Seeing Nature as a ‘universal store of genes’: How biological diversity became ‘genetic resources’, 1890-1940

Christophe Bonneuil (Research Director, Centre A. Koyré, Cnrs-Ehess, Paris Sciences et Lettres Research University) - christophe.bonneuil@cnrs.fr

Abstract

Till late in the 20th century, biological diversity has been understood and addressed in terms of “genetic resources”. This paper proposes a history of this “genetic resources” concept and the biopolitical practices it was related to. A semantic history of the ‘resource’ idiom first sheds light on how, in the age of empires and fossil industrialism, the Earth came to be considered as a stock of static mineral and living reserves. Then we follow how the gene became the unit of this “resourcist” view of biological diversity as static stocks of entities open to prospection, harnessing and “conservation”. Erwin Baur, Nikolai I. Vavilov, Aleksandr S. Serebrovsky and Hermann J. Muller were key biologists who introduced a spatial turn to the gene concept. Beyond the space-time of Neo-mendelian and Morganian laboratory genetics, genes became understood through a geographical gaze at a planetary scale. The world became a “universal store of genes” (Vavilov, 1929). From 1926 to World War 2, this advent of genes as new global epistemic objects went hand in hand with genes’ new modes of existence as geopolitical objects. The article documents Interwar years’ scramble for genes as well as first collaborative international efforts to conserve and exchange genetic material (which prefigured post WW2 initiatives), and situates the rise of the ‘genetic resources’ category within mid 20th century’s imperialism, high-modernism, agricultural modernization and biopolitics.

Seeing Nature as a ‘universal store of genes’: How biological diversity became ‘genetic resources’, 1890-1940

1. Introduction

In signing the Convention on Biological Diversity in 1992 in Rio, the international community identified as its objectives

the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources...
(Convention on Biological Diversity, 1992, Art 1.)

From the first FAO technical conferences on genetic resources in the 1960s to the institutionalization of the issue of biodiversity conservation internationally, the “proper use” of global nature was framed by the ideas of inventory, conservation, and use of its “components”, or “genetic resources”. While post-WW2 genetic resource conservation science and politics have already been widely studied (Fenzi & Bonneuil, 2016; Peres, 2016; Curry, 2017), the aim of this paper is to propose a deeper history of “genetic resources” as a category, i.e. the emergence of a genocentric and resource-centric ontology of the planet’s biological diversity. I explore how in the age of empires and the industrialization of living things¹, the Earth came to be considered as a reservoir of genes and life conceptualized as a stock of entities open to surveying and conservation in centralized institutions. Section 2 outlines how life became a static “resource” in 19th-century fossil industrialism’s new cosmovision. Section 3 sketches out how the unit of biological diversity shifted from species to varieties, traits and genes at the turn of the 20th century. Section 4 examines how Russian geneticists such as Nikolai I. Vavilov (1887-1943) and Aleksandr S. Serebrovsky (1892-1948) developed a “genogeography” that located genes within “genofunds”, comparable to oil reserves, that were to fuel Soviet agricultural modernization. Section 5 further analyses how the gene concept became a spatial and global object, and how European and US breeders and geneticists came to conceptualize the world as a “universal store of genes” (Vavilov, 1992[1929], p. 167). Section 6 documents the scramble for genes as a geopolitical race as

¹ On different perspectives on the entry of living entities into the realm of industrial capitalism in which experimentalization, industrialization, and commercialization went hand in hand, see Bud, 1994; Kloppenborg, 2004; Bonneuil, 2016.

well as calls and initiatives to organize the conservation of genetic resources at an international level in the 1930s. I conclude with discussing the category of ‘genetic resources’ and its central function in mid-20th century’s modernism and biopolitics.

2. The Earth as ‘stocks’ and ‘resources’: seeing nature like an industrialist

Where did the notion of living beings as “stocks” and “resources” come from? “*Ressource*” first appeared in the French language in the Middle Ages, while “livestock” emerged within English law and economic discourse in the 16th and 17th century to refer to a movable property of a farm or plantation. However, it was not before the end of the 18th century that “resource” and “livestock” underwent the major semantic shifts towards their current meaning.

Adam Smith elaborated the notion of “stock” in its most generic sense. For him, the division of labour was the key factor in the increase of wealth, but it required the possibility for specialized producers to accumulate “a stock of goods of different kinds” before they could receive payment from the sale of their own production (Smith, 1776, p. 327). Economists such as Heinrich Friedrich von Storch, who taught the wealth of nations to the future Tsar Nicholas I, and Frenchman Jean-Baptiste Say equated the English term “stock” with the French “*fonds*” (fund), a large and generic category, of which both capital and money were sub-categories:

We understand under the term of fund (*fonds*) any accumulated stock of wealth. A house, a workshop, a supply of food or staple, raw materials, manufactured products, commodities of all kind, constitute funds as much as an amount of money. When a fund is dedicated to the material production, it takes the name of capital (Storch, 1823, p. 207; see also Say, note 1 in Storch, 1823, p. 207).

