IMAGES, PLANTS, AND ENVIRONMENTS OF MEDIA

LIVING SURFACES

ABELARDO GIL-FOURNIER AND JUSSI PARIKKA

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LIVING SURFACES OF MEASURING NUMBERS

So far in this book, we have addressed different scales of soil and vegetal life in relation to the emergence and stabilization of surfaces of another kind, namely those of images. Images measure how light enters and reacts on the vegetal surface of the earth. Thus, also images participate in the metabolic processes that light enacts. This becomes even more evident the closer we get to the practices of modulation of light in terms of modern architectures of glasshouses and phytotrons, techniques and technologies from synthetic chemistry to data visualization, and other examples that populate this book. From the microscopic chloroplast to the ensemble of living matter, from leaves to agricultural landscapes, the sentient and terraforming characteristics of plants have been modeled from and through the environments of images. Environments where images are enmeshed as tiled maps of satellite images, datasets for machine-learning models, photogrammetric scans, and streams of networked cameras have reshaped the uppermost crust of the living earth and become a new multiscalar reality. This synthetic surface wraps the planet and alters its cosmic relations.

There is, however, a very specific scale that we have not addressed until now, which will be the subject of the last two chapters of this book. It is the scale of the vegetal communities that plants constitute and maintain on their own; it relates thus to the specific groupings of populations of different species of plants that coexist autonomously and spontaneously in the same geographical area or habitat. For example, we are thinking of the assemblages that make up the different grasslands and forests. As we will see in this chapter, these communities can be considered as having specific processes, functions, and characteristics that allow them to define and differentiate several stages of development. That is, the relationships among species and populations that coalesce in these stabilized associations of vegetation are the object of community ecology. Furthermore, it is a scientific practice involving not only plants but images and practices on top of images as well.

In this chapter, we examine the work of one of the pioneering figures of this discipline in the early twentieth century, namely the US botanist Frederic E. Clements, whose research included a theoretical conceptualization of these *plant formations*—his preferred term—as a new type of organic entity. His work proposed a quantitative plant survey methodology specifically designed to examine the formations. His use of images, statistics, and techniques of counting would already make the work interesting in the context of this book, but we also want to examine how his methods relate to the broader extension of quantitative tools outside the lab into the field.[1] Clements's entwining of experimental practice and theorization makes it a notable reference in the case studies we lay out in the book. While Clements was described by such contemporary ecologists and botanists as Alfred G. Tansley as "by far the greatest individual creator of the modern science of vegetation,"[2] it is also outside the area of research of vegetal life that his work resonates. Briefly stated, as a teaser of what is to come, his quantitative and statistical approaches to the spatial characteristics of plant communities are tightly linked to a specific domain of practices that have surfaced since the availability of satellite remote sensing images. Clements's practice is part of a quantification of living environments and surfaces that has given rise to operational techniques where plant population becomes a biomarker in fields such as military intelligence.

Clements's work can be linked with the systematic elaboration of image-based indicators of surface characteristics, such as the *photobotany* practiced by Cold War intelligence programs. We build on the research by Robert Gerard Pietrusko into such techniques of indication and on how ecological knowledge was integrated into remote sensing operations. We argue that the broader characterization of these ecological living surfaces is a version of what John May has defined as the "managerial surface," the "statistical-electrical control space" that nowadays mediates the surfaces of the planet for the contexts of environmental management.[3] Clements's project of numerically analyzing the vegetal ensembles that comprise prairies or forests took place in the pre-electronic era and long before the role of underground mycorrhizal networks performing their hidden "quiet agreements and search for balance"[4] were studied in scientific contexts.[5] A merging of statistics and image-based techniques allowed him to study the surface of these plant formations numerically, resulting in what has been described as a physiognomy of vegetal superorganisms.[6] Besides the discourse of superorganisms, the involvement of media techniques leads to a parametrization of vegetal forms that anticipates contemporary techniques of *photomorphology*, that is, reading photographic traits as one would read plant morphology.[7]

Clements's experimental methods were devised and put into practice in the vast Midwest prairie of Nebraska, as it was in the early twentieth century, with its smooth shifting mix of grasses. In the grasslands Clements established a connection between imaging and modeling surfaces of the earth in much the same terms as it operates in current environmental observation systems. Starting from grass, we will examine the nuances of this relation, taking into account Clements's work and his background at the University of Nebraska, and we will place the relation in the context of parallel discussions relating early photography to computation. Land cover classification and interpretation bend in multiple institutional contexts, demonstrating a key trait of how ecology and environmental knowledge become integrated into different planetary projects, including geopolitical ones. The knowledge practices that were gradually established from the late nineteenth century to the first decades of the twentieth century are reference points in establishing issues that resonate far outside their original domain; the statistical understanding of living surfaces comes to define one insight into the broader discussions about media techniques of ecological control.

THERE ARE NO INDIVIDUAL PLANTS

What is grass, anyway? What type of collective entity do *Gramineae* plants form? How is it that they come together to create a surface as a continuous vegetal entity, where the limits between individuals blur and disappear? The puzzling dissolution of the individual and the collective that characterizes vegetal life features strikingly in meadows and grass plains. "A plant is a colony," in the words of plant scientist Stefano Mancuso and writer Alessandra Viola, showing how plants trouble basic philosophical categories such as individual versus multiplicity and distinct versus anonymous.[8] The striking headless character of plant behavior also features in works of fiction.[9] "There are no individual plants," explains one of the characters in *Vaster than Empires and More Slow*, Ursula Le Guin's short story about an exploration of a planet fully covered by forests and grasslands.[10] A group of scientists realizes that the entire planet's vegetation constitutes an all-encompassing and sentient entity, perhaps somewhat reminiscent of the planet-brain ocean of Stanislaw Lem's *Solaris* (1961) and predating James Lovelock's point that "life exists planet-wide or not at all."[11] Camping on a vast prairie covered with grass-like plants, the scientists' attention shifts from the noticeable lack of animal life to this other form of habitation on the planet's surface. In the words of one of the characters: "Even the prairie grass-forms have those root-connectors, don't they? I know that sentience or intelligence isn't a thing, you can't find it in or analyze it out from the cells of a brain. It's a function of the connected cells. It is, in a sense, the connection: the connectedness."[12]

