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The End of Botany

Jorge V. Crisci,[1,*]
Liliana Katinas,[1]
María J. Apodaca,[1] and
Peter C. Hoch[2]

Biologists unable to recognize common plants, and a decline in botany students, faculty, courses, university departments, and herbaria, highlight the current erosion of botany. How did we reach this crisis, knowing that plants form the basis for life? What are the causes? What can we do to reverse it?

The current erosion of botany (the scientific study of green plants, including organisms that contain chlorophylls a and b, store their photosynthetic products as starch inside the double-membrane-bounded chloroplasts in which it is produced, and have cell walls made of cellulose) as a comprehensive discipline, (i.e., encompassing all levels of nature's hierarchy: molecules, cells, tissues, organs, organisms, populations, and species) is demonstrated by highly educated biologists not being able to tell apart even the most common plants. This situation was observed by scientists [1], and noticed by the media[i] and by members of the US 116th Congress 2019–2020, who introduced the 'Botany Bill' in both the House of Representatives and the Senate (Box 1).

This problem is not unique to the USA, but is happening worldwide [2] and reflected in a recent decline in the numbers of botany students and faculty, botany courses, plant collections, and indeed botany departments at universities [3].

How did we reach this crisis, knowing that plants form the basis for most life on Earth? Multiple causes, apparently disconnected from each other, are currently causing the decline of botany as a discipline: the rise of scientific reductionism; the decline of natural history collections; the application of market logic (i.e., the transformation of economic, human, and social relations into mere consumer values) to the evaluation of scientific activities; and the impact of language as a constructor of reality, as we explain in the following text. Here, we suggest individual responses and the culture of science (intellectual climate) actions as a starting point for efforts to reverse the decline of botany.

Scientific Reductionism

A reductionist program means that a set of scientific laws is deduced from laws at a lower level of organization, as when chemical laws are deduced from physical laws.

Through the spectacular advances of molecular biology, a methodological reductionism currently is prevalent (affecting aspects of scientific life; i.e., funding, jobs, promotions, courses, acceptance of papers by academic journals, and awards) in biology [4].This prevalence has an unintended side effect of devaluing botany, because a level of biological organization (molecules) exceeds in perceived scientific relevance (in an ambit of limited resources) a comprehensive multilevel discipline, such as botany.

While the proliferation of subdisciplines in botany is acknowledged, there are perils in adopting an unbalanced view where some subdisciplines (e.g., molecular biology) dominate over others, such as taxonomy and morphology. These tendencies have engendered a prevalent 1D thought that undermines the very foundation of a multidimensional discipline, such as botany [4].

Despite its centrality, molecular biology cannot dispense with the reference systems of biology as a whole provided by botany, among other disciplines. For example, it is impossible to complete a biological project at any level of hierarchy in nature without any scientific names associated with the observations or experimentations [5].

Natural History Collections in Jeopardy

Natural history collections, including plant collections (herbaria), curated by museums and universities worldwide, have an enormous value for society and constitute the foundation for understanding biological diversity and its distribution (Figure 1). Scientific collections have many specific uses [6]. Herbaria, for example, can be used to track phenology, gauge resulting impacts on pollination ecology, or examine how levels and/or types of herbivory have changed over decades or centuries; they are also essential for modeling how species might track spatial shifts in climate change envelopes.

Natural history collections and associated institutions increasingly face closure. The reasons given usually involve budget shortfalls and, unfortunately, collections are easy targets. The negative societal consequences of these closures have been widely noted in editorials of scientific journals [7] and even popular media, such as *The New York Times*[ii]. Botany is deeply impacted by these global threats to natural history collections, because many botanical research projects require unfettered access to collections of herbarium material.

Most biological research, including molecular and ecological, depends on the correct identification of the organism being studied, and the preservation of a reference specimen (voucher) of that organism in a natural history collection is essential. Such vouchers are the basis of reproducibility, an irreplaceable element of the scientific method.

Market Logic Applied to Science

The transformation of human and social relations into mere consumer relations

Box 1. The 'Botany Bill', Botanists, and the Word 'Botany'

The Botany Bill

On March 6, 2019, Representative Mike Quigley (D-IL) with 55 bipartisan cosponsors re-introduced (first introduced in 2017) in the US House of Representatives, and on July 31, 2019, Senator Mazie Hirono (D-HI) re-introduced (first introduced in 2018) in the US Senate with 11 co-sponsors, the so-called 'Botany Bill'. The official title of these bills is (H.R.1572, S2384): 'The Botanical Sciences and Native Plant Materials Research, Restoration, and Promotion Act'. These botany bills are the result of alerts issued by many agencies, such as the US National Park Service and Bureau of Land Management, indicating that they cannot find enough botanists to deal with invasive plants, wildfire reforestation, and basic land management. In response, these bills are intended to promote botanical research and science capacity, generate demand for native plant materials, and authorize related federal activities. Urgent action is required because it is projected that, within the next decade, the USA will lose through attrition (such as retirement without replacement) almost half of its experts in botany, and specifically those who know and can identify plants, which will generate direct and indirect biodiversity costs and economic consequences.

