). The variation in nomenclature reflected differences in these researchers' opinions about the role of microbes in fermentation and putrefaction (or decomposition). For a discussion of the wide variety of names for Mycoderma vini, see Brefeld, 1872, pp. 1-64; Resse, 1870, pp. 81-84.

[34] Vinogradskii, 1883, pp. 132-135.

[35] Ibid., p. 132. It is probable that in discussing the constancy of cell shape here, he is associating his investigation with debates on the nature of microscopic species.

[36] Ibid.

shape and life cycle.[37] Borrowing from Pasteur's publications, Vinogradskii used an apparatus—Geissler chambers—that permitted "attentive" and prolonged microscopical observation. He thus hoped to link "the observed characteristics of form and manner of growth in various nutritive liquids with the presence or absence of one kind of material in the liquid."[38]

So, within the confines of the small glass discs known as Geissler chambers, Vinogradskii actualized the "cycle of life." His "method of observation," he explained, "is distinctive because the cultures were maintained in special apparatuses for microscopic culture, consisting of a Geissler chamber connected with gutta percha tubes to two glass vessels [which contained the *Mycoderma* cultures]." (See Figures 2a, 2b) The Geissler chamber was beneficial in three important regards: it enabled Vinogradskii to observe the organisms for long periods, it allowed him the flexibility "to either supply fresh nutritive liquids continually or to alter the culture's conditions," and it "absolutely eliminated the danger of littering the cultures . . . with foreign organisms."[39] Peering into the Geissler chambers as he manipulated the environmental conditions within them, he made claims not only about the nutritional needs of a single species of microscopic fungi, but about natural processes on a much grander scale. In this investigation, Vinogradskii developed a repertoire of laboratory skills and the perspective that would guide his long lifetime of research.

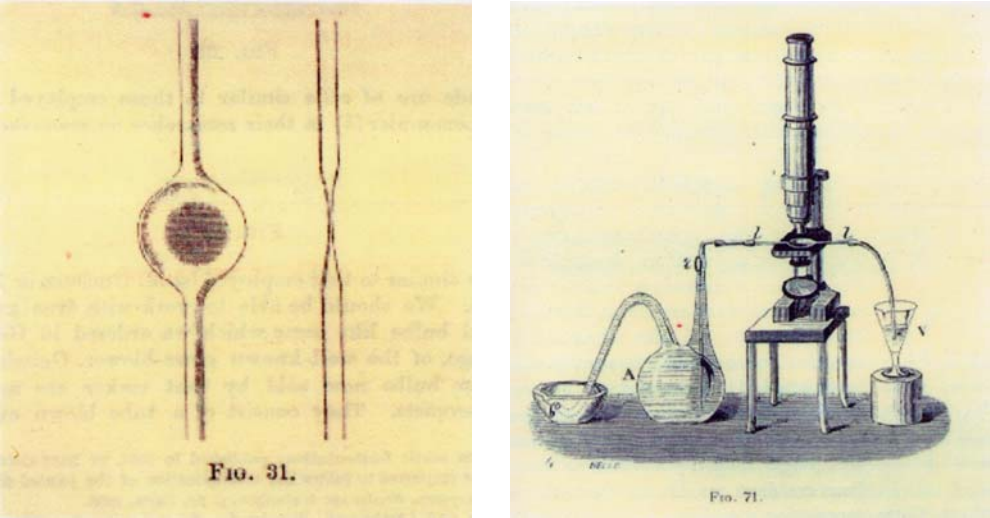

Figure 2. (a) Geissler Chamber; These chambers are flattened glass tubing that allow for culture liquids to pass slowly through, perhaps influencing the development of the microorganisms living in the chambers, (b) Geissler Chamber with a microscope. [Louis Pasteur, *Études sur le vinaigre: sa fabrication, ses maladies, moyens de les prévenir : nouvelles observations sur la conservation des vins par la chaleur* [Paris: Gauthier-Villars V. Masson et fils, 1868]]

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[37] Ibid. At the time Vinogradskii began his investigation there were no chemical methods available to accomplish Famintsyn's objective of studying the chemical processes inside cells. Using the next best method, the prolonged, 'direct' observation of the organism's development, Vinogradskii surveyed his *Mycoderma* cultures for how efficiently or effectively they exchanged matter and transformed energy—that is, grew—in varied substrates.

[38] Ibid.

[39] Ibid, 133.

Introducing “Free Nature” into the Laboratory

Vinogradskii demonstrated the versatility of his new assemblage of theoretical perspectives and laboratory methods in his next investigations. Taking advantage of his mentor’s international network, and following the contemporary trend among young Russian scientists to study abroad, he continued his graduate studies at the University of Strasbourg.[40] His move to Anton de Bary’s well-known botanical laboratory in Strasbourg marks his entry into a community of botanists and physiological chemists, the members of which he engaged on a variety of issues concerning technical approaches and theoretical problems. He did not abandon, however, the perspectives he had learned under Famintsyn’s mentorship. Employing the same microcultural methods that he had used to explore the nutrition of *Mycoderma vini* Vinogradskii now addressed a new experimental object—a genus of sulphur bacteria known as *Beggiatoa*. (See Figure 3.) This revealed his lasting commitment to Famintsyn’s approach to plant physiology.[41]

Vinogradskii’s choice of experimental organism, however, introduced a new dimension into his research—field studies. His first organism had been rather mundane—*Mycoderma vini* grew in wine, beer or almost any other fermentable liquid; his new interest, *Beggiatoa,* however, were the denizens of some of nature’s most exotic places—swamps, marshes, bogs, and sulphur springs on steep Alpine slopes. *Beggiatoa*’s peculiar physiology, especially their nutritional demands, forced Vinogradskii to search them out in their natural habitats. In response to these nutritional needs he also reconfigured his technical repertoire—adding to the Geissler chambers and retorts used in his first investigation new variations of slide microcultures and, most important, “artificial environments” that enabled him to observe his wild (*sauvage*) organisms in conditions that, he thought, might approximate their natural states. By correlating and comparing his observations across these cultures (back and forth between the laboratory and “free nature” as he called it) he brought the field into his laboratory. This enabled him, he believed, to reach novel conclusions about the role of sulphur bacteria in nature’s economy—conclusions that he considered more “natural” and less provisional than those of preceding investigators. His compulsion to substantiate his interpretation of laboratory experiments through natural historical observations—a reflection of his thermodynamic vision of the cycle of life—inspired him to create versatile microcultural methods for his Strassburg research.

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[40] Famintsyn and De Bary shared an interest in investigating symbiotic relationships in fungi and lichens. De Bary had coined the term “symbiosis” in his *Die Erscheinung der Symbiose* (Strassburg, 1879). They showed each other a mutual respect which would have enhanced De Bary’s positive reception of Vinogradskii in 1885. Both Famintsyn and his close friend and colleague M.I. Voronin had, following the advice of their advisor Lev Semenovich Tsenkovskii, spent 1858 expanding their scientific horizons under De Bary’s guiding charms. See Strogonov, 1996, p. 22.

[41] Although a self-conscious discipline of ecology would not form until the early-twentieth century, the conceptual frameworks and methodologies that defined that discipline were already prevalent in late-nineteenth century botany and plant physiology. Vinogradskii transferred his thermodynamic plant physiology to De Bary’s laboratory at a time when botany was becoming “ecological.” Vinogradskii did not, however, place his work in the Darwinian worldview being espoused by a handful of German botanists. These botanist shared training in plant physiology, an interest in the problem of adaptation and natural selection, and experiences in foreign and exotic lands. They were developing new approaches to plant anatomy, plant physiology, and plant geography that by the end of the nineteenth century would be identified as ecological. See Cittadino, 1990 for a discussion of these schools.

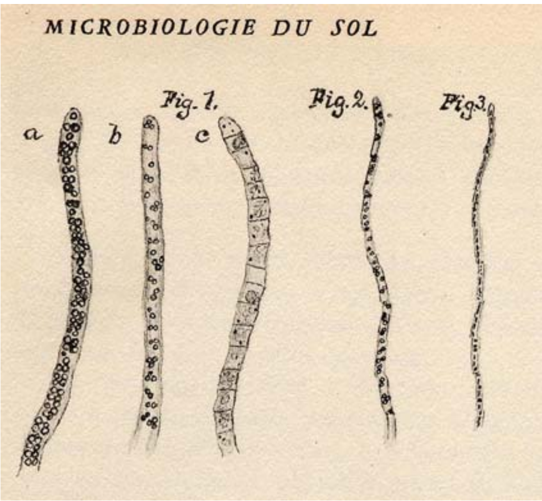

Fig. 3. Filamental sulphur bacteria *Beggiatoa* [Serge Winogradsky, *Microbiologie du Sol: Problèmes et Méthodes—Cinquante Ans de Recherches* [Paris: Masson et Cie.], p. 859.)

Vinogradskii's Strassburg research thus spilled out beyond the physical and intellectual confines of the laboratory. Immediately after his arrival there in November 1885, he conducted an expedition to observe how his organisms lived in their natural settings—sulphur springs—and to collect samples of them for his experiments.[42] That he made these difficult trips to such inhospitable sites reflects the strength of his theoretical commitments.[43] A naturalist searching for the secrets of "free nature," he sought sulphur springs not in the relatively accessible spas, but in the wild, far from human activity. Only here in savage nature did organisms play out their specific roles in the economy of nature.[44]

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[42] Following the advice of Dr. Eduard Fischer, he visited four sulphur springs, three located near Lake Thun in the Bern Canton, Switzerland and one at Bad Langenbrück in Baden, Germany. He found especially instructive the Rinderwald Spring (also called Fuchsweidli Bad) situated between the towns Frutigen and Adelboden along the Engstligen Valley, Adelboden Spring in Adelboden, and an unnamed spring near Leissigen.