This generic economic concept opened the way for conceptions of living beings as “stocks” or “funds” commensurate with capital. The wide use and the modern meaning of “resource” emerged in the following decades, hand in hand with a new industrial world order and world view. The industrial revolution’s shift in energy base from renewable energies to coal not only installed a new form of capitalism, it also progressively changed how the Earth and its beings were represented (Malm, 2016). Coal deposits differed from human, animal, wind, and hydraulic power in three important ways: they were inert reserves; they were docile

and predictable; and they could be seen as external to society since they came from another space (under the ground) and time (a deep geological past). This consolidated a great dualist divide between a dynamic *society* and an external inert (or slow) *Nature*. While early modern scientists considered the subsurface as a uterus where ores dynamically took shape (Merchant, 1980), industrial modernity saw mineral resources as originating from very ancient natural processes, now standing like Sleeping Beauties waiting for the industrialist's kiss to awaken them. Such a view was in line with liberal economists' category of "stock" and allowed various kinds of "natural resources" (minerals but also increasingly living beings) to be talked about using metaphors such as "deposit", "resources" and "warehouse".

The semantic history of the word "resources" illustrates this shift. This word appeared in the English language in the 17th century. It was an import from the French "*ressource*", a substantive of the verb "*ressourdre*", meaning to rally, to raise again², originating from the Latin *resurgere* ("rise again", "revive", or even "resurrect"). In Old French, "*ressource*" designated a recourse or a means used to face a difficult situation or, in falconry, the bird's flying up after descent, or also the ability to make a new intellectual, physical or financial effort³. In every sense of the word in both French and English, the idea of "resource" related to a dynamic upward movement of resurgence. A new static meaning of the word was established only very progressively, from the end of the 18th century to the end of the 19th century, hand in hand with a new wave of European imperialism and the ascent of fossil stock energy over flow energies (muscle, water and wind power, all originating from solar radiation), as documented by Christophe Bonneuil (forthcoming). Interestingly, the semantic field of "livestock" shifted in a similar way from its original (16th century) meaning of strain, with its dynamic notion of engendering, towards a more static meaning in the 19th century⁴.

In that respect, while late 18th-century authors such as Adam Smith and Edmund Burke provided early uses of "natural resources" as measures of the assets of competing

2 <http://www.etymonline.com/index.php?term=resource> and Oxford English Dictionary <<http://www.oed.com>>, accessed June 27, 2017.

3 See: Littré, 1874, p. 1674 ; see also: <http://www.cnrtl.fr/etymologie/ressource> and *Trésor de la langue française informatisé*: <http://atilf.atilf.fr/>

4 See <<https://www.etymonline.com/word/livestock>> and <<http://www.oed.com>>, accessed January 7, 2018

nations, their use of this idiom more often implied the former dynamic meaning (what rises again) than the new one (standing reserve). It took some more decades for the static meaning of “resource” to spread and become predominant in the writings of Victorian authors and colonial/commercial science journals (Cooper, 2011). Among them, John Yeats’ much re-edited *The Natural History of Commerce* exemplifies this new world view of the Earth as standing resources. He describes the technical and economic value of world resources viewed as “raw materials” and “elements of wealth” that pre-exist human labour:

In speaking of the natural resources of any country, we refer to the ore in the mine, the stone unquarried, the timber unfelled, the native plants and animals — to all those latent elements of wealth only awaiting the labour of man to become of use, and therefore of value (Yeats, 1870, 2).

Acclimatization societies, which were flourishing in the second half of the 19th century, extended this resource-centred vision of the globe from minerals to living entities. They undertook a kind of ecological re-engineering of the planet (Osborne, 1994; Tyrrell, 2004). Since antiquity, there had been a two-sided Western vision of nature: either a dynamic poietic process in *natura naturans* or a fixed product in *natura naturata*. With Linnaeus, species became the units of the *natura naturata* perspective (Müller-Wille, 2003). Whether dead or alive, these units were accumulated in imperial institutions and set in motion around the globe. “I cannot control the expansion of Kew herbarium”, Kew Gardens’ director explained in 1899, “because I cannot control the expansion of Empire... The expansion in the two fields is necessarily correlated” (quoted by Drayton, 2000, p. 264). Botanists and zoologists pictured overseas territories as storehouses of potentially useful animal and plant species to be inventoried, extracted and transported. Bequeathed from the past, they were “reserves of the future” as the director of the French National History Museum put it:

The inhabitants of the old world fix their eyes upon these virgin regions where nature is so rich and whose resources remain unutilized (...) we must increase the holdings of forthcoming generations, through the exploitation of the resources from the territories newly seized by France and where the reserves of the future are sleeping. (Milne-Edwards, 1893, p. 8)

Overseeing vast collections that they described as treasures, and eager to have their scientific expertise recognized as a tool for empire, naturalists tended to correlate the wealth of territories with the abundance of – potentially valuable – species. They played a key role in conceptualizing and redesigning diverse local and dynamic socio-ecologies as “natural resources”, whose units were species that could be abstracted from their initial socio-ecological attachments. Considering that Nature, God or evolution had distributed species

quite chaotically, naturalists hence endeavoured to survey and relocate, whenever possible, in every part of the globe, any species from any other part of the world that could be useful and productive in its new location. This global project and these knowledge practices construed (living and mineral) resources as kinds of global public goods to be developed for the well-being of the entire humanity. This scaling up of the resource concept took place within imperial discourses which increasingly justified colonialism through the argument of the inability of non-European peoples to make full use of their “natural resources”, now viewed as standing reserves, unevenly distributed throughout the globe, and waiting for the Western industrious and technologically superior (white) man to “develop” them (Drayton, 2000; Ross, 2017).

To sum up: from 18th-century political economy to early 20th-century colonial science, the concept of “natural resources” underwent significant developments from something of a dynamic character (financial and human means, soil fertility, and dynamics of production) to something static to be discovered, classified, improved and resettled. For minerals, but also living beings, the Earth became a storehouse of “dormant reserves” to be harnessed and put into motion by global (imperial) enterprises.

3. From species to varieties, traits and genes as the units of life diversity around 1900

Besides a representation of Nature as a stock, the 20th-century concept of “genetic resources” entails the additional idea that its diversity is primarily located at the gene level. From Linnaeus to late 19th-century inventories of colonial resources, species were the units of wealth in the eyes of naturalists who explored exotic territories or administered imperial botanical and zoological collections. However, Darwinism progressively challenged the ontological relevance of the species category. Furthermore, the story of the transplantation of the cinchona tree—with the Dutch, who had the good fortune to collect a subspecies/variety that was richer in quinine, taking the lead in world production and trade—showed that in the struggle between colonial powers, knowledge of not only species characteristics but also infra-specific traits was a key asset (Drayton, 2000, p. 210 & 246-47).

The director of the newly established US Office of Seed and Plant Introduction stressed this point:

The success or failure of a whole plant industry may depend upon obtaining a variety differing so slightly from others in cultivation that the ordinary observer would fail to detect a difference (Fairchild, 1898. p. 13).

At the same time, transformations of the epistemic space of heredity in the second half of the 19th century led biologists and breeders to focus on the heredity of differences at an infra-species levels, or even at an individual level with pedigree breeding (Muller-Wille & Rheinberger, 2007). Hugo de Vries, a protagonist of the ‘rediscovery’ of Mendel’s laws, was impressed by the isolation of hundreds of distinct stable lineages from a single landrace at the Svalöf breeding station in Sweden. This opened up “the almost inexhaustible wealth that cultivated plants offer to the scientifically educated farmer” (de Vries, 1906, p. 326). Our crops, he explained, “are composed not only of elementary species, as was long known before” but also of “sharply definite types (...) distinct from each other in botanical characteristics as well as in those properties which determine their utility from the breeder’s point of view, and thus they afford a rich material for selection” (de Vries, 1907, p. 93). Hence biological diversity’s wealth came to be located in varieties and lines rather than in species.

As pure line breeding and hybridization methods developed, an additional move came, when species, and even varieties, were increasingly conceptualized not as unitary wholes, but as “materials” harbouring a set of different “traits” that could be isolated and recombined. During the International Congress for Agriculture and Forestry in Vienna in 1890, the agronomist and industrialist Emanuel Ritter von Proskowetz suggested that the diverse crop varieties, which he regarded as “materials” (*Materialien*), be listed in a “sort of race catalogue” and classified (Proskowetz, 1890). The Austrian crop scientist Franz Schindler agreed and suggested creating a network of stations to study these crop varieties and “to test each of their traits and characteristics in terms of value for the breeder” (Schindler, 1890). At Vienna’s 8th international agricultural congress in 1907, Schindler called for “an international committee” to establish guidelines for the “systematic collection and inventory of landraces” and the establishment of a “races catalogue” (*VIII. Internationaler landwirtschaftlicher Kongress Wien. 1907*, p. 282). The congress hence adopted a resolution to that effect and the international committee included E. Ritter von Proskowetz (chair), F. Schindler (Austro-

Hungarian Empire), C. Fruwirth (then based in Germany), E. v. Tschermak (Austro-Hungarian Empire) and É. Schribaux (France), who would all play key roles in later decades (*VIII. Internationaler landwirtschaftlicher Kongress Wien. 1907*, p. 646-649).