While Le Guin's story merits much more than this brief mention, it is this inspiring and perplexing sense of connectedness caused by grass that we want to begin with, alongside questions of ground-level visibility versus underground invisibility. If grass had been analyzed in significant cultural histories from the nineteenth and twentieth centuries, in the second half of the twentieth century, grasslands came to be regarded as cybernetic surfaces and were modeled in systems theory.[13] As an example: the Grassland Biome project—a big-science initiative of the US administration in the late 1960s aiming to create a computational model of a grassland ecosystem—imagined cybernetical environmental management with all sorts of flows of energy and matter mapped as data streams.[14] At the back of the emergence of terms such as "ecosystem," the cybernetic research meetings and agenda after the Second World War started to produce different scales of applications relating to ecology. This included theoretical models, such as G. Evelyn Hutchinson's version of the biosphere in the context of the "calculation of information as the control mechanism for the flow of energy in natural systems,"[15] as well as the Odum brothers's work on ecosystems, information, energy, and their applications to agriculture.[16] Grass was thus one of many ecological elements that were subjected to different modeling and testing in ecosystem approaches.[17]

While Gaia theory emerged from comparative planetology, such as research on Mars,[18] science fiction had already imagined outer galactic grassland ecosystems in the early days of cybernetics. *Green Patches* (1950) by Isaac Asimov features a planet that is described as having a form of grass that does not grow only on the surfaces of soil but also in the eyesockets of the creatures populating it, such as grazing animals.[19] The theme of *grass replacing the eyes* is presented as the ultimate regulator of every single metabolic process in the alien biosphere. As in a cybernetic fantasy, grass establishes the planetary equilibrium by monitoring and controlling each exchange of matter and energy among living beings. Grass becomes seeing while seeing becomes cybernetic regulation and control in an alien version of not only Gaia theory but also smart city imaginaries of feedback loops of sustainability.

PLANT FORMATIONS AS SUPERORGANISMS

Before any such science fiction narratives of cybernetic plant-eyes, prairies of grass—such as in the American Midwest—became a platform for quantification, analysis, statistics, and modeling, Frederic E. Clements, a member of the so-called School of Ecologists of Nebraska, undertook a major study of these vast landscapes of plants, aware that this also meant tackling questions of visibility and (root system) invisibility. His approach combined a series of quantitative experimental methods with an ambitious explanatory framework: the plant succession theory. This theoretical framework aimed to introduce, at the same time, a structure underlying these forms of vegetal zoning and a temporal dimension of development stages meant to explain their variability. That is, extensions of grasses such as the ones surfacing the prairies of Nebraska were examined by Clements as the spread of an elemental unit of vegetation, the plant formation.[20] Plant formations were seen as complex organisms able to reproduce themselves, adapt to their surrounding environments, and evolve through a series of fixed stages. The following description by Clements presents concisely the concept and many nuances entailed by it:

> The plant formation is an organic unit. It exhibits activities or changes which result in development, structure, and reproduction. These changes are progressive, periodic, and, to some degree, rhythmic, and there can be no objection to regarding them as functions of vegetation. According to this point of view, the formation is a complex organism, which possesses functions and structure, and passes through a cycle of development similar to that of the plant. This concept may seem strange at first, owing to the fact that the common understanding of function and structure is based upon the individual plant alone. Since the formation, like the plant, is subject to changes caused by the habitat, and since these changes are recorded in its structure, it is evident that the terms, function and structure, are as applicable to the one as to the other. It is merely necessary to bear in mind that the functions of plants and of formations are absolutely different activities, which have no more in common than do the two structures, leaf and zone.[21]

The different types of prairies, forests, deserts, and Arctic landscapes, among other landcover types, are characterized as the habitats of a class of organisms distinct from that of the individual plant. Plant formations grow, evolve, and reproduce themselves, giving rise to landscapes of vegetal zoning. These are occupied by different types of formations involved in functions such as association, invasion, and succession—in other words, functions geared to maintain their own collective metabolism, spread into new areas, and reproduce themselves.[22] In spatial terms, the idea of plant formations allows for the projection of a sense of structure among the vastness of some of those vegetal surfaces. In relation to time, it introduces a vocabulary of types and stages of formation that accounts for the dynamic variability that an expert eye could observe inside those extensions.

Clements's ideas about plant formations are also linked to the terminology of "superorganisms," which is one of the reasons his work is still discussed, including within the context of Gaia theory and Anthropocene debates.[23] Indeed, Clements's work seemed to imply that the whole of the prairie could be, hypothetically, seen as an organism in its own right, although the empirical side of the work was more precisely defined. As Clements writes, "As an organism the formation arises, grows, matures, and dies. Its response to the habitat is shown in processes or functions and structures, which are the record and the result of these functions. Furthermore, each climax formation can reproduce itself, repeating with essential fidelity the stages of its development. The life-history of a formation is a complex but definite process, comparable in its chief features with the life-history of an individual plant."[24]

Clements's view of vegetation as an organism where the sum is more than its parts resonated with similar accounts in animal research. Some years earlier, in an article from 1911, William M. Wheeler had referred to the idea of "the ant colony as an organism,"[25] while in the 1920s, biological and ecological research on holism drew directly from thinkers such as Henri Bergson and Alfred N. Whitehead.[26] In 1926, Jan Smuts published his influential *Holism and Evolution*.[27] In all the accounts across the 1920s and 1930s, with different emphases and reference points, earlier mechanistic notions of life were replaced by descriptions of a vibrant relationality and ecology of interconnectedness as the driving forces of life. Furthermore, while critical of calling plant formations *organisms*, let alone *complex* organisms or even *communities*, Alfred Tansley acknowledged how Clements's solo and collaborative work contributed to ideas of quasi-organisms of plant life, and influentially, even a focus on "systems" that included organic and nonorganic parts in interaction.[28] Tansley was far from embracing the holism, let alone vitalism, of some of the contemporary thinkers of the 1920s and 1930s, and yet the lineage of succession, interaction, and complex relationality remained an important part of the methodology during the subsequent decades, when his notion of "ecosystem" continued to be picked up in the later era of cybernetics and systems theory.[29]

Clements's idea of a vegetal superorganism faced critique in the 1920s, perhaps with the underlying fear that the notion sounded too mysticizing and risked conflating complex organizational entities such as those in human and animal life with the way plant life developed. Yet the notion was not necessarily meant to refer to a horizontal organization of entities living in peaceful symbiosis. As Thomas Kirchhoff argues, the thesis should not be read as comprising "mutualistic unities but as multilevel top-down control-hierarchical unities."[30] Here the idea of a dominant formation as actively shaping the broader ecological context of life becomes a central part of this hierarchical way of understanding organicism: "A dominant is an organism with such definite relations to climate and such significant reactions upon the habitat, or in water upon the other community constituents, as to control the community and assign to the other species subordinate positions of varying rank."[31] In other words, the dominant formations are not merely expressions of the landscape surroundings and ecological relations but they also reform them: "It is an axiom that the life-form of the dominant trees stamps its character upon forest and woodland, that of the shrub upon chaparral and desert, and the grass form on prairie, steppe and tundra."[32] This description does not reduce the interesting aspects of Clements's ideas—that the activity of formations is irreducible to taxonomic categories—there is still at play a dynamic notion of a unified mechanism of plant community, even if this synergy is not entirely horizontal and mutualistic but defined by a rhetoric that sounds like some later realizations about control, feedback, and hierarchy found in Cold War–era cybernetics.[33]