[43] It was common practice in this community to share samples, even across disciplinary lines and with challengers to one's claims. The inspiration for Vinogradskii's sulphur spring expeditions came from several directions. He could have fulfilled the requirements of the investigation De Bary had recommended—to investigate whether certain species of microscopic fungi maintained constant life cycles in varied environments—by simply using samples of *Beggiatoa* already available in the Strassburg laboratories or local collections

[44] The novelty of Vinogradskii's approach to plant physiology emerges when viewed against the background of developments in German botany during the 1880s. Eugene Cittadino has identified a generation of German botanists, who were part of an entrenched laboratory tradition, and were practiced in the tenets of Darwinian evolution and had made significant contributions to Darwinian biology. In some ways, Vinogradskii fits this profile quite well—he, too, trained in botany anchored in a well-established laboratory tradition during the post-Darwinian period. The differences, though, that set him apart from this cohort are significant and telling. He came from a very different geographical setting with a distinct complement of flora and fauna—for him, Strassburg was already a foreign land. He needed to go no further than the poisonous waters of sulphur springs located on steep Alpine slopes to find the extreme conditions and exoticism so sought by his peers. Vinogradskii diverged most significantly from the German botanists, by his extensive training in and commitment to plant physiology. Vinogradskii's research on microorganisms, and specifically on their vital processes of nutrition and respiration, demanded the specialized laboratory manipulations that the German botanists had relinquished when nature became

In the late fall of 1885, he returned to the laboratory, arms laden with collection bottles and prepared to address De Bary's assignment—to investigate recent claims challenging De Bary's assumption that a class of microscopic fungi (including *Beggiatoa*) maintained constant, rather than variable, life cycles.[45] Vinogradskii began to investigate *Beggiatoa* nutrition by applying the lessons he had learned during his first investigation. His *Beggiatoa* specimens, however—living in bottles "not entirely hermetically sealed" in the laboratory—held an important surprise.[46]

Post-Kochian bacteriology mandated that a successful morphological investigation of bacteria required the use of the pure liquid and gel cultures that had become standard in the 1880s. Following the prescribed methods, Vinogradskii tried to cultivate the *Beggiatoa* samples he had collected on his sulphur spring expedition in a series of artificial solutions. Surprisingly, none of the resulting cultures proved healthy enough for him to investigate them morphologically.[47] Frustrated by *Beggiatoa*'s inability to grow in the standard cultures, he changed his line of research to investigate their nutrition.[48] Testing how well *Beggiatoa* grew in a series of nutrient solutions and gelatin plates, he always received poor results.[49] With the lessons of his sulphur springs expedition in mind, he explained his experimental observations in terms of natural phenomena. In the laboratory cultures, he observed, organic material actually hindered *Beggiatoa* growth and simultaneously favored the development of other bacteria, which through their vital activities produced a decomposition product noxious to *Beggiatoa*.[50]

As Vinogradskii's nutrition experiments progressed, he relied increasingly on the repertoire of techniques he had developed in Famintsyn's physiological laboratory. Using a

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their laboratory. This early divergence between Vinogradskii and the German Darwinian botanists would expand over the next four decades and into the twentieth century. At that time, the efforts of these plant adaptationists would influence the founding of the new science of plant ecology. Vinogradskii's perspective would also contribute to the founding of new ecological disciplines—in soil science and microbiology.

[45] If Vinogradskii could corroborate De Bary's ideas, the next task would be to establish a new classification system for these organisms. Vinogradskii's assigned project was central to De Bary's own interest in investigating the stability of microorganism species. Vinogradskii was intimately familiar with this question, and no doubt consented to pursue it because it formed the core issue in a long-standing debate about the fundamental nature of microbes. Direct observations and the study of life cycles were central to De Bary's study of *Peronospora infestans* the parasite responsible for the 1861 potato blight. This research brought him wide recognition and involved him in the question of spontaneous generation. See Robinson, 612-613. Vinogradskii, 1949a, p. 14.

[46] Winogradsky, 1888, p. 588.

[47] Ibid., p. 569.

[48] Ibid. In his published account, Vinogradskii claimed that he was forced to adopt a physiological approach at this juncture in his investigation. It is clear, however, that his investigation, since its inception, was at its core physiological.

[49] Ibid., pp. 556, 569-570. For example, he experimented with various concentrations of sugar, peptone, ammonium nitrate and other organic materials.

[50] Ibid., p. 570. This assessment had broader significance for the organism's place in nature's economy: *Beggiatoa's* "beautiful development" in the sulphur springs, he thought, was "easily understandable" as the result of competition between *Beggiatoa* and other microorganisms. *Beggiatoa* exist in "complete purity" only in the sulphur springs, because there they find the necessary nutrients and "endure no competition (*die Concurrenz*) from other bacteria," which cannot propagate in the poisonous waters. In environments where *Beggiatoa* did live "in society" with putrefying bacteria, the latter, which propagated at a rate much greater than the slow-growing *Beggiatoa,* were able to decompose all the organic nutritive material.

complex yet complementary set of cultures—grown on microscope slides, in retorts, in parallel tests, and in artificial sulphur environments—he hoped to tease apart *Beggiatoa's* nutritional processes in order to understand better that organism's natural role in the cycle of life. By applying methods that he vaunted as "direct," he correlated his observations of microbial activity in these laboratory cultures with those he had encountered during his expedition. Placing organisms from "free nature" into drops of solutions on slides under his microscope ocular, he was, in effect, opening a portal between the natural and artificial, nature and the laboratory, and also between the particular phenomena of individual organisms and his grand vision of the cycle of life.[51] As he attempted to corroborate and refine his interpretations of *Beggiatoa* physiology these juxtaposed dichotomies shifted in response to his various experimental manipulations.[52] He used his experiments not only to answer specific questions about *Beggiatoa* nutrition, but also to describe a more general natural phenomenon, one even more fundamental than the nature of bacterial species.[53]

Since he relied upon "direct" observations of laboratory microcultural environments, Vinogradskii believed that his conclusions had the same epistemological significance as those made from observations in "free nature." He conducted a series of experiments using the approach he had developed for his investigation of *Mycoderma vini* during his St. Petersburg apprenticeship. Using slide microcultures very similar in design to the Geissler chambers of his first investigation, he attempted to elucidate the physiological role of the sulfur granules in *Beggiatoa*.[54] In a series of experiments, he made a series of correlations—first between the

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[51] By 'free nature', Vinogradskii meant the organisms he observed were living outside the influence of artificial conditions, such as he would administer in his "direct" experiments. Here we see the distinction he made drew between nature and the laboratory. The rhetorical use of the notion of "direct" observation or experimentation was widespread during this period. It is certainly related to Pasteur's microbial investigations, but must extend beyond and earlier to that. It is also in Cohn's writing. In this period, it is essentially related to the use of microscopes, which allowed investigators to see into nature in increasingly greater magnifications and detail.

[52] Ibid., 532. Vinogradskii conducted a series of experiments between December 1885 and January of the next year.

[53] In the next decade, in part due to Vinogradskii's nitrification research at the Institute of Experimental Medicine in St. Petersburg, Russia, this larger phenomenon would come to be called 'nitrogen cycles' and 'sulphur cycles.' He was not the first to wonder at the curious relationship between sulphur granules and the filamental bacteria in which they were deposited, and in his 1887 report, he presented a historical overview of the work he thought most relevant. Cohn's contribution was first and foremost. In the early 1870s, had Cohn described a group of bacteria that contained sulfur granules in their filaments and were able to live in an environment rich in hydrogen sulfide, a compound poisonous to most other forms of life. Drawing on the work of Adolf Engler and Georg Winter, Cohn agreed that the sulphur granules were the organism's defining morphological characteristic. Later, A. Ehtard and L. Olivier had explained the granules as the organism's chemical response to the presence of sulfates. Zopf thought them merely an indicator of the filament's age—the more granules, the older the filaments. Vinogradskii criticized the conclusion that the granules were simply either surplus reserves or waste material, because he felt that the investigators had not done careful enough experiments, or, he wrote, were based simply on "deductive reasoning and incorrect experimental methods." He did not believe that these sulphur granules were, in fact, simply the morphological characteristics Cohn and others had assumed, not did he accept Zopf's notion that they were merely the result of a mechanical absorption of sulphur from the immediate surroundings.

[54] Ibid., 503. These regular washings removed that bacteria and infusorians that he knew *Beggiatoa* could not compete with. Since *Beggiatoa* filaments attached themselves along their length to the surface of the glass, they were not washed away by the slight flow of the liquid under the cover slip. With this apparatus, he could observe directly the bacteria's movement as it negotiated the artificial environment he had created. He finally obtained healthy growths of *Beggiatoa*, which he could maintain over prolonged periods (up to several months) by washing the microculture several times per day.

presence of sulphur granules in *Beggiatoa*'s filaments and the presence of hydrogen sulfide—which allowed him determine the origin of the sulphur. The "extraordinary speed and constancy with which *Beggiatoa* stored sulphur" led Vinogradskii to conclude "that the production of sulphur granules occurred only through the oxidation of hydrogen sulfide."[55] Having tamed *Beggiatoa*'s most intriguing physiological characteristic, he could now expand his investigation to address the questions that lay at the heart of his grand vision of nature.