Breeding techniques for artificial hybridizations to combine traits from two varieties into one new cultivar developed from the 1880s (Paul & Kimmelman, 1988; Harwood 2012) and then gained scientific legitimacy with the 1900 ‘rediscovery’ of Mendel’s laws. This paved the way for a view of organisms as collections of discrete traits, behaving as self-standing building blocks, to be manipulated and combined by breeders to order, as William Bateson radically expressed it:

The essential point which Mendel discovered in peas, and others are now discovering in various fields of inquiry, is that, though a plant or an animal may be made up of a great complex of characteristics, height, size, colour, hairiness, form of fruits and organs, etc., yet in a very considerable number of cases (...) many different characters in animals or plants which are unit characters, and in the formation of gametes are treated as distinct entities or units. (...) You can take out greenness and put in yellowness; you can take out hairiness and put in smoothness; you can take out tallness and put in dwarfness, etc. (Bateson, 1904, p. 2).

Following on from Bateson, Erwin Baur, the rising star of German genetics, conceptualized biological diversity along Mendelian lines:

The vast amount of races and varieties within a species results from the again and again differing combinations of a relatively small number of mendelizing basic differences (*Grundunterschieden*), the so called factors or genes (Baur, 1914, p. 105)

Hence the task of the “scientific” breeder: to extract by “modern combination-breeding”, from “ancient landraces”, which by themselves were “not suitable for anything”, a “single important trait” such as resistance to a pest or hardiness (Baur, 1914, 107):

We have in our old landraces an abundance of material (*Material*), that will bear a growing importance for future rational cross-breeding (Baur, 1914, 107).

Among advocates of so-called “modern genetics” and “modern breeding”, the idea therefore emerged that, while local varieties were inferior to “modern” cultivars obtained by separation of lineages and/or controlled cross-breeding, and were thus destined to give way to the latter in agricultural landscapes, they were not entirely to be left in oblivion since they harboured useful traits for future breeding. The disqualification of farmers’ landraces as *obsolete* and *unproductive* and their concurrent re-labelling as *gene stores* went hand in hand. Baur hence sounded the alarm on the disappearance of ancient varieties:

The profusion of ancient crop varieties is giving way to an increasingly limited number of selected, undoubtedly highly valuable elite varieties. (...) Although this improvement of our grain varieties and agricultural economy is desirable (...) there is also a dark side to this process. If it were to continue, we would deprive ourselves of the possibility of further enhancements of our cultivated crops. (...) in a few years the best starting material for cross-breeding will vanish (Baur, 1914, p. 104 & 107).

Baur's warning went beyond Germany; it was global in its scope:

What applies to our ancient landraces may apply even more to very primitive cultivated races of wheat and barley, a large quantity of which still exist in the East, particularly in central Russia and Persia, farther in Asia Minor, China, North Africa and Abyssinia. All these landraces cannot hold competition with our elite cultivars, but some of them contain singular traits of great interest that may be extracted (*herausgeholt*) by rational crossings. (...) Most of these varieties will soon disappear with the extension of civilization (...) [and] the wild relatives of cultivated wheat and barley are also in danger of extinction. This is why we must, as long as this is still possible, collect and preserve our landraces and primitive races, and we must also preserve the wild relatives of our cultivated plants which are in danger of extinction (*in Gefahr auszusterben*) (Baur, 1914, p. 107-109).

Baur thus displayed a thorough reflexiveness about the loss of cultivated plants' diversity and a very explicit framing of this problem as a paradox of modern breeding's modernization front, which threatened its own future as it moved forward, sawing off the branch it was sitting on. In the face of this predicament of "modern breeding", he advocated a modern solution: the creation of a state-funded Office (*Zentralstelle*) in charge of "collecting and conserving a large varietal standing collection (*Sortenbestand*)" (Baur, 1914, p. 109). Such a systematic conservation mission, he argued, "cannot be expected from individual practical farmers" and was too expensive for individual breeders. Establishing such an Office (with an annual expense of 5,000 Marks) was a state duty, he concluded, to assist private breeders with upstream research and conservation work, rather than compete with them in releasing public varieties (Baur, 1914, p. 109).

The Austrian breeder Erich von Tschermak, who along with de Vries and Correns had "rediscovered" Mendel's laws, agreed with Baur's warning: initiatives should be taken up "before [local and exotic landraces] totally disappear in the foreseeable future" (Tschermak, 1915, p. 160). He also grounded such measures on the same modernization/replacement story and the same preservation rationale for future breeders' need for "starting material" (*Ausgangsmaterial*):

The pursuit of landrace improvement logically results in the disappearance of those populations (*Formengemische*) with high value, from which the best has not yet been extracted (*herausgeholt*) (Tschermak, 1915, p. 160).