NUMBERS: A MINUTE STUDY OF THE UNSEEN CHANGES

In addition to the discussion of plant formations as living organisms distinct from individual plant specimens, one of the most salient characteristics of Clements's work was his continuous drive to think quantitatively. He relied on existing instruments, such as the automatic ones he recommended, for periodic measurement of the physical factors surrounding a specific stage of any plant formation—such as humidity, light, temperature, and wind.[34] But in addition, he had to design new techniques when no other options were available. This was the case in particular in the measurement of the spatial structure of a formation and its relation with adjacent formations. Clements's view of formations as organisms, together with his insistence on quantitative methods, got him involved in the development of specific techniques of plant surveying precise enough to provide the researcher with "a minute study of the shifting and rearrangement of the individuals."[35]

Until then, quantitative plant survey methods had dealt with the spatial and geographical dissemination of plant species, that is, plant geography. At the back of colonial travel and logistics, access to different regions allowed new comparative perspectives and even quantified analysis to emerge. Beginning in the nineteenth century, for instance, sponsored by the Spanish crown, reaffirming its grip on its American colonies, Alexander von Humboldt pursued the first major step in quantification in plant geography.[36] His experimental practice, described by Marie-Noëlle Bourguet as part of a material culture devised to arrive at a "physics of plants," relied on the estimation of ratios of species and genera in a landscape and their subsequent correlation with climatic indexes.[37] The isotherm line, for example—a visual medium consisting of a line on a map connecting points of equal mean temperature—became a famous comparative graphic instrument that concatenated statistical variations across vast geographical areas into stabilized regions to show potential comparisons. These regions were plant formations, such as forests, grasslands, and deserts, that divided the earth's surface into identifying categories, even if somewhat ideal.[38] Humboldt's system allowed us to visualize planetary patterns of distribution of flora, although it was useless for territories of a smaller scale. It was unable to provide the "minute study" required by Clements of the smaller variations that ecological areas exhibited across seasons and life cycles. The situated details were missing.

Aware of the limitations of Humboldt's system, a subsequent German school developed an alternative framework of phytogeography, which was gradually improved until the end of the century. The main technique was the partition of a space into a grid of squares or rectangles of the same size, a technique related to earlier practices in the context of German forestry.[39] The size of the rectangles was large—roughly 20 kilometers squared—and the methods for the quantitative estimation of the abundance of species were imprecise. Surveyors relied only on "visual impressions"—expert panoramic views of the landscapes—and on a simple scale of five degrees of the abundance of species, which increased from "scarce" to "sparse," "copious," "gregarious," and "social," with "social" being the characterization of grasses in a prairie.[40] At the end of the century Clements and his colleague Roscoe Pound applied this phytogeographic framework to the habitat they wanted to survey, the vast Midwest prairie in Nebraska. When starting to apply it in practice, however, they soon realized the deficiencies of the method.

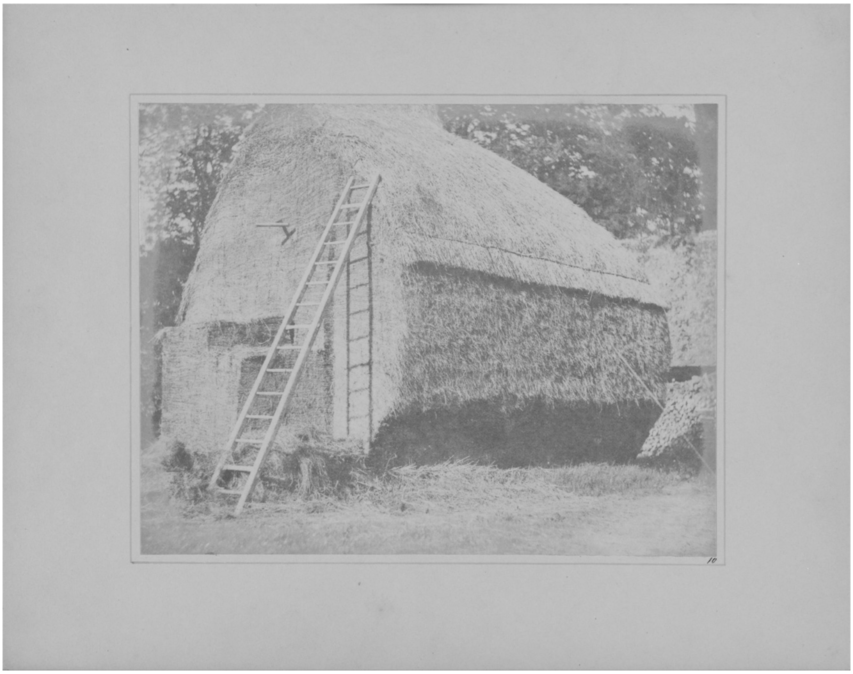
Visual impressionism, the sensory approach that this methodology advocated, was deceptive: plants and flowers that seemed dominant to the eye were actually not the dominant ones. Even the trained eye would be likely to miss a plethora of significant traits that remained under the threshold of (qualitative) visibility. In addition, an even bigger issue made the method useless for the context of the prairie: estimations by naked eye were unable to capture the slow shifts and transitions from one type of grass to another. Vegetal formations shaded in and out and remained imperceptible to this manner of surveying. This “silent and insensible shift”[41] was part of the core epistemic concern, which necessitated methodological solutions beyond the register of visibility. Needless to say, the unnoticed changes in grass types were here an epistemic and aesthetic dilemma that should raise implicitly or explicitly the question: Unseen or invisible to whom? The settler colonial scientific gaze? To the original inhabitants of the lands? Under which kind of visual regime is the depiction of visible or invisible, chaos or order being inscribed?

In any case, this unsolvable difficulty regarding the transitions and the problem of tracking the shift between different prairie grass formations led the researchers to their own method, which relied on the “actual enumeration” of the individual plants.[42] For the sake of accuracy and more objective survey results, the impressions by eye needed to be replaced by quantifying techniques of counting in order to track the imperceptible shifts in the meadows. Counting individual plants across a sample patch was meant to provide new objectivity, not by means of mechanical instruments only but through techniques of freeze-frame sampling and statistical analysis. As we will see next, this counting was, in principle, the same operation that photography had enabled. Photographic surfaces also functioned as sites of numbering as they enabled second-order analysis to emerge from what was captured in the first place in the image-cum-sample. In Clements’s experimental practice—notably, he was the son of a photographer—images and enumeration coalesced on the same surface.