In Vinogradskii's "cycle of life," microorganisms played specific roles as "agents" of chemical transformations. Through processes of decay, fermentation, oxidation, and reduction, they drove the changes that organized nature's building blocks—the elements. These agents determined their niche in the cycle of life by their vital physiological processes of nutrition and respiration. This perspective guided Vinogradskii's next experiments on *Beggiatoa* nutrition. Convinced now that *Beggiatoa* required both oxygen and hydrogen sulfide to produce sulfur granules in their filaments, he took what he considered "the next logical step." [56] Imagining himself in *Beggiatoa*'s environment, he tried to understand how *Beggiatoa* negotiated the liquid strata in which they lived.[57] Correlating his observations in nature freely with those made in the laboratory, he developed a coherent understanding—one that was simultaneous environmental and physiological—of *Beggiatoa*'s spatial negotiation of their environment relative to two natural elements—hydrogen sulfide and oxygen.

In the laboratory, the immediacy of his microscopical techniques and apparatuses provided a clear picture of *Beggiatoa*'s preference for strata with less oxygen. His observations of *Beggiatoa* in slide microcultures, he thought, demonstrated how they regulated their own need for hydrogen sulfide and oxygen. When placed into a drop of solution devoid of hydrogen sulfide *Beggiatoa* filaments moved to the center of the drop and formed into a dense ball or tuft.[58] After adding a drop of diluted hydrogen sulfide, the *Beggiatoa* "migrated immediately to the edge of the drop where . . . they formed a thick white border visible [even] to the naked eye."[59] This border, Vinogradskii observed, always grew one millimeter from the edge of the drop. If there were enough filaments in the drop, they would even create a solid wall between the slide and

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[55] Ibid., p. 505.

[56] Ibid., pp. 513-517. Drawing on his own observations and those made by Ehtard and Olivier, and Hoppe-Seyler, Vinogradskii accepted that they required a supply of oxygen. How did *Beggiatoa* manage their nutritional needs—that is, where did they find enough free oxygen to oxidize hydrogen sulfide? He assumed that *Beggiatoa* must find the oxygen in the water they lived in, however, free oxygen could not exist in hydrogen sulfide-rich liquids. To resolve this contradiction he again resorted to his slide microcultures.

[57] The phenomenon of scientists seeing into nature by imagining themselves as part of it has captured the attention of historians recently. For a good discussion of Barbara McClintock's own "process of integration" see Comfort, 2001, pp. 67-68. Not limiting his mind's eye to the slides in front of him, he compared observations of three environments—retorts, sulphur springs, and microcultures. In retorts, *Beggiatoa* accumulated primarily at the water's surface where they formed tender nets and tufts; however, as they spread out across retort's glass wall they avoided the surface of the water never growing closer than one millimeter. In the sulphur springs *Beggiatoa* behaved similarly—they always congregated just below the surface of the water. On the other hand, neither did they grow in the water's depths—he had never found them at the bottom of any pool deeper than a half meter. In contrast, "they always grew abundantly at the effluence of pools where the water was only a few centimeters deep."

[58] Winogradsky, 1888, p. 515.

[59] Ibid. Vinogradskii uses a descriptive language very adroitly here, as in other sections of his paper, effectively drawing his readers not only into his argument, but also through his microscope into the secret world of the sulphur bacteria.

cover slip. Upon microscopic investigation, these *Beggiatoa* borders struck him as "very peculiar": [60]

> The filaments form a thickly woven mass stretching parallel to the cover slip. They are pressed thickly together and creep to and fro, in and out. Other [filaments] travel across (*durchkreuzen*) the mass in various directions, twining themselves around one another and the straight filaments in the most whimsical manner. Rising . . . from this netting filamental tails and curves oscillate to and fro, at times retreating into the mass of filaments and later emerging again—it is an extremely elegant and animated image.[61]

For Vinogradskii, the elegance of this image carried significance well beyond the *Beggiatoa* border. Watching the bacteria form a ring-like border in an intermediary position between the hydrogen sulfide water and the free oxygen of the atmosphere, he interpreted their oscillating movements as an exchange of gases between these organisms and their environment. Here he was looking at this phenomenon through the lens provided, not by De Bary's morphological approach, but rather, by Famintsyn's physiological thermodynamics.[62] For him this was no less a respiratory act than was an animal's inhalation of oxygen and exhalation of carbon dioxide, or a plant's absorption of carbon dioxide and emission of oxygen.

The nature of *Beggiatoa*'s sulphur—a riddle that had preoccupied Vinogradskii for the past two years of experiments, during countless hours of peering through his microscope as he washed slide after slide—could now be investigated as a nutritional process. Now knowing that *Beggiatoa* needed hydrogen sulfide to live, Vinogradskii addressed the "kernel" of the larger question: Why did *Beggiatoa* need so much sulphur and what was its nutritional significance?[63] Vinogradskii's sulphur bacteria investigations were the first stage of a research program that would define a crucial aspect of his scientific legacy. They would lead him in the next phase of his scientific career to discover a new physiological process by which organisms were able to live on inorganic materials, a process he called chemosynthesis.

In the course of his Strassburg research, Vinogradskii practiced the skills he had leaned with Famintsyn in St. Petersburg. Specifically, he synthesized the cycle of life vision with a laboratory-based experimental program organized around a strong inventory of flexible techniques and a conceptual and rhetorical strategy of direct observation. Vinogradskii had developed under Famintsyn the theoretical approach and basic experimental design (the direct method) that he used in his Strassburg work. During his German internship, however, he was able to apply this Russian training to new questions under the mentorship of one of Europe's foremost botanists. The mature research style he developed in contact with these two schools would lead to his path-breaking discoveries of chemosynthesis, the nitrogen cycle, and a new ecological method in soil microbiology.

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[60] Ibid.

[61] Ibid.

[62] Ibid., pp. 515-516. At this stage in his investigation, Vinogradskii imagined a correlation between the activity of the sulfur bacteria filaments (their intricate negotiations of strata) with their nutritional and respiratory processes—as they moved inside the border they absorbed hydrogen sulfide and when outside they oxidized it. Thinking physiologically, he imagined that the *Beggiatoa* were "regulating this two step process according to their own [nutritional] needs."

[63] Ibid., 546-547.

In 1888, Vinogradskii left De Bary’s laboratory to search for an academic position in the Russian university system.[64] Failing to find a position either in St. Petersburg or Kiev, in the autumn he returned to Strassburg. Upon his arrival, however, he learned that De Bary was suffering from a serious cancer in his jaw. This precipitated the third stop on Vinogradskii’s international journey; leaving Strassburg, he visited his previous homes in Kiev and St. Petersburg before settling finally in Zurich, Switzerland in late 1888.

From Physiological Types to Chemosynthesis

Extending his investigation of inorganic respiration to the question of nitrification, Vinogradskii eventually proposed a novel physiological law that he would call “chemosynthesis.”[65] In Zurich, he worked in two laboratories—at the Institute of Hygiene at Zurich University and the Laboratory of Agricultural Chemistry of the Zurich Polytechnic.[66] Moving from De Bary’s mycological laboratory to the chemistry laboratories in Zurich, he brought with him the cycle of life perspective he had refined and deepened in his research on sulphur and iron bacteria. Applying this approach to new experimental objects—non-filamental nitrogen bacteria—he asked new questions and advanced new experimental methods. Vinogradskii adjusted his investigation to address the nutritional requirements of his new organisms—where sulphur and iron bacteria flourished in very specific environments, nitrogen bacteria populated many environments. He did not limit his shift from the specific to the general to his laboratory investigations; he applied this broader focus to his conclusions about the structure of nature.

Nitrification research filled the journals in the 1880s-1890s, yet there was no consensus about the nature of this phenomenon. Agricultural chemists, plant physiologists, and microbiologists debated whether it should be investigated as a chemical, biological, or physical process. Several investigations—for example by Schloesing and Müntz, and by Hereaus—had provided strong evidence linking nitrification in the soil with the presence of living organisms.[67] Vinogradskii—thinking as a plant physiologist with strong microbiological interests—accepted

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[64] Omelianskii, 1927, p 18.

[65] Vinogradskii first described this law as a new physiological type that was capable of “de synthese chimique.” Serge Winogradsky, “Recherches sur les Organismes de la Nitrification, 2nd Mémoire” *Annales de l’Institut Pasteur,* Vol. 4, No. 5, May 1890. Wilhelm Pfeffer coined the term “chemosynthetische,” which superseded Vinogradskii’s “physiological type” and clumsy “anorgoxydant.” In effect, Pfeffer translated Vinogradskii’s idea into German and into his own notion of a circulation of nutrients (*Kreislauf der Nahrstoffe*). See Pfeffer, 1897, pp. 346-349 for his discussion of Vinogradskii’s work and pp. 278-283 for his global views of the circulation of matter and energy in nature.

[66] During this period he worked to improve his knowledge of chemistry with Ernst Schultz and Arthur Rudolf Hantzsch.