However, Tschermak did not share Baur's preference for a central institution to stock world's landraces and crop wild relatives. He suggested rather that collection, conservation and study of local landraces should be done by provincial stations – both in the Austro-Hungarian Empire and abroad – because otherwise “some typical traits of these varieties would be considerably altered due to change of soil and climate” (Tschermak, 1915, p. 160). Prefiguring the future *in situ* vs *ex situ* debate in genetic resource conservation arenas (Pistorius, 1993; Brush, 2004; Fenzi, 2017), this controversy had been sparked off at the Vienna 1907 Congress. There, Schindler, Fruwirth and Tschermak's views on the limited practical use of pure line breeding clashed with promoters of “modern” pedigree breeding. W. Johannsen, a Dane, and Swede H. Nilsson-Ehle hence did not join the international committee on landraces' collection, conservation and study (cf. *supra*).

This divide between holders of divergent views on how to conserve and use landraces was part of a wider controversy opposing a “local strategy” and a “cosmopolitan strategy” in German-speaking plant breeding, as analysed by Jonathan Harwood. On one side, Baur and other breeders who had collaborations and affinities with industrial millers, private breeders, large agricultural estates in favourable conditions in Northern and Central Germany, developed a cosmopolitan strategy to get outstanding cultivars producing good results practically everywhere (under intensive farming conditions, using mineral fertilizers). Calling themselves ‘scientific breeders’, their breeding goal was the “universal variety” (*Universalsorte*) obtained by crossing varieties from almost anywhere in the world so as to combine favourable traits/genes (Harwood, 2012, p. 45-46). On the other side, breeders from public stations in Southern Germany and Austria, working for small farmers and situated in diverse and less favourable soil and climate conditions, advocated for decentralized forms of breeding for local conditions, with some forms of farmer participation. These peasant-friendly public scientists, such as Carl Fruwirth, had observed that high-yielding English commercial cereal varieties did not behave well in cold-winter continental Europe and hence argued for the improvement of local landraces as a starting point for breeding work (Harwood, 2012, p.46-50). It was precisely this group that pushed to make Vienna's 1907 international agricultural congress adopt a resolution on conserving landraces, which stated that “the local landraces deserve just as much attention as other landraces as well as races obtained by breeding” (Art. 1) and emphasized the study of local ecological adaptation of landraces (Art. 5) and “local-breeding” work (Art. 2) for “smallholdings” (Art. 3) ((*VIII. Internationaler landwirtschaftlicher Kongress Wien. 1907*, p.645-646). However, as was masterfully

documented by Harwood (2012, p. 46-96), the locally-oriented public sector soon came under private breeders' fire and declined in the interwar years, leaving the stage to the private seed sector and Baur's cosmopolitan-oriented views of world landraces as of no value except for some individual genes they might contain.

This cosmopolitan perspective also increasingly became the backbone of the US Office of Seed and Plant Introduction, established in 1898 – the very year when the USA became a colonial power in Hawaii, Puerto Rico, Guam and the Philippines – to “search out new varieties and secure them” through a “comprehensive exploration of the cultivated territory of the globe” (Fairchild, 1898, p. 14). Over the next 25 years, 48 expeditions scoured the world for useful crop varieties (Kloppenborg, 2004, 67). The Office's director, plant hunter David Fairchild, who contributed to the introduction of more than 200,000 exotic plants and crop varieties, viewed plant and animal breeding as “becoming a manufacturing process” for which his task was to furnish “the materials and the tools” (Fairchild, 1905, 92) from all over the Earth. “The time has arrived”, he however argued, when biologists should be “searching the world for living forms which have a bearing upon the plant and animal productive capacity of the civilized world” (Fairchild, 1905, p. 99). An extinction narrative also provided a rationale for the global collecting enterprise:

The disappearance of valuable exotic sorts, whose characters should perhaps quickly be mingled with those of our indigenous ones, make it urgent that the work of introduction be done on a large scale to help the breeders in this unprecedented work of plant and animal breeding (Fairchild, 1905, 99-100).

The Middle East, viewed as the place of origin of major crops, attracted particular attention, and gave rise to the most pressing extinction speeches as well as the boldest promises of new resources. In 1906, the botanist Aaron Aaronsohn claimed to have found a new wild wheat species in Syria. In the hope that “the cultivation of wheat may be revolutionized by the utilization of these wild forms”, via hybridization, to develop new varieties suited to arid zones of the US (Aaronsohn, 1910, p. 52), Fairchild's Office funded several expeditions to the Middle East, soon to be followed by German and Soviet ones. From Palestine, Aaronsohn warned against:

“the danger of the destruction of these races of plants in consequence of the general levelling which is a necessary accompaniment of national awakening and progress” (Aaronsohn, 1910, p. 33).