NUMBERS AND PHOTOGRAPHY: A BRIEF INTERLUDE

Before specifying how this enumeration operated for Clements, let us remind ourselves how images, calculation, and computation had already featured in discourses of early photography. Providing one reference point for our argument about the transformation of visual technical media, Geoffrey Batchen has observed how photography early on was already linked to the idea of counting and computation in what he named as the conceptual convergence of photo-media and computing in the 1830s.[43] Batchen builds his argument about early photography involved in computation by reading some of the interactions between Charles Babbage and William Talbot, two pioneers of computing and photography, respectively, and also "expert mathematicians." As Batchen argues, reading Talbot's point about light and shadows, the informational economy put into place was premised on the variation of those two binaries—light and shadow—in ways that established the "system of representation involving the transmutation of luminous information into on/off tonal patterns made visible by light-sensitive chemistry."[44] Focusing on Talbot's 1845 "Lace," plate XX from *Pencil of Nature*, the haptic touch of lace on the contact print of photographic paper represents not only a material aspect of this process but also allows for the image to emerge from the play of presence and absence (of objects). The details of minuscule threads become, in Batchen's parlance, "a ghostly doubling" and an informational patterning of details—even geometrical units—as in the lace.[45] Photographs were seen as tools of counting with a precision that enumerated details in the objects on the surfaces of images. As for their epistemic value, photographs did not "necessarily offer a truth-to-appearance" but "truth-to-presence."[46] Instead of being only visual objects, images were addressed as spatial data arrangements. In Batchen's words, photography involved "an abstraction of visual data, a fledgling form of information culture."[47]

For Talbot, the ability of photographs to "introduce into our pictures a multitude of minute details" characterized the new medium, beyond the lace, as the particular informational unit of depiction.[48] For our purposes of tracking the green surfaces information economy, Talbot's words were suitably accompanied by a photograph of a haystack (figure 6.1) where



6.1

William Henry Fox Talbot, *The Haystack* (estimated 1841). From the collections of the Met Museum, Gift of Jean Horblit, in memory of Harrison D. Horblit, 1994. Public domain. https://www.metmuseum.org/art/collection/search/289179.

the straws are visible, producing one example of this epistemological and aesthetic pairing: how to count through an image?

Instead of the conundrum of individuating pebbles of sand from the grain of a photograph, a more apt assessment in light of the media historical cases we are discussing would be counting blades of grass and hay.[49] It would be impossible, and probably unbearably tedious, for any human to individuate and copy all the blades faithfully in a large-scale prairie of grass. However, photography set the ground for the possibility of doing such tasks by other means. As writer Oliver Wendell Holmes Sr. put it in 1859: "Theoretically, a perfect photograph is absolutely inexhaustible. In a picture you can find nothing which the artist has not seen before you; but in a perfect photograph there will be as many beauties lurking, unobserved, as there are flowers that blush unseen in forests and meadows."[50] In most cases, the epistemic significance of photography went beyond artists or photographers being primary eyewitnesses, let alone counting clerks; instead, it was the surface of the image itself that became defined by such an abundance of information. Photographic images would be "data mined" in multiple ways afterward.[51]

Beyond a characteristic analog-media belief in the possibility of full recording, which Babbage cherished, this fantasy of microscopic detailing of abundant scales of information surrounding photography set the ground for a further set of techniques that grew out of these discourses and material practices. In other words, counting, measuring, finding patterns, and statistical inferring leaped into the domain of the unseen flowers in the meadows mentioned by Holmes, and they also leap into the contexts of prairies made visible and countable by means of Clements's decision to use predefined quadrat areas as units of geometric sampling.

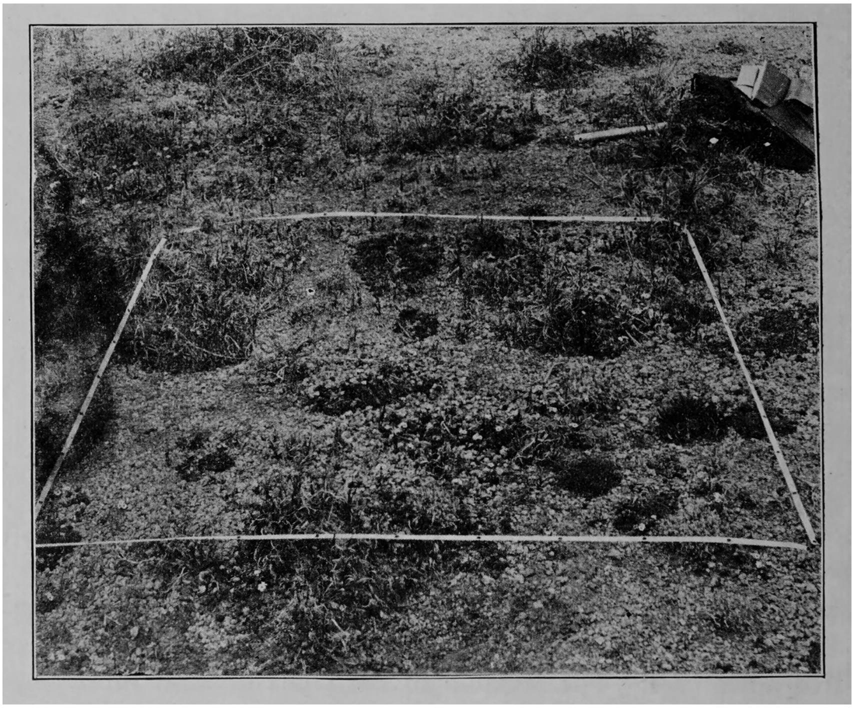
THE QUADRAT METHOD: STATISTICS AS VISUAL TECHNIQUE

This brief interlude—to remind us about the media archaeological link connecting photographs, enumeration, and a representational love for details—invites us to revisit what was taking place in prairie ecology. In particular, it looks at the tension embodied by surfaces of grass between the indistinguishability of individuals against the striking homogeneity of the compound body and the need to perform “a minute study of the shifting and rearrangement of the individuals.”[52] This tension is resolved in Clements’s and Pound’s work thanks to a specifically designed methodology where images and statistics coincide.

While such attention to detail would seem to echo Lorraine Daston and Peter Galison’s work on the photography-based notion of mechanical objectivity,[53] counting individual plants in this context emerged from a different background: the use of statistics in the Nebraska School. Different from the work on visual statistics as it featured, for instance, in the charts designed by W. E. B. Dubois and his students for the Paris Exhibition in 1900, Clements’s and Roscoe’s approach to a quantitative physiognomy of plant formations was related instead to the way “statistics translated into images,” in other domains such as criminal photography.[54] As part of their education in the University of Nebraska context, Clements and Roscoe were introduced to the applications of statistics in the context of plant geography. They had also assumed as one guiding premise of Darwin’s key idea that populations of individuals evolved rather than individuals.[55] The shifts in the grass were to be read as shifts in population, and counting was the core technique when dealing with population figures.[56]

The replacement of the expert eye did not involve a replacement of the surveyor. Quite the contrary, surveyors were needed to solve how to count individual plants of grass on the visually limitless prairies of the Midwest. This is the same problem we addressed earlier in relation to photography’s “minute attention to details,” but now surfaces of vegetation were approached as though they were an image of sorts: framed and quantified. In this regard, the solution was not photographic in an analog sense but involved a completely different approach to visual technical media that became prevalent much later. The statistical approach relied on both concrete sampling and mathematical powers of abstraction.