[67] See Schloesing et Müntz, 1877, Vol. 84, No. 7, pp. 301-303; Idem., Vol. 85, No. 22, pp. 1018-1020; Idem., 1878, Vol. 86, No. 14, pp. 892-895; Idem., 1879, Vol. 89, No. 21, pp. 891-894 ; Idem., No. 25, pp. 1074-1077. On the contributions of Schloesing and Müntz to the history of microbiology see: Doetsch, 1960, pp. 103-107; and Waksman, 1932, pp. 62-63. For a discussion of the relationship between soil chemistry and plant growth see Ihde, 1964, pp. 420-426. Hereaus, 1886. For a longer list of the previous research cited by Vinogradskii see Winogradsky, 1890, pp. 215-220.

this conclusion and oriented his own research in this direction. In his opinion, however, this work had not identified precisely the responsible organism and he set out to solve the mystery.[68]

Drawing on his Strassburg research, he assumed that “if there are organisms like sulphur bacteria, which can oxidize hydrogen sulfide, then one with good reason may suggest the existence of specific organisms that live on such a rich source of energy as the oxidation of ammonia.”[69] Motivated by his discovery of an entire world of microbes that can subsist on inorganic matter, he assumed that he could locate the “elusive agent of nitrification.”[70] This research was clearly guided by his commitment to the cycle of life concept. He now assumed that behind every natural process—such as the conversion of ammonia into nitrogen—resided a microbiological agent. Following standard procedures based on Koch’s principles, Vinogradskii first attempted to isolate the nitrifying organism using standard gelatin plates.[71] This approach proved futile; he could achieve only an extremely weak production of nitrification. Abandoning the usual methods of the bacteriologist, he returned to the physiological methods he had applied during his sulphur and iron bacteria work.[72]

Vinogradskii again went to wild, free nature to collect his experimental organisms. Avoiding the cultures already in the laboratory, he used two different kinds of Zurich soil. Inoculating a variety of solutions with these little clumps of complex nature, he attempted to create a “liquid nutritive environment,” which produced a strong appearance of nitrification. Trial and error confirmed his expectation that nitrification occurred only in cultures devoid of organic matter. This led him to a “breakthrough”; not only did the process of nitrification not require organic material—organic material actually impeded it.[73] His subsequent manipulations—refining the specificity of nutritive solutions, and making careful microscopic observations of bacterial behavior in varied artificial environments—revealed that not one, but two species worked symbiotically to produce nitrification.[74] The characteristic that most interested him about these nitrogen bacteria was their ability to live “normally” without energy from light. His investigation of this phenomenon would lead him to define a new physiological type of organism.

Vinogradskii’s commitment to the cycle of life concept predisposed him to extrapolate from his laboratory experiments to challenge fundamental assumptions of general physiology.

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[68] In a series of five articles, Vinogradskii published his Zurich research. There he drew on and challenged the views of Schloesing and Müntz, and Heraeus, who had preceded him in biologically oriented nitrification studies. Winogradsky, 1890, pp. 215-231; 257-275, 760-811, Idem., 1891, pp. 92-100, 577-616. See A. Koch, 1891, pp. 669-672, 680-685,698-701.

[69] Winogradsky, 1890, pp. 215-216.

[70] Ibid.

[71] Ibid., p. 222.

[72] Ibid., pp. 220-222.

[73] Ibid., pp. 222, 227.

[74] In order to refute the doctrine “held by physiologists world round,” that organisms can survive without organic nutrients, one would have to provide very weighty proof. For three months, he successfully cultivated them in a solution, which was excruciatingly prepared to be devoid of organic matter (including boiling all his glassware twice in sulfuric acid). To prove definitively the nature of nutrition he measured the amount of organic carbon in the sediment of his cultures. If carbon appeared during the experiment, only *Nitrosomonas* could have produced it. He varied the cultures by adding different forms of nitrogen to them. In all cases, carbon appeared in the test cultures, proving, he thought, that *Nitrosomonas* possessed the ability to assimilate carbon from carbon dioxide.

Although he accepted that his predecessors Schloesing and Müntz had found a special organism related to nitrification, he did not initially accept their term "*ferment nitrifique*."[75] The idea implicit in that term—that a single organism was responsible for "exercising that function on the entire surface of the globe—seemed to him improbable. In its place, he proposed using a broader classification, based on "physiological types" because under it one could classify numerous species or varieties.[76] He suggested that this new physiological type, representing an entire cast of nitrifying organisms, existed not only in Zurich soils but also in all soils on the Earth.

This global perspective was no mere rhetorical flourish. Vinogradskii's vision of the cycle of life now generated a comparative study of nitrifying organisms around the world. Drawing on his international contacts he requested soils from Europe and other "exotic sources" such as Africa, Asia, South America, and Australia.[77] He tested the organisms in the soil samples for their relative ability to oxidize ammonia into nitrites in both liquid cultures and directly in their original soils. His found that all these organisms—from diverse localities—oxidized ammonia at the same rate. Nitrification, he concluded, was a universal, biological phenomenon that transcended local conditions and thus existed everywhere.[78]

The nitrification research provided Vinogradskii with his third example of an inorganically based respiration from which he divined what he called a new physiological fact—the fact of chemosynthesis. His experiments had shown, he argued, "that living beings could accomplish a complete synthesis of organic matter on our planet independent of the solar rays."[79] That is, since they contained no chlorophyll, these organisms could not obtain energy from light to drive their oxidation processes.[80] Chemosynthesis, then, was the process by which organisms developed in a purely mineral environment, acquiring their only source of nutrition from some single inorganic material. In these investigations, he found new experimental evidence to support his cycle of life perspective.

From his investigation of sulphur, iron, and nitrogen bacteria, Vinogradskii now confidently extended his vision of the cycle of life to all of nature. A substantial number of species did not require what most physiologists considered the necessary ingredients for life. Not only did new organic matter arise from the life processes of living beings through photosynthesis, he argued, but also as a result of chemosynthesis. This notion swept through the scientific community and was adopted by scientists in a broad spectrum of disciplines including

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[75] He did eventually use this term after he isolated the two species of microbes that participated symbiotically in nitrification—calling them *ferment nitreux* and *ferment nitriques*. See Winogradsky, 1891.

[76] Winogradsky, 1890, p. 230 ; Idem., 1891, p. 593.

[77] He requested samples from Emil Duclaux, Cramer (Zurich), Treub (Buitenzorg), and Cavalcanti (Campinas). From Europe he used soils from Zurich, Gennevilliers, Kazan, and his home town of Podolia (He had investigated these two Russian soils previously, in the winter of 1889-1890.) He received his African soils from La Reghaia, Rouiba, Mitidja, and Tunis. The Asian soils were sent from Buitenzorg, Java, and Tokyo, Japan. The American soils were from Campinas, Brazil, and Quito, Ecuador. The Australian soil came from Melbourne. Idem., 1891, p. 581.

[78] Ibid., p. 593

[79] Winogradsky, 1890, p. 275.

[80] Ibid. Although he did not apply the term chemosynthesis to this phenomenon until later, the concept—that a general physiological condition existed, in which organisms did not need light or oxygen to live—was implicit in his description.

plant physiology, soil science, and eventually ecology. It also had the immediate effect of launching Vinogradskii on a career in microbiology.[81]

On the Role of Microbes in the General Cycle of Life

One consequence of Vinogradskii's enhanced reputation was a number of job offers from prestigious institutions: from Pasteur himself at his Parisian Institute, from the Institute of Hygiene in Zurich, and from the newly formed Imperial Institute of Experimental Medicine (IEM) in St. Petersburg. After long deliberation, Vinogradskii accepted the Russian offer and in 1891 moved there to head the laboratory of general microbiology.[82] In addition to editing the IEM's journal, training a small number of students, and satisfying the bureaucratic and social duties associated with working for his patron, a Prince in the Russian royal family, he continued his research on chemosynthesis.[83]

Utilizing the IEM's extensive resources, Vinogradskii converted his global conceptualization of physiological types and chemosynthesis into a laboratory investigation of the cycle of life. In Zurich, he had discovered that nitrification was not the simple natural process scientists had thought it to be. It consisted of two separate stages—first the transformation of ammonia into nitrite, and second, of nitrite into nitrate. Having isolated the microbes responsible for each stage, he now applied his method to related soil processes. Nitrogen fixation—the conversion of free nitrogen gas in the soil into a bound state, thus making it accessible to plants—for example, had previously been related to the presence of organic compounds. His investigations since his apprenticeship had strengthened his commitment to the idea that each conversion of matter in nature was produced by a specific microbial species. The methods he had developed during this research gave him the tools to isolate these organisms from the biological chaos of the soil. By creating cultures that provided conditions favorable for only a single vital function—such as, nitrogen fixation—he used the struggle for resources between microbial species to "select" or isolate a species.

In 1899, Vinogradskii extrapolated from the struggle for resources he observed through his microscope to a grand nitrogen cycle operating on the entire planet.[84] Synthesizing his observations on the "great sensitivity" of nitrogen bacteria to organic materials, he enumerated the series of nature's physiological stages that occurred in the soil: ammoniafication, nitrification, and denitrification.[85] He imagined nature as a living organism in which microbes responded sensitively to their conditions of existence—living in a tight competition for materials—thus performing the vital functions of that super-organism. In this living organism, specific microbes could survive in environments that consisted of specific organic and inorganic materials. Other microbes would find these same environmental conditions inhospitable.

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[81] Vinogradskii, 1951, p. 169.

[82] Writing to Metchnikov in July 1891, just after accepting the Prince's offer, Vinogradskii described his tour of the grounds and his negotiations for laboratory space. Letter from Vinogradskii to Elie Metchnikov of 1 July 1891, in Reikhberg, 1931, p. 156.

[83] See Todes, 2001 on the Imperial Institute of Experimental Medicine.

[84] Winogradsky, 1949b, p. 234.

[85] Ibid., pp. 235-238.