While World War One put such extinction and conservation concerns on hold, it also (in particular with the famine in Germany during the 1917-18 blockade and the famines of the early Soviet Union) brought food self-sufficiency to the forefront of political agendas. In many European countries, scientists promised self-sufficiency through new crops and varieties containing genes combined from varieties and species collected and brought back from all over the world (Heim, 2002 & 2008; Wieland, 2009). It was in the Soviet Union that the idea of genes as resources unevenly distributed on the planet's surface emerged, along with a set of theories ("diversity centres"), methods ("genogeography"), and practices (collecting and banking) as well as new banking and mining metaphors on biological diversity.

4. Soviet biology, agricultural modernism and the concepts of "genofund" and "resources of genes"

After the First World War and the re-establishment of international scientific relations, the neo-Mendelian particular and combinatory reading of heredity, reinforced by the chromosomic theory, had crowned the gene (allele) as the basic stable building block of variation and heredity in microbes, plants and humans (Müller-Wille and Rheinberger, 2012). It was in this context that the cosmopolitan breeding strategy developed into a "genetic modernisation" project (Flitner, 2003), and that genes became global objects of knowledge and geopolitics under the new category of *genetic resources*. This new category emerged in the work of Nikolai Vavilov and Aleksandr Serebrovsky. Both were heirs of Mendelian "analytical genetics" and Morganian "topographical genetics" (as Serebrovsky, 1929a, p. 162, put it), and both endeavoured to add a third, geographical dimension to the gene. The "genogeography" they developed thus aimed at "*studying the geographical distribution of all genes on the surface of the Earth*" (Serebrovsky⁵, 1929a, p. 162).

Vavilov received training in Mendelian genetics from William Bateson in Cambridge in 1913. For his part, Serebrovsky, strongly influenced by the chromosome theory, became

5 Serebrovsky's 1929a article was later quoted by Sewall Wright, and was a key step towards the synthetic theory of evolution.

the first Russian geneticist to adopt fruit flies as model organisms and suggested a new nomenclature of mutations in decimal mode, inspired by Dewey. Both Vavilov and Serebrovsky belonged to the world-famous interwar generation of Russian geneticists, (Philipchenko, Timoféeff-Ressowsky, Dobzhansky, Levitt, etc.), which until the repression of genetics by Lysenkoism after 1934, received strong support from the Soviet government (Graham, 1993, 129-131; Kremenstov, 1997). Vavilov was president of the Soviet Academy of Agricultural Sciences (VASKhNIL) from 1929 to 1935, while Serebrovsky headed the genetics department of the University of Moscow from 1930 to 1948. In return, these geneticists put their expertise in the service of a state-led fast-paced modernization of the Soviet Union through the overtaking of biological evolution by science and the Plan, in order to develop new productive plants, animals, and communist Man, thanks to applications of eugenics (Adams et al., 2005).

Following the success of the 1920 Congress of Soviet breeders and geneticists, Lenin's government soon founded the appropriately named Pan-Soviet Institute of Plant Industry (VIR according to its Russian acronym), headed by Vavilov. In 1920 and 1921, the USSR endured major crop failures due to civil war and drought. The People's Commissariat of Agriculture of the Russian Republic and Soviet geneticists responded with a large-scale program which included breeding, testing and promoting new productive and drought-resistant cereal cultivars. In June 1921, Lenin issued a decree that ordered local authorities to compile a register of crop varieties, establish experimental stations and accumulate a stockpile of "selected seeds" to pass on to farmers. In December 1927, the government prepared a five-year seed-production plan (Tauger, 2017, 102-103). From 1929 on, the Stalin regime launched its forced farm collectivization policy. The violent "dekulakization" is only the best-known aspect of a broader administrative control extended over agriculture to industrialize Soviet farming, which also included the massive expansion of agricultural research and dirigiste seed policies. These forced farmers to grow only the varieties prescribed by the state under Vavilov's plans (Tauger, 2017, 104). This authoritarian state-led agricultural modernization was inspired by a strong Taylorist ideal, and hundreds of US experts came to help mechanize Soviet farming from 1928 to 1932 (Fitzgerald, 2003). Vavilov belonged to those who spread the industrial gospel:

Breeding had now to be associated with the mass production of pedigree seed and livestock. Factories were set up with the labor and equipment requisite for extensive serial output. (...). From an art, breeding has thus to large extent become an industry or a trade (Vavilov, 1949[1935], p. 3)

Between 1918 and 1937, as part of a wider agronomic technostucture with 1,300 institutions (as of 1932) and research stations funded by the Commissariat for Agriculture, Vavilov's VIR established 35 stations for the study, crossing and selection of varietal resources from all over the world, and for cultivar testing on the vast Soviet territory, employing 1,500 agents (Flitner, 1995, p. 57, Lokustov, 1999). They aimed not only at improving crop yields, but also providing the southern Republics with new crops. This latter goal required them to survey the genes of plants such as rubber, fodder plants, cereals, sunflower, and cotton throughout the world (Vavilov, 1997[1940]).