The researchers knew that instead of counting all the individual plants in a valley, they could work on a selection of samples of terrain and infer from them the bigger picture. This way, taking statistics on the one hand and the phytogeographic grid on the other, they arrived at the method that is still used today when teaching about plant surveys—the quadrat method. The method consists of setting up stations around which several squared frames delimit sample areas (figure 6.2). Described in Tobey’s words:



6.2

A photograph of a quadrat, showing the process of sampling as image framing as well as gathering data. From Frederic E. Clements, *Research Methods in Ecology* (Lincoln, NE: University Publishing Company, 1905), 168–169.

All the plants within the square were counted and their locations plotted on a grid-graph representing the square. In practice, the scientist used meter tapes along the sides for accurate location. A fifth meter tape was run across one side. Individual plants along the fifth meter tape were counted and located by Cartesian coordinates. When all the plants along the tape had been located, the tape was next moved down the quadrat a few centimeters for counting and plotting the next line of plants along it. This procedure continued until the entire quadrat was counted.[57]

The quadrat describes a method for manually framing and scanning a sample of land, usually 4 square meters. The method involves setting up a station within which a set of physical and meteorological variables are to be measured, as well a number of randomly scattered quadrats around it that would be manually turned into spatial arrangements of information. By doing this, in Clements's words: "The deficiencies resulting from the small size of the plots are corrected by taking a large number of plots at each station and averaging the results."[58] Importantly, it seems that Clements and Pound were actually surprised that the results produced by this method "turned out to be very different from naked-eye estimates."[59]

With the aid of this statistical sampling of the terrain, the researchers could keep track of the otherwise invisible transitions of grass types and calculate averaged plant population data around each station. The continuum of the prairie was this way parsed as a spatial array of data stations measuring plant population shifts and ratios as well as environmental parameters.[60] Photography was in the mix of the instruments that were employed to observe and to measure, as images of the quadrats also needed to be taken for later analysis and verifiability. "No ecologist is equipped for systematic field investigation until he is provided with a good camera,"[61] Clements emphatically pronounced. In his book on method, he offered details on the types of cameras, lenses, tripods, exposure times, and developing techniques required to obtain adequate pictures—even zenithal ones—of the quadrats.[62] Exhaustive and clear, these could be read as a quick introductory course to field photography.

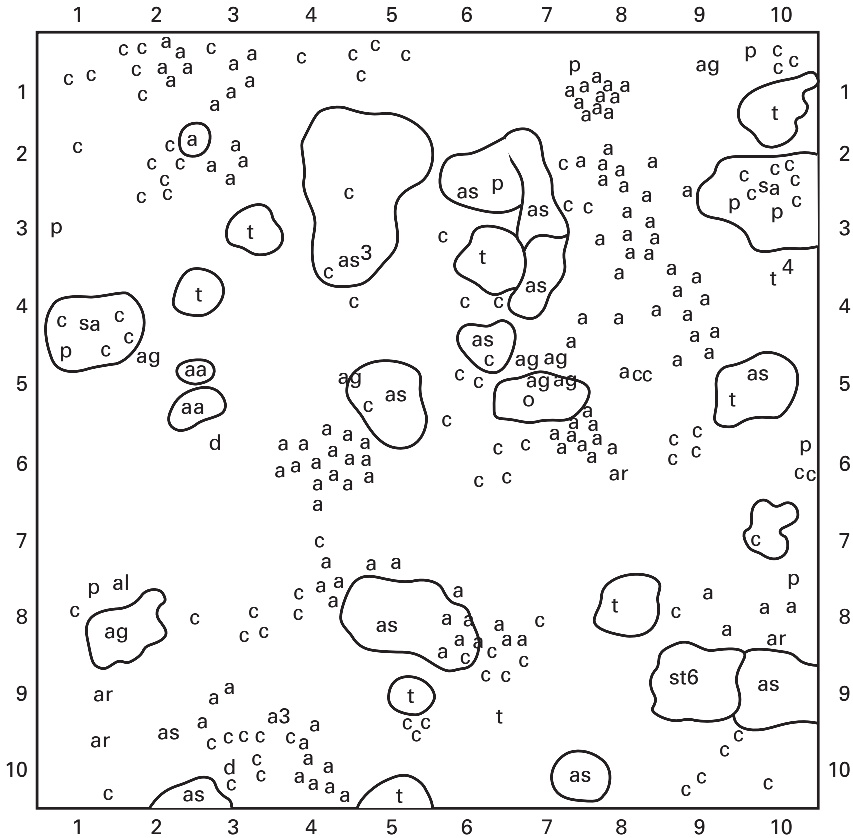
Clements also described what the photographs should look like, adding a further data layer about which kind of media made the living surface addressable: "The ecological view should be a picture as well as a map, . . .

when one must be sacrificed, artistic effect must yield to clearness and accuracy, i.e., technically speaking, contrast must give way to detail."[63] Again, the meticulous attention to detail comes to the fore; this time, however, it is layered across the data image surface (figure 6.3), which became a primary unit for statistical analysis. This offers an insight into a particular technique of both description and averaging that brings enumeration early on into a connection with the framed territory and the photographic image. In other words, these were images of populations on top of a data layer made up of populations—of plants, of quadrats, and of photographs of those quadrats—offering a view to appreciate the image on top of the image: the territory as a site of growth, images as registering these frames of populations of plant life, and the mathematical methods as building these images into useful models.