Drawing an analogy to medical bacteriology, he described anti-microbial organic materials as "antiseptics."[86]

Vinogradskii unshackled his vision of nature from the details of his laboratory data to bring his grand vision of the cycle of life to the broader public. In 1896, while actively engaged in his elective culture research, he delivered a popular lecture at the IEM "On the Role of Microbes in the General Cycle of Life."[87] Sounding the same note that reverberated in his scientific investigations, he described the cycle of life as "a single huge organism." The body of this entity was composed of the entire planet's organic material; it borrowed what it needed from nature's inorganic reserves, used it purposively and, finally, returned it to the dead, inorganic realm of nature. In this vision of the cycle of life, Vinogradskii delegated the essential role to microorganisms. Only through their agency did matter circulate between nature's two realms. Microbes regulated this circulation by the endlessly varied reagents in their physiological processes that constantly decompose and synthesize organic compounds.[88]

Vinogradskii applied his cycle of life concept and the methods he used to explore it not only to microbes but also to human society. Between 1905 and 1920, when his own life cycle seemingly entered a period of retirement, he lived on his Ukrainian estate, practiced "scientific farming" there, and enjoyed his family and his horses. Russia's civil war (1918-1921), which was especially destructive to the Kiev area, forced Vinogradskii and his family to flee for their lives. Eventually securing a teaching position at the University of Belgrade, he spent his time catching up on microbiological research and writing anti-Bolshevik newspaper articles. Through these articles he expressed his anger at the Bolshevik party for its heavy-handed revolutionary tactics and indignantly rejected Bolshevik rhetoric about the "Soviet Experiment."[89] Meanwhile, dissatisfied with the scientific facilities in Belgrade, he looked elsewhere for a place to continue his research.

Vinogradskii's Turn to Ecology

Drawing on his international contacts Vinogradskii requested assistance from the director of the Pasteur Institute, Emil Roux. Having recently received a donation from a wealthy patron, Roux used it to create a position for his émigré colleague. As the director of a new laboratory of agricultural microbiology in the small town of Brie-Compte-Robert, just outside of Paris,

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[86] Ibid., pp. 235-236.

[87] Vinogradskii, 1897, pp. 26-27.

[88] Ibid.

[89] If anyone should experiment with society, Vinogradskii argued, it should be well-trained scientists and especially "naturalists." He accused the Bolsheviks of appropriating the language of science without either properly understanding its methods and requirements or dismissing them completely. Seeing no "experiment" in their brutal methods of social reconstruction, Vinogradskii criticized their merely rhetorical use of "experiment." If Lenin, Bukharin, and Trotsky desired to conduct a social experiment, Vinogradskii wrote under the pseudonym "Starnat" for "Old Naturalist," they should do it correctly—they should rely on the naturalist's method of choice, using direct observation of social phenomena in controlled environments.[89] Not wanting to merely criticize, he proposed his own political platform—his "Naturalist's party" offered to manage society by applying the scientific method properly. The frustration of his political critiques in the political chaos of this period and his increasing dissatisfaction with his professional situation in Belgrade drove him to search for new employment.

Vinogradskii organized a science estate that included a small castle, a gardener's house, and a two-story laboratory.[90] (See Figs. 4 and 5)

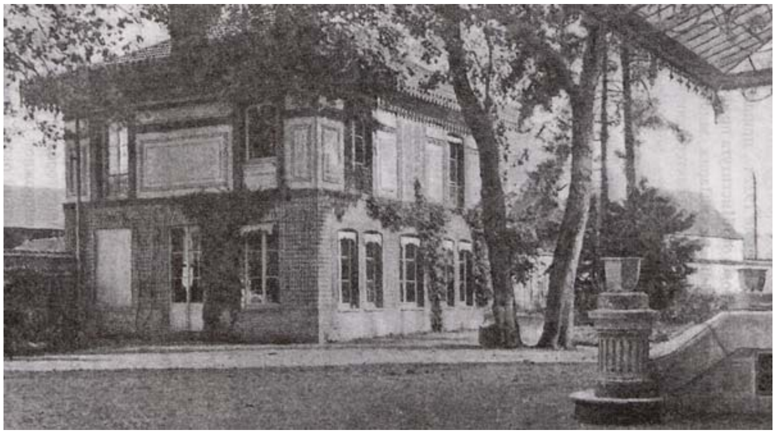

Figure 4. The Laboratory of Agricultural Microbiology at Brie-Compte-Robert
[Selman Waksman, *Sergei N. Winogradsky: His Life and Work*
[New Brunswick, N.J.: Rutgers University Press, 1953], p. 49.]

Under the influence of his new institutional context, Vinogradskii sought to put his longstanding scientific vision to practical use in soil science, which led him to develop what he called the "direct method." In a variety of forums between 1923 and 1925—including courses, public lectures, and discussions with the international scientific community—Vinogradskii promoted his new approach. Describing his direct method as an improvement upon the "the fragmentary and imprecise knowledge of microbial phenomena in the soil," he urged his colleagues to relinquish their devotion to pure culture methods. Agricultural microbiologists should break their thirty-year practice of studying laboratory collections in artificial solutions, and instead should study the biological relationships that reign in the soils and regulate the fate of soil microorganisms.[91]

This "direct" method evolved over the next twenty-five years, but consistently featured a core group of techniques. For Vinogradskii, "direct" primarily meant visual observations, thus microscopy and microphotography occupied a central place in his method. What, however, were soil microbiologists to photograph? First, he suggested, they would need to identify the "normal" condition of the soil. Sifting soils that had not been fertilized for at least three years and dyeing them using a procedure developed by the American bacteriologist H. J. Conn, Vinogradskii photographed what he called the "biological content of the soil."[92] This procedure failed to capture the dormant microbial species hibernating in the form of spores, however, so he added a new dimension to it.

Changing the environmental conditions in his cultures, he disrupted the soil's "biological equilibrium." Adapting his elective culture method of the 1890s to induce microbial competition for particular nutritive solutions he produced what he called a "biological reaction." During this

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[90] Vinogradskii, 1942, pp. 1,7.
[91] Winogradsky, 1935, p. 59.
[92] Ibid.

Figure 5. Vinogradskii in 1923 (Selman Waksman, *Sergei N. Winogradsky: His Life and Work* [New Brunswick, N.J.: Rutgers University Press, 1953], p. 50)

event, new microbial species would emerge from dormancy and enter the competition for resources.[93] He then used staining methods and microphotography to capture images of these biological states. In this manner, he contended, microbiologists gained "direct access to the microscopic landscapes of soils." They could now observe the means by which "the totality of natural forces" influenced the composition of a microbial population. The innovative aspect of Vinogradskii's direct method was that it did not rely on pure cultures—he observed microbial physiology directly in the complexity of its natural environment. These "microscopic landscapes" represented his latest experimental actualization of nature's cycle of life. (See Figure 6.)

In 1919 Vinogradskii surprisingly found himself portrayed as an ecologist. That year, to prepare for the job market, he had conducted a survey of the recent literature to both update himself on his specialties—iron, sulphur, and nitrogen bacteria research—and to explore the fate of his own legacy. He was especially intrigued by one article in the *Zentralblatt für Bakteriologie,* in which the author, A. Krainskii, a Russian working in the Microbiological Laboratory of the Technical College in Delft, portrayed Vinogradskii's research and methods as ecology. Moreover, Krainskii placed Vinogradskii in a lineage of ecological investigators that included Pasteur and the renown Delft microbiologist, Martianus Beijerinck (Krainskii's mentor at the time).[94] Krainskii believed that Vinogradskii had developed an ecological approach to microbiology "with the use of the elective and accumulation methods." Finding the whole of

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[93] Ibid.

[94] Krainskii drew on S. Tschulok's *Das System der Biologie: Forschung und Lehre* (Jena: G. Fischer, 1910), 197, where Tschulok divided biology into seven disciplines. Krainskii, 1914, pp. 649-688. It was the fourth, ecology, that caught Vinogradskii's attention. Winogradsky, 1919.

Krainskii's work "excellent, clear, thorough, and an excellent exposition," Vinogradskii highlighted only a single of the author's remarks—his definition of ecology.[95]

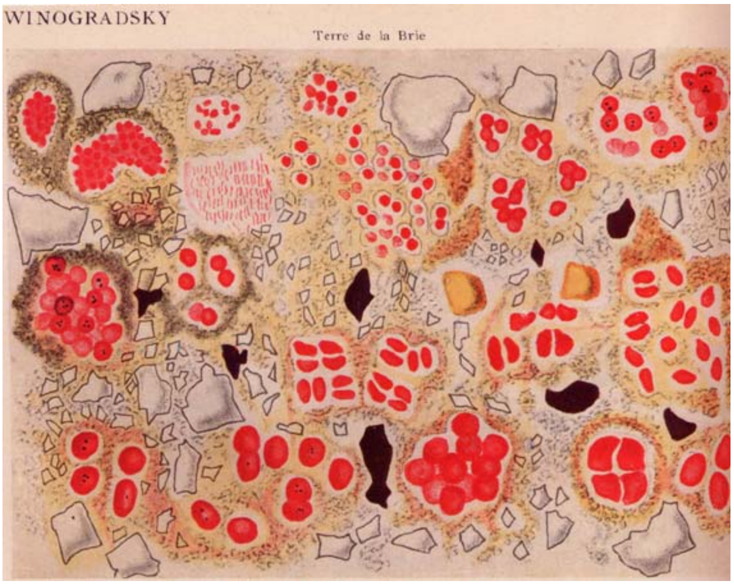

Figure 6. Vinogradskii's Drawing of a Soil Landscape. A Brie Sample.
[Serge Winogradsky, *Microbiologie du Sol: Problèmes et Méthodes—Cinquante Ans de Recherches* [Paris: Masson et Cie, 1949], p. 859.)

Over the next thirty years, Vinogradskii exercised his new ecological imagination in his scientific correspondence and investigations. He published a series of variations on the direct method. These variations, which appeared in reports, speeches, and his final monograph—represent stages of his development as an ecologist. During this time, he explored numerous ideas and described them using a wide variety of terms. His lexicon evolved from one founded in the language of biology, chemistry, and physics to one that simultaneously drew upon and redefined the terminology of ecology. Three key concepts are traceable from his first explication of the direct method to his 1949 rewriting of his earlier contributions: First, he continued to study the biological aspects of the soil. Second, to study the biology of the soil—the microflora or "florule" as he called it—he applied the complex of chemical and physical techniques that made up his direct method. Third, he increasingly moved away from trying to isolate the microflora (the biological component of the soil) from the soil's physical and chemical characteristics (its particles and processes, respectively) toward describing the soil as part of a whole. As he fine-tuned his experiments to investigate microbial nutrition more precisely, he developed the direct method into a synthetic approach that could account for nature's biological, chemical, and physical characteristics in a single system. By the 1940s, he had honed the less-than-perfect direct method into a comprehensive ecological method.