Botanists and the Word 'Botany'

The word 'botany' was coined during the 8th century BC by Homer, in *The Iliad*. The word spread throughout the Roman Empire, survived to the Middle Ages and the Inquisition, and increased its practical value (e.g., plants as medicines) during the Renaissance. Botany participated in the origin of modern science, as a cornerstone for the ideas of Linnaeus and Darwin, and established itself in the works of great naturalists during the 19th and 20th centuries. However, the word 'botany' is for the first time in 2700 years threatened with extinction, even unintentionally by some of its own practitioners.

At the most recent International Botanical Congress held in Shenzhen, China, in 2017, and attended by some 7000 scientists from around the world, the Shenzhen Declaration on Plant Sciences [12] was promulgated. This declaration, written by a committee of 14 internationally renowned botanists, establishes seven strategic action priorities. Despite being the proclamation of the largest botanical congress, the word 'botany' cannot be found anywhere in the text of the declaration, having been replaced by 'plant sciences', presumably in an effort to avoid any negative connotations of the word 'botany'.

has become second nature in our current market-driven society. One manifestation of this phenomenon in science is the use of bibliometrics to judge the quality and impact of scientists and their research. Bibliometrics measure, directly or indirectly, the number of citations (consumers) of an academic journal or article. The criticisms (of its assumptions, the way it is calculated, and/or the consequences of its application) of this widespread method of evaluating scientific activity are numerous, serious, varied, and overwhelming (e.g., [8][iii]). Yet, despite these criticisms, administrators, tenure committees, and funding agencies worldwide often rely on these poor proxies to judge the value of scientists and the quality of their work. Botany is strongly devaluated by bibliometrics, as measured by the much lower scores and rankings of botanical journals and articles than of those focused on molecular or ecological research. As a consequence, bibliometrics inhibits creativity and innovation by strengthening the dominant paradigms (which encourage citations) and punishing those papers that challenge them.

Language as a Constructor of Reality

Language is a vehicle of expression, a generator of perceptions, judgments, and knowledge, a foundation of thought, and a constructor of reality [9]. In modern times, the name and discipline of botany have been subject to a process of pervasive denigration.

In a *Nature* article [10], Kirshner criticized the authors of another article in the same journal about the appearance of a supernova by stating: 'The spectral classification of supernovae carries a distasteful aura of botany for many astrophysicists'. Similarly, the British biologist John Maddox [11] provided the following criticism: 'Much of contemporary cell biology is but high level botanizing'. Even among its practitioners, there are efforts to avoid use of the word 'botany' (Box 1).

Part of this image problem is based on misconceptions of how some botanical subdisciplines work. For example, the view that taxonomy is a purely descriptive branch of knowledge that consists only of observations is a clear example of these misconceptions. In fact, taxonomy is a scientific discipline that requires description, but also theoretical, empirical, and epistemological rigor, a hypothesis-driven approach, and field and lab expertise [4].

Turning Thought into Action

Possible solutions are twofold: what individual botanists can do irrespective of what the current culture of science is doing; and what the current culture of science can do irrespective of what any individual is doing. By the culture of science, we mean the intellectual climate of conventional and unquestioned assumptions that are implicit in the spirit of science at a given time.

Some individual responses might be: (i) valuing the word 'botany', and rejecting its use in a pejorative way; (ii) pursuing risky but potentially ground-breaking work in research areas currently out of fashion but underexplored; (iii) thinking critically and rigorously, and questioning ideas and assumptions that favor an unbalanced emphasis on a reductionist program, rather than accepting them at face value; (iv) considering that peer-reviewed research papers will remain a primary research output that informs research assessment; (v) envisaging work as a creative scientific task, and not in terms of the production and consumption of goods and services, the ultimate goal of which is a search for citations; (vi) rejecting bibliometrics as the way to evaluate scientific activities; and (xii) valuing natural history collections.