NEAR SENSING

The curious case of quadrat methods in early prairie ecology shows how shifts in vegetal surfaces turn from invisible to visible both as images and as enumerated samples. The two merge. On the one hand, vegetal areas capture photosynthesis in different intensities and become numbered images—whether through digital techniques or even, in predigital, premachine vision versions, by identifying and counting prairie plants through sampling. On the other hand, different "pixels"—whether on the surface of the image, as part of landcover indexes, or as quadrats that sample 4 square meter pieces of land—are determined not as visual representations but as quantified occurrences and values, where identifying edges and the change of type become the crucial epistemic concerns.[64]

Vegetal surfaces have been interpreted using comparative perspectives of inference and proxies, harnessing the idea of plants as sensors and indicators. Enumerated, computable, indexed, and searchable surfaces are examples of how contemporary management of the earth takes place. The earlier shift to cybernetic management of ecosystems is perhaps one phase in this larger scheme of techniques for making environmental changes visible. The current planetary computational technologies—as well as imaginaries—of digital twins, AI models, and



6.3

A “map” view of a quadrat showing the process of sampling as image framing as well as gathering data. From Clements, *Research Methods in Ecology*, 168–169.

prediction environments are echoed in this instance by a quote by Microsoft's chief environmental officer, Lucas Joppa: "Imagine if we had a planetary computer that could tell us exactly what we needed to do to protect planet earth—a system that was capable of providing us with information about every tree, every species, all of our natural resources."[65] As Shannon Mattern points out, the corporate-epistemological dreams of countability, algorithms, and dashboard governance drive many of the current versions of environmental management. Here she is echoing Jennifer Gabrys's point about such plant data as "recourse to metrics that in turn legitimate specific technological interventions to meet targets for averting environmental catastrophe."[66]

Similar elements also define the remote sensing imaginary that takes place across different institutional contexts, from military to scientific earth observation, including sustainability programs.[67] The trope of the surface of the earth as a searchable and manageable database includes governmental remote sensing and earth observation agencies as well as private environmental intelligence companies providing services to use this imagined database. Not that all of it was merely imagined; one could do a whole study of how it is actually the different databases that lie at the back of projects rather than photographic images of the "whole earth" that aim to instantiate the addressability of the earth as a target, as resources, as the digital environment.[68] But such databases and software environments are always much more limited in scope and ambition than the broader discursive production of imaginaries. In this regard, as shown in the next section, when geospatial intelligence companies such as Descartes Labs proceed to build a "living, breathing atlas for the world,"[69] they are not only piggybacking on the historical reference to atlases as ways of organizing knowledge about nature into instrumental collections, they are also finding ways of dealing with surfaces as continuous exchanges between matter and information, the surfaces being both physical and chemical, as well as images, such as those produced through remote sensing, datasets, and data visualization.

Counting vegetal surfaces does not emerge only in remote sensing but in "near sensing," too. Our argument about grass—and counting grass—may be peculiar in the context of statistical techniques of defining and managing surfaces, but it also aligns with the longer genealogy of the green mantle that we referred to above.[70] This quirky choice of an entry point to questions of surfaces, collectivity, and enumeration becomes clearer as we address this particular characteristic that so prominently features in the grass and vegetal surfaces as they are viewed, surveyed, analyzed, and articulated as objects of knowledge and as living, dynamic, interconnected systems. The continuity of grass grounded and stabilized a series of techniques and conceptualizations closely linked to current remote sensing practices in environmental sciences and landscape design: the interweaving of statistics and (what are traditionally considered as) images. While in the previous chapter, we saw how the techniques of building environments of images entailed a transfer from the ground to the surfaces of the image, now we address how continuous slow changes on the large-scale vegetal surface also traveled from the prairies to quantitative descriptions that resulted from networked monitoring stations.

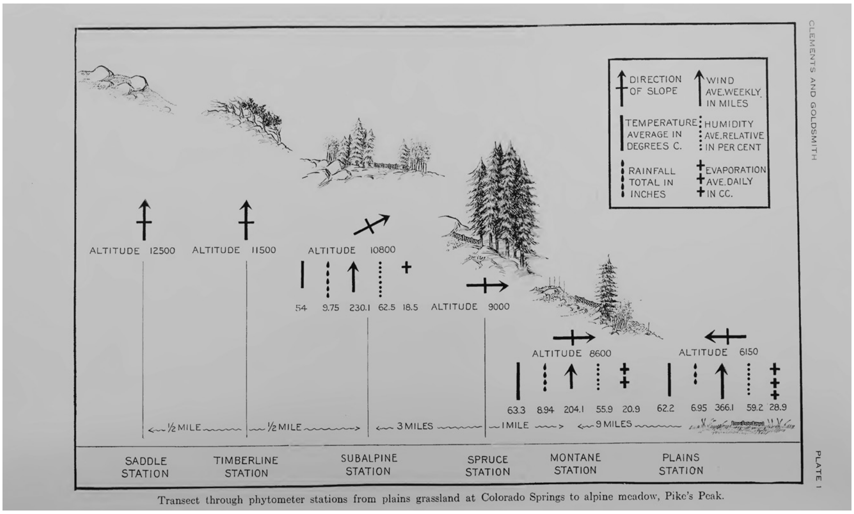
While moving toward this contemporary context where AI techniques and statistical methods are central to counting vegetal surfaces in both urban and nonurban areas,[71] we address grass as a milieu that has given rise to an assemblage of techniques from data sampling to statistical inference as an early example of a managerial surface, which starts to include the key characteristics of computation such as addressability.[72] As briefly outlined in the introduction, while May focuses on the electronic space, the concept of the managerial surface has interesting possibilities in dealing with such images that are not perspectival or representational so much as statistical. What for May is the Cold War–era birth of a "fully automated electronic surface"[73]—defined as "a statistical representation of the continuous surface of the ground, by a large number of selected points with known *xyz* coordinates"—becomes in our focus also part of the predigital, pre-electronic age of operational images that start to govern how we understand environmental phenomena, such as the distribution of ecological life of plants across surfaces of soil, as we have seen in this chapter.

PLANTS AS LIVING MEASUREMENTS

There is an interesting twist in Clements's account that has significant ontoepistemological consequences for how we consider sensing. While his work established both the sampling methods and the categories that define the different forms and evolutions of plant formations, Clements argued that these epistemic categories were not only second-order projections. That is, the plants themselves organized their distribution into zones as they expressed the ecological context. In Clements's words, reflecting this commitment to a realist notion of scientific work: "Zonation is the practically universal response of plants to the quantitative distribution of physical factors in nature."[74] This view of "zoning" thus starts from the activity of the plant, not the mind of the observing scientist: the plants themselves are sensing and inhabiting surface and subsurface areas in ways that also give shape to meaningful classifications. Through plant formations, vegetal surfaces become a primary force that divides space, creating particular ecologically meaningful couplings and inviting thus all sorts of references to "superorganisms" or, in the more modest terms of Clements's later critics such as Tansley, "quasi-organisms."[75] Furthermore, these are not just any plain soil grounds or visible surfaces. The landscapes surrounding plants are *numbered* landscapes; they are quantitative distributions of physical factors, not different from the managerial surfaces we have just described as coming out from the near sensing—statistical sampling and counting—of ground.[76]