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[95] Krainskii defined ecology as "the adaptation (*Anpassung*) of organisms to the external world (*Aussenwelt*)." Winogradsky, 1919. Vinogradskii had developed the elective culture method and Beijerinck the accumulation method. In the 1920s, Vinogradskii criticized Beijerinck for using the elective culture method and calling it the accumulation method—they are basically the same method. The studies conducted with these methods yielded "not only important diagnostic species characteristics, but also served as a means for maintaining certain species." Krainskii, 1914, p. 650.

The Uptake of Vinogradskii’s Research

In subsequent years, Vinogradskii’s scientific approach was appropriated by a number of leading figures known for their application of ecological thinking to a variety of questions. In this essay, I cannot explore the complex historical process in which these scientists drew upon and deployed Vinogradskii’s work within their own complex institutional and intellectual contexts. Rather, I will touch briefly upon several of these individuals and milieus to illustrate the breadth of his influence and the significance of his legacy for ecological thinking in the twentieth century.

At Rutgers University in New Jersey, Selman Waksman and Rene Dubos drew upon Vinogradskii’s legacy in these studies of soil microbes that resulted in the discovery of streptomycin and other antibiotics. The soil scientist Selman Waksman, who later won the Nobel prize for his discovery of the antibiotic streptomycin, drew on Vinogradskii’s discoveries and methods in his earliest research.[96] In 1915, Waksman grounded his investigation of the role of microscopic fungi in the sulphur oxidation composts on Vinogradskii’s sulphur bacteria research.[97] (Waksman considered his debt to Vinogradskii so profound that he wrote a biography of him.) Rene Dubos, who earned his Ph.D. in soil microbiology at Rutgers with Selman Waksman, conducted his doctoral work in the “spirit of Vinogradskii.”[98] His reading of Vinogradskii’s idea “that microorganisms should be studied not in artificial laboratory cultures but in their natural environments in competition with other bacteria” inspired Dubos to launch a career in microbiology and to embrace an ecological approach in it.[99] At the very core of Dubos’ scientific vision lay Vinogradskii’s perception that “countless microbes perform limited, well-defined tasks to recycle organic matter so that it does not accumulate in nature.”[100] Dubos turned this vision of the cycle of life into a broad environmentalist and ecological perspective in the mid-late twentieth century.[101]

At the Rothamsted Agricultural Experiment Station in Harpenden, England, Sir Edward John Russell, his colleague H. G. Thornton, and student Ward Cutler, investigated the relationship between soil conditions and plant growth, focusing especially on the role of microorganisms.[102] After hearing Vinogradskii’s presentation in 1924 on the direct method, Russell initiated a correspondence with, as he called him, “the founder of soil microbiology.”[103]

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[96] Waksman, 1954, p. 103.

[97] Waksman, 1922, pp. 231-238, 239-256, 605-608, 609-616. Waksman helped to promote Vinogradskii's place in the history of soil science by encouraging Vinogradskii to organize autobiographical materials, which Waksman later turned into a biography. Waksman also organizing support for the publication of Vinogradskii’s *Microbiologie du Sol* during the financially difficult period of World War Two.

[98] Moberg and A. Cohn, 1991, pp. 66-72. On Dubos see also Cooper, 1998.

[99] Moberg and A. Cohn, 1991, p. 66.

[100] Ibid., 66-67.

[101] Dubos coined, for example, the phrase, “Think Globally, act Locally,” which reflects the sentiments of Vinogradskii’s cycle of life concept.

[102] John Bennet Lawes founded the Lawes Agricultural Trust at Rothamsted Agricultural Experiment Station in 1843, making it the oldest institution of its kind (at least in England). The station expanded continuously until finally the British Government purchased it in 1934. The botanist, bacteriologists, and chemists housed there investigated the use of fertilizers crop production, and animal nutrition. See Russell, 1966, pp. 289-332; Russell, 1921; Idem., 1923; and Idem., 1956).

[103] Russell to Vinogradskii, 1924.

Through this dialogue, he and his students kept in close touch with developments in Vinogradskii's direct microscopic examinations of the soil. The Russell group relied heavily on pure cultures to investigate microbial physiology, tracking changes in these cultures with bacterial counts and statistics.[104] Vinogradskii agreed that pure cultures were the only way to study a microbe's physiological possibilities, but he considered them unreliable for studying the natural state of the soil. This led him to distinguish fundamentally between general microbiology—the study of microbial morphology and physiology—and soil microbiology, which he explained to Russell, was "principally speaking a microbial ecology." Vinogradskii convinced Russell's colleague H. G. Thornton, then head of the bacteriological department, who synthesized the two methods of bacterial statistics and the direct method.

If Vinogradskii failed to convince Russell to rely solely on the direct method, he fared better with Thornton, head of Rothamsted's bacteriological department. Thorton attempted to synthesize the Rothamsted lab's methods of bacterial statistics with Vinogradskii's direct method. Russell shared his letters with his colleagues, leading Thornton to initiate his own correspondence with Vinogradskii. Thornton had followed "with great interest" the correspondence between Russell and Vinogradskii on the methods of investigating soil bacteria.[105] Vinogradskii's work on the direct examination of these organisms interested Thornton "extremely" and he entirely agreed with Vinogradskii's "opinion that the Ecology of bacteria in soil can be studied most directly by such a method."[106] Thornton was troubled, however, by the difficulties he perceived in using a method that allowed one "to distinguish morphological groups" of bacteria and not "the physiological groups" that were "of importance in relating the activity of bacteria to biochemical processes in the soil."[107] He recommended supplementing the observations made with Vinogradskii's direct method "by studying the bacteria they [the Rothamsted group] had found to multiply in the soil in isolation."[108]

Vinogradskii's ecological perspective also resonated with the Delft school of microbiology, which was famous for the work of its founder Martianus Beijerinck. H. J. Kluyver's student Lars Gunnar Romell incorporated Vinogradskii's direct method into his research. Romell worked with Vinogradskii at Brie-Compte-Robert in the 1920s and became a staunch supporter of Vinogradskii's direct method as well as his ecological views. Romell applied the direct method in his forest soils research at the New York State College of Agriculture at Cornell University in the 1930s. Summing up Vinogradskii's contributions to soil microbiology at the 1947 Antoine van Leeuwenhoek Symposium in Delft, Romell defined that discipline not as mere bacterial physiology, but as the ecology of the microbial soil population." For Romell, the methods Vinogradskii developed in the 1920s made it possible to study natural competition within the soil environment and the reaction of the soil population as a whole.[109] In

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[104] R. A. Fisher assisted them with their statistical modeling.

[105] Undated letter from Thornton to Vinogradskii, probably written in late 1927-early 1928, 1. Winogradsky Papers, Service des Archives, Institut Pasteur, Box Win 2, Correspondence International, Anglettere, Thornton Folder.

[106] Ibid.

[107] Ibid.

[108] Ibid.

[109] Winogradsky Papers, *Archives de l'Institut Pasteur*, Box WIN ??, Folder L.G. Romell, Letter from Romell to Vinogradskii 20 April 1947, 7.

his own research he investigated this “natural living soil” as a micro-ecological plant community.[110]

In Russia, too, Vinogradskii’s vision and methods were appropriated by a variety of scientists in a wide range of disciplines. Anecdotal evidence that his approach was appreciated by his Russian audience appears in the letter informing him of his selection as an honorary member of the Microbiological Society on the occasion of its fiftieth meeting in 1910. Omelianskii and another of Vinogradskii’s prominent students, D. Zabolotnyi, informed their teacher that, as “Your closest students, not losing hope for collaborative work in the future, with a feeling of lively happiness [we are] sending to you the corresponding diploma, which grants you, along with I.I. Metchnikov, E. Roux, A. La’veran, R. Koch, E. Behring and D. Ehrlich, an honorary role in the *cycle of life* of the Microbiological Society.”[111]

In Russia, Vinogradskii’s these methods contributed to the development of new research directions in soil science, ecological microbiology, and biogeochemistry. The founder of this last discipline and the scientific investigation of the “biosphere,” Vladimir Vernadsky, acknowledged his great debt to Vinogradskii’s discovery of organisms that “live independent of the energy of light, because they get the energy for their vital processes from minerals.”[112] Vinogradskii’s contribution was essential to Vernadsky’s understanding of the “geochemical history of living matter,” in which studying the role of autotrophic bacteria helped to understand how “living matter transports chemical elements through the biosphere.”[113]

As an émigré during the Soviet period, Vinogradskii enjoyed great recognition in his homeland. Even during the Stalinist years, when it was extremely risky for them to associate with émigrés, Russian scientists corresponded with and visited Vinogradskii. Vinogradskii’s student and assistant Vasilii Omelianskii adopted his mentor’s perspective in his microbiological research. Combining the cycle of life view with his own chemistry training, he envisioned the role of microbes in nature as “living reactives.”[114]

A New Dimension to the History of Ecology

In this essay, I have woven together historical threads from Vinogradskii’s life and scientific work to describe a new dimension of the history of ecology. Lying along an obscure trajectory in that history, Vinogradskii’s story accentuates the role—not of natural historians, Darwinists, and plant communities—but rather of experimentalists (who often fused their laboratory investigations with field observations), holists, and soil microbes. As this cast of characters suggests, incorporating this dimension of the history of ecology into the larger disciplinary story requires that we include a neglected set of scientists who perceived themselves as pursuing an experimental investigation of energy, matter, and life. By recognizing the influence of Pasteur, Famintsyn, Dokuchaev, Vinogradskii, and other such late-nineteenth

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[110] Ibid.