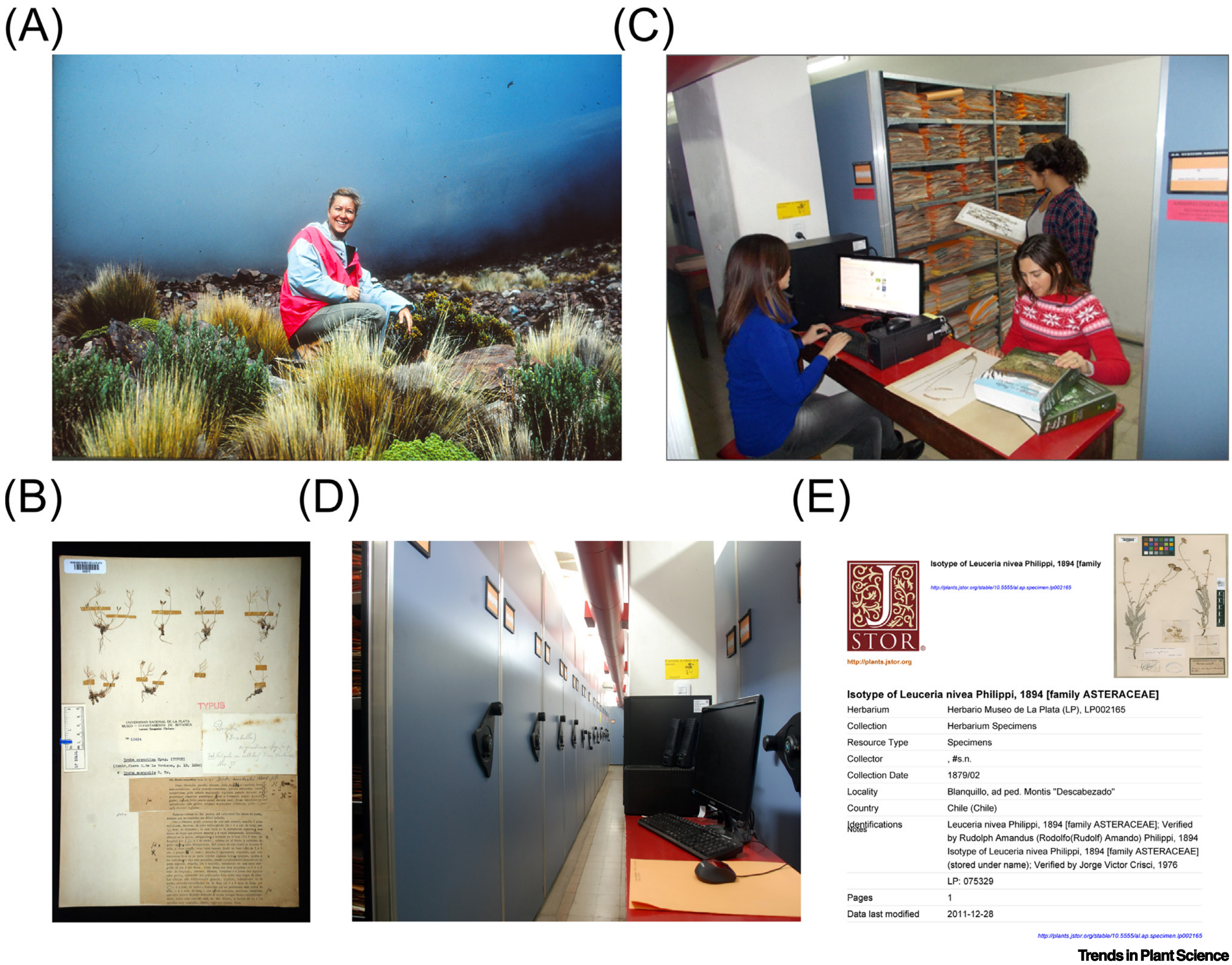

Figure 1. Example of how a 21st-Century Herbarium Operates: Herbarium of Museo de La Plata, Argentina (Founded During the 19th Century), which Houses Half a Million Specimens, Mainly from South America. (A) Collecting plants in the Andes of northwestern Argentina at an altitude of 4915 m. (B) Specimen voucher with labels providing information about locality, date of collection, collector´s name, accession number, georeferencing, and, if available, ecological data of the site of collection. (C) Specimen identification and digitization of related images and label information. (D) Storage of specimens in compactors under strict environmental controls to protect against potential pests. (E) Digitized data of specimens are available worldwide on different online portals to be used by researchers, policymakers, educators, and the general public.