In the mid-1930s, the VIR possessed over 250,000 accessions. These included 30,000 wheat landraces and wild relatives, as well as cultivars developed by Soviet and foreign breeders. It was the world's first large-scale seed collection, built up over 180 survey missions (140 in the Soviet republics, especially in Central Asia, and 40 in the rest of the world) carried out between 1917 and 1940 (Tauber, 2017, 101). Similar missions were also organized to collect animal races, such as the 23 poultry missions headed or initiated by Serebrovsky between 1925 and 1933 in Central Asia.

Vavilov and Serebrovsky thus benefited from a favourable context on three levels: i) *intellectually*, as 1920s Soviet biology was at the forefront of the world's most advanced genetics research; ii) *geographically*, since the Soviet Union bordered three of the main centres of origin of cultivated crops in the world, while the United States bordered only one and Germany none; iii) *politically*, with the support from a state pursuing a productive conquest of territory and political control over the peasantries. Vavilov and his colleagues managed a gigantic network of stations and collection sites throughout the world. At the crossroads of these three driving forces, genes became not only objects of laboratory knowledge and state policy but also new *epistemic objects* of a global "genogeography" and new *policy targets* in interwar world politics.

In 1926, following several major missions (Iran and Pamir in 1916, North America in 1921, Afghanistan in 1924, and Uzbekistan and Turkmenistan in 1925), Vavilov published a study on the "*Centers of Origins of Cultivated Plants*" (Vavilov 1992[1926]). He revisited the botanical geography approaches of De Candolle using not only the presence of neighbouring species but also the infra-species level to identify the centres of origin of cultivated plants: a centre of origin is characterized by the great concentration of forms (sub-species, "races" or varieties) that co-exist in it. Thus, "establishing the distribution of the hereditary variants of

the forms of a species” makes it possible to determine “the geographical centres of accumulation of varieties” (id., p. 32). With this method, Vavilov proposed five centres of origin for most of the world’s cultivated species (p. 127, see figure 1), as well as centres of secondary diversification (subsequent to domestication, but also rich in diversity). Lastly, he challenged the previous assumption of a Middle Eastern origin for soft wheat, by situating its centre of origin on the southern flanks of the Himalayas.

<Insert here> Figure 1 . Vavilov’s 1926 five centres of origin (Vavilov 1992[1926], p. 127)

Vavilov argued that the knowledge of “specific distribution and the foci of the genes (...) can be of practical value” for breeding work (id. p. 34). However, apart from this quote, Vavilov’s 1926’s work did not use the word “gene.” His method was based on taxonomy, not genetics. He only recast his theory in genic terms from 1927 on, under the combined influence of his trip to Abyssinia (1926-27) and the work of his colleagues Chetverikov and Serebrovsky.

Indeed, Chetverikov had published a seminal article in 1926. Following the work of Herman Muller on artificially induced mutations, he deduced that mutations must also occur in natural populations, at low frequency (Chetverikov, 1961[1926], p. 170). They are, for the most part, made invisible by their recessive nature and the fact that “a species, like a sponge, absorbs heterozygous mutations, while appearing (phenotypically) homogeneous from the outside” (id., p. 178). All other things being equal, without selection nor isolation, “the older a species is, the larger its number of accumulated mutations” (id., p. 178). Noting that a rapid reduction of the size of a population increased the likelihood that two individuals carrying the same recessive mutation reproduced, Chetverikov then stressed the role of geographical isolation in making visible new traits from the – thin and often recessive but continuous – “torrent” of mutations (id., p. 178-179. See also p. 192).

The path opened by Chetverikov enabled his colleague from Moscow’s Experimental Biology Institute, Serebrovsky, to align this new knowledge of gene mutations with Vavilov’s geographical study of agricultural resources. Following Chetverikov’s call to move genetics from the laboratory to natural populations and explain evolution in terms of frequency of

genes in time and space, Serebrovsky developed a research program that he named “geographic genetics or genogeography” (Serebrovsky, 1929a, p. 162). In 1925, he set off to study the *in situ* distribution and frequency of alleles in poultry raised in Central Asia. While for the first authors of what came to be known as population genetics, such as G.H. Hardy and W. Weinberg, the “p” constant referred to the frequency of a phenotype in a population, it was used by Serebrovsky to refer to the “gene concentration”, i.e. the frequency of given alleles within genotypes of a population in a given region (Serebrovsky, 1929a, p. 167, see Fig. 1).