[111] Vinogradskii Correspondence, Letter dated March 8, 1910, Archive of the Russian Academy of Sciences, St. Petersburg Branch, Fund 1601, Delo 140, Listy 1-2. My emphasis.

[112] Vernadsky, 1930, p. 88.

[113] Ibid., p. 89.

[114] Omelianskii, 1909, pp. 188-195.

century microbiologists, plant physiologists, and soil scientists, historians of science will derive a fuller and ultimately more satisfactory account of the historical development of ecology.

The essence of this story is how scientists negotiated the shifting relationship between natural history and laboratory research. Vinogradskii's career exemplifies how scientists could balance their commitments to romantic ideals associated with natural history, on the one hand, with the escalating interest in another kind of knowledge—the ideal of experiment, on the other. In the first half of the nineteenth century, efforts to categorize nature slowly yielded to increasingly dynamic natural historical systems including Humboldt's phytogeography, Lyell's historical geology, and Darwin's theory of evolution. The second half of the century was characterized by an increased reliance on the laboratory, which—with its focus on experiment and the physical and chemical investigation of organic and inorganic bodies—threatened natural historical values.

The laboratory revolution was neither a paradigm shift nor a changing of the guard. It was, rather, a period of slow transition marked by the blending of traditions. When Vinogradskii decided to study botany with Famintsyn and not Beketov, he signaled his preference for the newly popular plant physiology over the seemingly staid morphological approach. For Vinogradskii's generation, physiology elicited visions of the heroic efforts of Robert Mayer, Claude Bernard, and Louis Pasteur to bring laboratory science to bear on the nature of life—to tease apart the delicate fabric of vital processes. By choosing plant physiology, Vinogradskii had chosen a science that brought together three of the most experimental biological sciences in the second half of the nineteenth century: physiology, biochemistry, and bacteriology.

Like his teachers Famintsyn, Beketov, and even Pasteur, Vinogradskii had grown up in a culture bathed in naturalistic holism. Vinogradskii came from the land. Growing up in a southern Russian *pomeshchik* family that earned its wealth from agriculture, sugar refining, and banking; and being musically trained, for Vinogradskii, cycles—seasonal, industrial, and economic, and harmonious—resonated especially strongly. Moreover, when he studied the natural sciences at St. Petersburg University, these colloquial and vague cyclical referents came alive as a scientific conceptualization of the cycle of life.

Step-by step, Vinogradskii found a way to express his natural historical vision of the cycle of life in the language of the laboratory. He introduced the analytic and observational power of the laboratory into the wild of nature: first as Famintsyn's apprentice, then in De Bary's laboratory, and later in Zurich. Under the ocular of his microscope, in the microbial landscapes of his Petri dishes and the elective cultures of his retorts, Vinogradskii achieved a synthesis of the natural and the experimental. At the turn of the twentieth century, for him, the synthesis came to completion in the study of microbial nutrients cycling in nature. Soil science and geobotany had assimilated his research, and his students were continuing his labors. Had he glided quietly out of science at that time, he would still have enjoyed the admiration of his peers and an important place in the history of science.

While he was living what he called "the life of a latent scientist," the approach Vinogradskii had developed over the 1880s-1890s lay dormant. Like the microbial spores he investigated, his approach awaited a time when new conditions would again breathe life into it.

That time came when Vinogradskii resurfaced in the early 1920s. Haeckel's term "oecology" of 1866 was now much in vogue in the biological sciences. Ecology was emerging as a self-conscious discipline, celebrated by the publication of new journals, papers, and textbooks; the offering of new courses at universities; and the foundation of new scientific institutions. Although these efforts appear to have crystallized around the simple principle that ecology is the study of natural relationships, early ecologists struggled to define a coherent agenda. In this melee, Vinogradskii successfully promoted as an ecological method his cycle of life perspective and the methods he developed to investigate it experimentally.

In the 1920s, soil scientists, microbiologists, plant ecologists, and forestry scientists—whose investigations required them to deal with the complexity of the soil—sought ways to meet the obligations of ecological thinking. Raised within the tradition of Vinogradskii's microbiology, and familiar with, or themselves now investigating, the autotrophic bacteria he had discovered; they found themselves learning again from a living classic. Vinogradskii's ecological methods of the 1920s stood on the scientific authority he had earned in the 1890s, and now they reaffirmed and extended that authority. His work found and created new audiences—ecologists adopted his methods and new disciplines formed around his approach.

The consideration of Vinogradskii's contributions to microbiology opens a new perspective on the history of ecology; one that demands further explanation. Usually portrayed as emerging from the synthesis of Humboldtian phytogeography with Darwinian evolutionary theory by botanists in the late nineteenth and early twentieth century, ecology is also historically rooted in microbial physiology. Although historians of ecology recognize that early plant ecologists identified their science closely with plant physiology, these historians mistakenly limit plant physiology to the study of complex plants and plant communities. Eugene Cittadino and Joel Hagen have pointed out, for example, that the American ecologists Henry Cowles and Frederic Clements, and the British ecologist Arthur Tansley, considered the physiological work of Eugenius Warming, Oscar Drude, and A. F. W. Schimper "crucial to their new science."[115] Cittadino and Hagan gave no indication that these founding figures in the history of ecology devoted much research to investigating microbial fungi and bacteria. The evolution of Vinogradskii's career from plant physiologist to ecologist demonstrates that early ecologists could consider physiology much more than the study of the nutritional needs of individuals or the formation of communities; it could encompass the entirety of nature—the cycle of life.

Cycles populated Vinogradskii's life from his boyhood on the black earth of a Russian farm to his intellectual ferment at St. Petersburg University, during his travels through the exotic landscapes of Alpine swamps and carefully prepared microscope slides, to his laboratory at Russia's premier medical research institution, to his scientific forestry on a Kiev estate, and finally to his resurrection as an ecologist in France. Vinogradskii discovered cycles in the microbial nutrition, in sulphur springs, in the soil, and in the biosphere. In a sixty-year career in microbiology, he transformed the grand cycle of life into narrowly-focused nutritional cycles of individual species, and back out again, into physiological taxonomies of genera, and beyond there to nutrient cycles of the biosphere. Much of his work enjoyed his colleagues' respect. Acknowledging in his fifty years of research a plodding devotion and, at times, even genius, they always recognized the language of cycles as their own. Here, familiarity bred contentment. Why?

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[115] Cittadino, 1990, p. 150; Hagan, 1992, pp. 24-26.

Jorge Borges expressed it best when he wrote that “it may be that universal history is the history of the different intonations given a handful of metaphors.”[116] The fabric of human culture, language, and thought are woven from metaphors as enduring and ubiquitous as the cycle of life.

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[116] Borges, 1964, p. 192.

Bibliography

Acot, Pascal. 1988. *Histoire de l'Ecologie*. Paris: Presses Universitaires de France.

Browne, Janet. 1983. *The Secular Ark: Studies in the History of Biogeography*, New Haven: Yale University Press.

Borges, Jorge Luis. 1964. "The Fearful Sphere of Pascal" Trans. James E. Irby. *Labyrinths: Selected Stories & Other Writings*. New York: New Directions. Pp. 189-192.

Brefeld, Oscar. 1872. "Mucor mucedo, Chaetocladium jones'ii, Piptocephalis freseniana. Zygomyceten." *Botanische Untersuchungen über Schimmelpilze*. Leipzig: Verlag von Arthur Felix 1:1-64.

Bulloch, William. 1938. *The History of Bacteriology*. London: Oxford University Press.

Cittadino, Eugene. 1990. *Nature as the Laboratory: Darwinian Plant Ecology in the German Empire*, 1880-1900. Cambridge University Press.

Cohn, Ferdinand. 1870. "Untersuchungen über Bacterien." *Beiträge zur Biologie der Pflanzen*. Breslau: J. U. Kern's Verlag 1 (1):127-222.

------ 1872. "Ueber Bacterien, die kleinsten lebenden Wesen." *Sammlung gemeinverständlicher wissenschaftlicher Vorträge*. Berlin: C. B. Lüderitsche Verlagsbuchhandlung 7 (165).

------ 1939. *Bacteria, the Smallest Living Beings*. Baltimore: Johns Hopkins University Press.
Cohn, Pauline and Rosen, Felix. 1901. *Ferdinand Cohn: Blätter der Erinnerung*. Breslau: J. U. Kern's Verlag.

Coleman, William. 1886. "Evolution in Ecology? The Strategy of Warming's Ecological Plant Ecology." *Journal of the History of Biology* 19 (2):181-196.

Comfort, Nathaniel, 2001. *The Tangled Field: Barbara McClintock's Search for the Patterns of Genetic Control*. Cambridge, MA: Harvard University Press.

Cooper, Jill Elaine. 1998. *Of Microbes and Men: A Scientific Biography of Rene Jules Dubos*. Ph.D. Diss, Rutgers, The State University of New Jersey.

Doetsch, Raymond N. 1960. *Microbiology: Historical Contribution from 1776 to 1908 by Spallanzani, Schwann, Pasteur, Cohn, Tyndall, Koch, Lister, Schloesing, Burrill, Ehrlich, Winogradsky, Warington, Beijerinck, Smith, Orla-Jensen*. New Brunswick, N. J.: Rutgers University Press.