Regarding the contribution of the current culture of science to value botany properly, there are several ‘actors’ that must perform actions in that effort. For example: (i) governments: enhancing the stature of botany through supportive legislation and policies, such as the botany bills; (ii) scientific community: valuing natural history collections, and changing the ways in which the output of scientific research is evaluated by funding agencies, academic institutions, and other parties. One example is the worldwide initiative named DORA (San Francisco Declaration on Research Assessment) signed by 2015 scientific organizations and 16 331 individuals (August, 2020); (iii) institutions: balancing institutional disciplinary expertise by providing job opportunities to trained organismal biologists, not just to molecular biologists; and viewing natural history collections not as costly impediments but rather as vibrant assets for stimulating scientific research and preserving biodiversity; (iv) funding agencies: diversifying the criteria by which the scientific productivity of grant applicants is evaluated, recognizing the importance of research in botany and its value to other branches of science, and supporting natural history collections; (v) universities: encouraging the teaching of botany courses, and balancing their faculties by hiring scientists able to teach those courses and to carry out research in botany; (vi) editors of scientific journals: avoiding potential bias against manuscripts dealing with organismal botany, and encouraging their submission; and ceasing to promote bibliometrics to provide a richer view of journal performance; (vii) academies of science: bringing this crisis to light and encouraging their constituencies to examine/discuss this topic; (viii) media and the general public: enhancing media coverage of botany, including exciting advances in our knowledge of plants and their importance to society, the relevance of natural history collections, and the critical importance of individuals able to identify plants and other organisms, and to share that knowledge widely; and (ix) educators: give our youth a sense of the interconnectedness of life, the importance of plants for human survival, and of biodiversity as the essential tool for understanding and conserving plants and the natural communities that sustain all life.

Concluding Remarks

Botany can be considered a vibrant discipline as demonstrated by two unrelated phenomena: The enormous popular interest in gardening, and the new technologies (e.g., digitalization of botanical collections) that are generating exciting new opportunities for integrative and interdisciplinary research.

The title of the article was chosen intentionally, to be an ambiguous prophecy, or to express severe pessimism about the future of botany. We choose optimism, and advocate for the critical importance of botany now, and in our future.

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Resources

[i] www.wsj.com/articles/rhododendron-hydrangea-america-doesnt-know-anymore-1534259849

[ii] www.nytimes.com/2016/04/03/opinion/ournatural-history-endangered.html

[iii] www.ascb.org/dora/

[1]División Plantas Vasculares, Museo de La Plata, Paseo del Bosque s/n, 1900 La Plata, Argentina
[2]Missouri Botanical Garden, 4344 Shaw Blvd, St Louis, MO 63110, USA

*Correspondence:
crisci@fcnym.unlp.edu.ar (J.V. Crisci).

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Spotlight

Lighting the Way: Advances in Engineering Autoluminescent Plants

D. Nikki Reuter,[1,2]
C. Neal Stewart, Jr[1,3] and
Scott C. Lenaghan[1,2,*]

Until recently, robust autoluminescence in plants has proven elusive. Two recent pioneering manuscripts (Khakhar *et al.* and Mitiouchkina *et al.*) expand our understanding of fungal bioluminescence to provide a new blueprint for engineering autoluminescence in plants. Here we discuss translating a fungal bioluminescence pathway into plants, along with potential future applications.

History of Plant Bioluminescence

The first demonstration of plant bioluminescence was achieved in 1986 when tobacco was engineered to stably express firefly luciferase, generating luminescence upon addition of the luciferin substrate [1]. Since this breakthrough, a variety of bioluminescent enzyme/substrate pairs have been leveraged for studying gene expression [2]. While bioluminescent assays using plant cells are commonplace, limitations in the cost and delivery of luciferin to whole plants and tissue have hindered progress on whole-plant imaging. One solution to this problem was achieved by employing nanotechnology to deliver the components of the firefly luciferase system (luciferase, D-luciferin, and coenzyme A) into plants [3]. This strategy achieved extremely high luminescence, 1.44×10^{12} photons/s; however, the signal decayed significantly over time and needed to be replenished with D-luciferin to extend its lifetime [3]. The only strategy that provides an adequate solution for long-term study is autoluminescence, in which plants are engineered to produce both luciferase and luciferin; exogenous substrate applications would not be required. To meet this challenge, the complete *lux* operon (*luxCDABEG*) from *Photobacterium leiognathi* was engineered into tobacco chloroplasts [4]. The transplastomic tobacco plants were bright enough to see in a darkened room by the naked eye (1.3×10^6 photons/s) [4]. However, most plant species, and all monocots, are refractory to chloroplast biotechnology, significantly limiting the approach. In addition, high expression of heterologous proteins in chloroplasts often leads to a decrease in plant vigor and growth upon transfer of plants to nonidealized growth conditions.