Plants' primary dividing force is addressed in Clements's work in relation to these surfaces of numbers. In chapter 2, we saw Julius Wiesner describing the growth and shape of plants in relation to the numbered volumes of light intensity resulting from the practice of the photometer: Clements's reasoning follows a similar path. Plants' spatial life, defined against a background of quantitative landscapes, also becomes a practice of the number. In Clements's words: "Every plant is a measure of the conditions under which it grows."[77] Plants do not merely respond to the continuities and fluctuations of the quantified landscapes which surround them, but they are measures of their own conditions of existence *as well as* a proxy of the site they inhabit: the plant "is an index of soil and climate, and consequently an indicator of the behavior of other plants and of animals in the same spot."[78] We even find a hint of this proxy thinking in Nathaniel Ward's much earlier nineteenth-century meditation that highlighted plants as a form of remote sensing across time and space: "Almost every different region of the globe is characterized by peculiar forms of vegetation, dependent upon climatal differences; and thus a practiced botanical eye can, with certainty, in almost all cases, predict the capabilities of any previously unknown country, by an inspection of the plants which it produces."[79] Here the passage that started from Humboldt's investigation of the geographic distribution of plants through the phytogeographic methodologies of gridding and sampling ends now in plants embodying the numbers they are modeled with. As in Wiesner's case, in Clements's work, plant sensing also becomes a nonhuman practice of measuring.

The elemental ("natural") techniques of measuring and zoning that we discussed in chapter 2 might not be taken as cultural techniques in the traditional sense of "cultural." However, they need to be understood as a recursive part of the agricultural, ecological, and biological epistemes and methods of how so-called natural life is seen as producing fundamental divisions and differences in the nonrepresentational kind of matter that is full of signaling processes.[80] As a matter of fact, Clements's view of plants as living measurements of their surrounding conditions was not an anecdotal characterization of vegetal spatiality but a summarized presentation of the premise that grounded his practical book on plant indicators. There, the correlations between landscape types and plant formations articulated by his earlier work are presented under the epistemic figure of the indicator, following a practice of agricultural indicators that Clements traces in an opening section devoted to historical references. Through the figure of the indicator, then, the book presents specific and easily traceable vegetal formations as living signs of landscape parameters such as slope, altitude, fire, and animal presence, among many other factors and processes (see figure 6.4). The whole method becomes a form of reverse-engineering through the logic of the proxy that complements the earlier presented quadrat sampling method in the full arsenal of "datafication" of ecological surfaces. Here the idea of making "plants into quasi instruments for directly measuring the capacity for environments to sustain their growth" is a substitute for building specific technological instruments that would act like plants.[81] In other words, it meant that instead of making artificial instruments to produce "data that could be *correlated* to the life of plants," the aim was to perceive the whole environment as measured through and by the plant.[82]



As we will see next, such proxy techniques and indicators did not stay limited to ecological research or agricultural use. As part of the weaponization of the capacities and characteristics of nature, this notion of plant indicators is directly related to remote sensing during and after the Cold War, in operational uses where the entwining of images and vegetal surfaces we are tracing becomes emphatically clear. In this way, Clements's analytical merger of plant sensing and zoning into a practice of measuring evolved into an "applied science" intelligence operation of sensing and a late satellite-era version of landscape physiognomy, reading geographical traits as signatures of their hidden insides.[83]

6.4

Transect from plains grassland to alpine meadow, featuring vegetation types as plant indicators. From Frederic E. Clements and Glenn W. Goldsmith's *The Phytometer Methodology in Ecology: The Plant and Community as Instruments* (Washington, DC: Carnegie Institution of Washington, 1924), plate 1.

PHOTOBOTANY AND COLD WAR PLANT INDICATORS

In the previous chapter, we discussed how the techniques for generating knowledge about the surfaces of the planet shifted during the twentieth century from the ground to the environments of images, resulting in complex infrastructures of hardware and software that could aggregate and address both terrestrial and extraterrestrial surfaces. On such platforms of images and data, once the appropriate circuit for remote sensing is set up and conveniently validated with ground truth data, it makes no difference whether or not the source of the images is physically accessible, either on earth or in outer space. "Digital twins" already exist in different institutional practices: these are environments of images and data (or images as data) that provide the necessary testing grounds for running relevant operational simulations.

Operational image layers multiply; simulations and other techniques give rise to image-based circuits that further transform the surfaces from which they emanate. These circuits also respond to what Orit Halpern signals as a characteristic of visualizations: "They make new relationships appear and produce new objects and spaces for action and speculation."[84] So far, our book has explored this ontogenetic character of data visualizations and images, including all sorts of targeting, defining, and refining surfaces through a myriad of tools and cultural techniques. And yet, surfaces are not passive even if taken as material for design in all sorts of ways and with all sorts of means that have implications far beyond the original agricultural connotation of cultural techniques. The meaningful relation that surfaces and living formations play as expressions of their own conditions of existence becomes a sign of what sort of *environment* of images they are. The continuous monitoring and observation of these surfaces are premised on the idea that they are already monitoring their own surroundings, acting as sensors and indicators. "Nature is a language, can't you read?," as The Smiths put it in the song "Ask." For the cybernetic-data period of remote sensing it could be rephrased as "Nature is a trace of patterns and signatures, can't you sense?"

For sensing to happen, it has to have happened already: photosynthesis, plant growth, chemical reactions from solar energy to soil ecologies, plant formations to the quasi-organisms of autogenic succession where plants shape their surroundings.[85] Technical sensing is, in this way, trying to catch up, to produce images of what has taken place, to establish categories such as vegetation indexes or engage in producing other aesthetic knowledge forms along the axis of seeing-to-classification. This recursive trait of *sensing sensing* characterizes a plethora of operations that form a genealogy of contemporary data culture, from labs, such as sensing human sensing in psychophysics, to, in our case, landscape surfaces of plant growth.[86] An extended and active surface that is not only the object but also the productive affordance of remote sensing is defined as a new environment of material relations: dynamic vegetal surfaces of growth and change, technical images, data circuits, and platform operations as coproducers of these relations that feature in different institutional practices.[87]

To address the nuances of this understanding of the environmental surface as affordances, we will discuss a case that took place during the Cold War, where the lack of physical access to the enemy's territories forced the intelligence agencies to deploy several initiatives geared at generating valuable new data out of aerial images that were also interpreted in relation to ground observations of plant-soil relations in different geographical areas. Methods from plant ecology became the mediator in this interpretation of plants as indicators and expressions of their own conditions of existence.

Consider this as a case of an abstracted yet active vegetal surface prepared for comparative operational purposes. Robert Gerard Pietrusko has analyzed the role that the observation of plants, trees, and other vegetal formations played for the cartographers of the US Department of Defense, who developed techniques of comparative aerial reconnaissance aimed at obtaining meaningful details of the Soviet landscape. The aim was to build models of the terrains based on the vegetation data obtained from high-altitude aerial photographs, while also actively mapping similar ground data that helped to analyze operational conditions, for example, for troop and vehicle access. With the help of the expert knowledge of botanists and ecologists, the teams sought to obtain plausible indicators of the slope, soil type, and soil moisture. As Pietrusko points out, these methods employed the ideas concerning plant indicators developed by Clements and others in the 1920s and 1930s.[88] Now though, the approach to plants as active surfaces of sensing and indication was not for "descriptive naturalistic terms" but because "plants directly indexed the ground's capacity to support military activities."[89] In short, the idea that plants became channels for gathering intelligence was not merely about their turning into media but into a very particular kind of operational media in the Cold War context.