Dumas, Jean-Baptiste. 1842. *Essai de Statique des Etres Organises*, 2nd édition, Paris: Fortin, Masson, and Ce, Librairies.

Famintsyn, A.S. 1860. "Organismy na granitse zhivotnago i rastitel'nago tsarstva," *Sbornik Izdavaemyi Studentami Imperatorskago Peterburgskago Universiteta*. S.-Peterburg: Tipografiia II-go Otd. Sob. E. I. B. Kantseliarii.

------ 1889. *Obmen Veshchestvo i Prevrashchenie Ehnergii v Rasteniiakh*. Sankt-Peterburg: Imperatorskoi Akademii Nauk. Republished Kursanov, A.L. ed. 1989. *Idem*. Moskva: Nauka. 2:18-62. My citations refer to the 1989 edition.

Fruton, Joseph S. 1972. *Molecules and Life: Historical Essays on the Interplay of Chemistry and Biology*. New York: Wiley-Interscience, a Division of John Wiley and Sons, Inc.

Geison, Gerald L., 1970. "Ferdinand Julius Cohn." *Dictionary of Scientific Biography*, III:336-341.

Glas, Eduard. 1979. *Chemistry and Physiology in their Historical and Philosophical Relations*. Delft University Press.

Golley, Frank Benjamin. 1993. *A History of the Ecosystem Concept in Ecology*, New Haven: Yale University Press.

Hagan, Joel B. 1992. *An Entangled Bank: The Origins of Ecosystem Ecology*. New Brunswick: Rutgers University Press.

Hereaus. 1886. “Sur les Bactéries des Eaux de Source et sur les Propriétés Oxydantes.” *Zeitschrift für Hygiene*.

Holmes, Frederick Lawrence. 1974. *Claude Bernard and Animal Chemistry: The Emergence of a Scientist*. Cambridge, MA: Harvard University Press.

Ihde, Aaron J. 1964. *The Development of Modern Chemistry*. New York: Harper and Row.

Koch, Alfred. 1891. Review of “Serge Winogradsky, Researches sur les Organismes de la Nitrification.” *Botanische Zeitung*. 49 (40):669-672, 680-685, 698-701.

Krainskii, A. 1914. “Die Actinomyceten und ihre Bedeutung in der Nature.” *Zentralblatt für Bakteriologie, Parasitenkunde und Infektionskrankheiten* Abt. II, 41 (6):649-688.

Kremer, Richard L. 1990. *The Thermodynamics of Life and Experimental Physiology, 1770-1880*. New York: Garland Publishing, Inc.

Kursanov A.L., ed. 1981. *Andrei Sergeevich Famintsyn: Zhizn' i Nauchnaia Deiatel'nost'*. Leningrad: Nauka.

Lenoir, Timothy. 1982. *The Strategy of Life: Teleology and Mechanics in Nineteenth Century German Biology*. Dordrecht, Holland; Boston, MA: D. Reidel Publishing Co.

Manoilenko, K. V. 1981. “Rol’ A. S. Famintsyn v Razvitii Ehvoliutsionnoi Fiziologii Rastenii.”

Kursanov et al., *Andrei Sergeevich Famintsyn: Zhizn' i Nauchnaia Deiatel'nost'*. Leningrad: Nauka. Pp. 131-149.

McIntosh, Robert P. 1985. *The Background of Ecology: Concept and Theory*. Cambridge University Press.

Mendelsohn, John Andrew, 1996. *Cultures of Bacteriology: Formation and Transformation of a Science in France and Germany, 1870-1914*. Ph.D. diss., Princeton University.

Moberg, Carol L. and Cohn, Zanvil A. 1991. “Rene J. Dubos.” *Scientific American*. Pp. 66-72.

Nicolson, Malcolm. 1996. “Humboldtian Plant Geography after Humboldt: the Link to Ecology.” *British Journal for the History of Science* 9 (3), No. 102:289-310

Omelianskii, V.L. 1909. *Osnovy Mikrobiologii*. S-Peterburg: Tipografia Imperatorskoi Akademii Nauk.

------ 1927. “Sergei Nikolaevich Vinogradskii: Po Povodu 70-letniia so dnia Rozhedeniia,” *Arkhiv Biologicheskix Nauk*. XXVII (1-3):10-36.

Pfeffer, Wilhelm. 1897. *Pflanzenphysiologie: Ein Handbuch der Lehre vom Stoffwechsel und Kraftwechsel in der Pflanze*. Leipzig: Verlag von Wilhelm Engelmann. 2nd ed.

Reikhberg, G. E., ed. 1931. *Bor’ba za Nauku v Tsarskoi Rossii*. Moskva and Leningrad: Gosudarstvennoe Sotsial’no-Ehkonomicheskoe Izdatel’stvo.

Resse, Max. 1870. *Botanische Untersuchungen über die Alkoholgährungspilze*. Leipzig: Verlag von Arthur Felix.

Robinson, Gloria, 1970. “Heinrich Anton De Bary.” *Dictionary of Scientific Biography*. 1:612-613.

Rosen, George. 1959. “The Conservation of Energy and the Study of Metabolism.” Brooks, Chandler McC. and Cranefield, Paul F., eds. *The Historical Development of Physiological Thought*. New York: The Hafner Publishing Company. Pp. 243-263.

Russell, Sir Edward John. 1921. *Soil Conditions and Plant Growth* in the series *The Rothamsted Monographs on Agricultural Science*. London: Longmans, Green and Co.

------ 1923. *The Microorganisms of the Soil*. London: Longmans, Green, and Co.

------ 1956. *The Land Called Me; An Autobiography* London: George Allen & Unwin, Ltd.

------ 1966. *A History of Agricultural Science in Great Briton, 1620-1954*. London: George Allen & Unwin, Ltd.

Schloesing, J. and Müntz, A. 1877. “Sur la Nitrification par les Ferments Organises.” *Comptes Rendus de l’Academie des Sciences* 84 (2):301-303; 85 (22):1018-1020; 1878. 86 (14):892-895; 1879. 89 (21):891-894; (25):1074-1077.

Strogonov, B.P. 1996. *Andrei Sergeevich Famintsyn, 1835-1918*. Moskva: Nauka.

Teich, Mikulas. 1970. “The Foundations of Modern Biochemistry.” Needham, Joseph, ed., *The Chemistry of Life: Eight Lectures on the History of Biochemistry*. Cambridge University Press. Pp. 171-191.

Todes, Daniel P. 2001. *Pavlov’s Physiology Factory*. Baltimore: The Johns Hopkins University Press.

Tschulok, S. 1910. *Das System der Biologie: Forschung und Lehre*. Jena: G. Fischer.

Vallery-Radot, Pasteur, ed. 1939. *Oeuvres de Pasteur*. Paris: Masson et Cie Editeurs.

Vernadsky, V.I. 1930. *Zhivoe Vechestvo*. Moskva: Gosizdat.

Vinogradskii, S.N. 1883. “O vliianii vneshnikh uslovii na razvitie *Mycoderma vini*.” *Trudy Sankt-Peterburgskogo Obshchestva Estestvoispytatelei* XVI, 2d ser.:132-135.

------ 1888. “Ueber Schwefelbacterien,” *Botanische Zeitung*. 45:489-507, 513-523, 529-539, 545-559, 569-576, 585-594, 606-610.

------ 1890a. “Researches sur les Organismes de la Nitrification.” *Annales de l’Institut Pasteur*. 4:215-231, 257-275, 760-811; 1891. 5:92-100, 577-616.

------ 1890b. “Sur les Organismes de la Nitrification.” *Comptes Rendus des Seances de l’Academie des Sciences*. 60 (19):1013-1016; 1891. 63 (2):89-92.

------ 1897. “O Roli Mikrobov v Obshchem Krugovorote Zhizni,” *Arkhiv Biologicheskix Nauk* 7 (3):1-27.

------ 1919. *Bibliography of the Zentralblatt für Microbiologie, 1895-1920*. Serge Winogradsky Papers, Service des Archives de l’Institut Pasteur, Box. Win 3, unnumbered pages.

------ 1935. “The Method in Soil Microbiology as Illustrated by Studies on Azotobacter and the Nitrifying Organisms. *Soil Science* 40:50-76.

------ 1942. “Copie d’un formulaire allemand sous l’occupation,” Serge Winogradsky Papers, Service des Archives de l’Institut Pasteur, Box WIN.2, Folder: Serge Winogradsky, Correspondence, France.

------ 1949a. *Itogi (In the End)*. Archives of the Russian Academy of Sciences, Moscow Branch, Fond 1601, Opis’ 1, Delo 13.

------ 1949b. “L’Influence des Substances Organiques sur le Travail des Microbes Nitrificateurs” *Microbiologie du Sol: Problèmes et Méthodes—Cinquante Ans de Recherches*. Paris: Masson et Cie.

------ 1951. *Mikrobiologiia Pochvy: Problemy i Metody, Piat’desiat let issledovanii*. Imshenetskii, A.A. ed. Moskva: Akademiia Nauk.

Weiner, Douglas R. 1988. *Models of Nature: Ecology, Conservation, and Cultural Revolution in Soviet Russia*. Bloomington: Indiana University Press.

Waksman, Selman A. 1922. “Microorganisms Concerned in the Oxidation of Sulfur in the Soil.” *Journal of Bacteriology* 231-238, 239-256, 605-608, 609-616.

------ 1932. *Principles of Soil Microbiology*. Baltimore: The Williams and Wilkins Company. 2nd ed.

------ 1953. *Sergei Winogradsky: His Life and Work.* New Brunswick: Rutgers University Press.

------ 1954. *My Life with Microbes*. New York: Simon and Schuster.