The vegetation-covered areas were turned into indicator signatures, made possible through an exhaustive practice of comparing terrains and plant formations in the United States against the images from reconnaissance missions flown at high altitudes over the Soviet Union. Different expeditions sent to study ground conditions in North America provided the empirical data for detailed proxy analysis that could offer the speculative and comparative ground truth for visual analysis—for example, that "black spruce along the Albany River [indicated] an opportunity for camouflage, cover, and concealment," but also that the same vegetation could indicate "landscape's slope, soil type, and wetness" of significance for military logistics.[90] The observed and inferred correlations together suggested a series of plants and trees that could be recognized in aerial images. They provided visual clues but also invisual data for computational techniques of modeling. One could argue that they also produced the point about the vegetal cover as a data image in its own right. In Pietrusko's words, "Vegetation became a new form of photographic media":[91] vegetal formations surfaced as data sources feeding details of the terrains photographed so as to model an inaccessible region. The characteristics of the slopes that would eventually be crucial for the movements of troops and artillery in a conflict, for instance, were inferred from the systematic identification of vegetal species on the surface of the image.

One of the practitioners of this process of interpreting aerial photographs named this practice "photobotany," reflecting how aerial photography affected how the experts conducted their work at a distance.[92] First, it altered how they defined the plant communities that they studied. Pietrusko speaks of "photo-determined communities," where the team was interested in aerially imageable plants only.[93] Plant species that were small, sparse, or thrived in the shadows of other vegetation were not studied as they could not produce the proper spatial extent in these photographs. Second, the practice of photobotany also shaped the way the actual plants were characterized: "Their concern for vegetation's photographic signature affected the language that [was] used to describe the species."[94] Instead of the usual descriptors employed in botany and plant physiology, this analysis used a language grounded in tonal patterns, visual contrasts, and so forth: *a photomorphology* instead of a plant morphology, as Pietrusko emphasizes. This sort of "zoning" in and through the image provided a framework that built on the organicity of plant life while recursively treating it as data that could be appropriated into categories of operational use.[95] In this practical application of botanic indication, plants transform into light-emitting sources of signal intelligence, as photos transform into proxies of plant surfaces for morphological data analysis.

Pietrusko describes a case where the entwining of images and vegetal surfaces gave rise to a media-specific epistemic practice similar to those performed by the First World War RAF photo interpreters discussed by Paul Saint-Amour that we addressed in the previous chapter. Moreover, the case of photobotany makes it clear that there are material aspects of the imaged surfaces that enable the circulations to become meaningful for various epistemic practices, some more scientific, some more obviously operational. In particular, each specimen of the plant species identified by the experts was alive and maintained exchanges of matter, energy, and information with its surroundings when the aerial photographs were taken. This is not as obvious a fact as it may seem: many military surveying operations involved the extermination of vast extensions of vegetation, as we will see in more detail in the next chapter. Permanent features of much of the Cold War period were not only the weaponization of environmental data measurement but also the use of active agents—chemicals and pests—to kill crops and cause large-scale landscape damage.[96] In the case we are dealing with here, the actual life of plants was essential for the extended signal intelligence uses by the US Department of Defense. Plants as sensing biological entities were part of a broader circuit of capture and interpretation of different kinds of signals. This meant in this case understanding how the ecological exchanges between the plant, the soil, and other neighbor plants could be abstracted in the photointerpretation process and lead to operational knowledge of soil conditions. Just by being alive and connected to their surroundings, plants provide the elemental labor necessary for their operational functioning.

ADVANCED PLANT TECHNOLOGIES

Fast forward to 2017. The Defense Advanced Research Projects Agency (DARPA) announces its interest in plant studies, although on the more operative side as they declare the potential of Advanced Plant Technologies (APT) for military intelligence. One could claim that this is a mere continuation of what had already been in place since the Cold War, not just weaponizing different chemical or biological agents for active warfare but also developing techniques of interpretation and sensing that work through already active capacities of plants. The APT project presents itself as wanting to harness "plants' innate mechanisms for sensing and responding to environmental stimuli, extend that sensitivity to a range of signals of interest, and engineer discreet response mechanisms that can be remotely monitored using existing ground-, air-, or space-based hardware."[97] Unlike Clements's measurements, which were done by plants just being plants—after all, "plants are the best measure of plants"[98]—these plant sensors were already modified by way of the "advancement of technologies for performing multiple, complex modulations to plants, without sacrificing their environmental fitness."[99] Thus APT was conceived fundamentally as about genomic modification and synthetic plant biology, the central element of its promise being that nature was programmable: "Emerging molecular and modeling techniques may make it possible to reprogram these detection and reporting capabilities for a wide range of stimuli, which would not only open up new intelligence streams but also reduce the personnel risks and costs associated with traditional sensors."[100] The choice between designing artificial devices to act like plants or making plants act like (scientific) instruments was resolved by doing both.[101]

One would be tempted to see such large—and speculative—research projects as the culmination of the narrative we have presented, from plant ecology to the proxy type of indicating and sensing that informed Cold War period intelligence gathering. Plant landscapes could be read as proxies of their ecological formations and soil types, and interpreting images of those landscapes could be like reading plant morphology: a surface upon a surface that looped together in totalizing operations research that made cybernetics and ecosystem thinking seem modest by comparison.

Yet, even without such linear pathways of history that leave out many twists and turns of detail, it would be fair to say that APT crystallizes many elements of quantification of plant formations and demonstrates how their interpretation bends to many operational uses across the twentieth and twenty-first centuries. This case also presents a strong link to how environmental sensing starts as part of the narrative of the computational, programmable planet. As Jennifer Gabrys has shown, this view presents different scales of the earth as "an object of management and programmability,"[102] while creating technogeographies where "sensors as proxies are not standing in for a more-real version of environments, but are rather sensory operations that mobilize environments in distinct ways."[103] The reverse engineering at play is premised not to read from technics to nature but to place different combinations of technics-as-nature and nature-as-technics at the forefront of sensing networks, indicating, interpreting, and quantifying with a plethora of different institutional directions. Such fabrication of sensors and sensor networks is a version of the "managerial surface" we pointed to, which grows from quantitative management to management by creating sensor environments as vegetal surfaces. Contra Kittler, war and the military were not always necessarily the starting point but the end application of many technological and scientific innovations.