Vavilov welcomed this genic discretization of his botanical geography, since it enabled him to introduce a cutting-edge genetics perspective into his geobotanical work and make it more visible to an international community of geneticists that was increasingly drawn to Morganian and mutationist theories. In 1927, Vavilov thus “Mendelized” his views and presented Linnaean species and the “races” that they contained as “systems of genes”, focusing on their “concentration” (Vavilov, 2009[1927], p. 71 & 77). He then revisited his theory, characterizing the centres of origin not only by their great diversity of varieties and species, but also by the abundance of dominant genes, and the centres of secondary diversification by a great diversity of recessive genes. This was in accordance with Chetverikov’s idea of the genic richness of the ancient centre of the species, with the more visible appearance of recessive traits resulting from a migration and isolation process. Vavilov noted that the centres of origin of cultivated plants were also regions settled by darker-skinned human races (he considered white skin, like blue eyes, to be a recessive trait):

The Northern type seems like the result of the failing of the dominant genes. Proportionally to the spread of isolation, proceeds the accumulation of recessive forms. Thus arise recessive boreal types. As if by physical dispersion, spreading through space, proceeded the division of the original dominant forms, the individualization of recessive forms (Vavilov, 2009[1927], p. 75).

This understanding – then quite common as racial theories turned Mendelian – echoed frequently occurring comments in Vavilov’s travel reports about the low degree of civilization in the regions he visited (Vavilov, 1997[1940]). This eventually produced a great genetical-Orientalist narrative of the evolution of both plants and human societies as a “decrease in the number of dominant genes from the centres to the periphery of dissemination” (Vavilov, 2009[1927], p. 74-75), explaining civilization as the skimming of recessive, yet superior, genes:

The concentration itself of an abundance of genes in the centres where the forms have originated, not always favours harmonious combinations in the sense of the

plant breeder. This may be the reason for the poor agricultural value of the Asiatic and African varieties, of the low degree of culture shown by the peoples living in the ancient seats of agriculture. The cultivated type in the scheme is the recessive type, as is perfectly obvious in plants, animals, and people themselves. (Vavilov, 2009[1927], p. 78)

The civilization process was thus explained not simply in racial, Darwinist terms, but more specifically by a cosmovision in which genes, as stable, mutable, discrete and commanding units, played a central role in the formation of a superior race destined to rule the globe:

From a general cultural-historical point of view this process was positive, having given rise to the great cultures of the North. Genetically they have, being recessive in the composition of their genes, brought under their control the potentially richer conglomerates of genes of the initial peoples living in the primary seats of human culture. (Vavilov, 2009[1927], p. 78)

The theory of centres of origin and the global undertaking to collect genes were thus included in the framework of an imperial project, which entitled “superior” races carrying recessive genes to take control over resources from regions inhabited by primitive populations. The civilized Northern races, with their reduced number of dominant genes, were called upon to take control over richer gene stocks from the less-civilized regions, exploiting these stocks and re-instilling certain primitive genes most valuable to their modern agriculture.

Vavilov viewed his work as an exploration of “centres where the genes of cultivated plants are accumulated” (Vavilov, 1992[1927], p. 157). This search for “the area where the maximum accumulation of its elements of diversity is located” (Vavilov, 1992[1929], p. 160), and the characterization of centres of origin as places of accumulation of dominant genes, and secondary centres as places of accumulation of recessive genes, shifted ways in which life’s diversity was understood. Biological diversity became seen as genes’ *stock*, *reserve*, *fund*, or even *capital* of world interest, all of which are metaphors projecting political economy, finance or the mineral resource extraction industry onto living organisms.

Aleksandr Serebrovsky was the first to explicitly develop these analogies in 1926 when he coined the Russian term *genofond* (Adams, 1979). Against neo-Lamarckians, he advocated “the significant durability and constancy of genes” and argued that the wealth of the USSR came not only from the production of wheat or cows, but also from “people who

carry out work of a certain quality” (Serebrovsky, 1926, p. 115 and 115-116). Serebrovsky introduced (with 13 occurrences) the term *genofond* to refer to the sum total of genes behind this national human capital:

This question is especially important when we move to the ‘higher’ levels of human creativity such as art, science and organization (...) And if these elements actually rest on a basis of heredity, then we have every right to look upon the totality of such genes which create in human society talented outstanding individuals, or to the contrary idiots, as national wealth, a gene fund [*genofond*] from which the society draws its people. It is clear that (...) we must see if there are processes operating within the gene fund which are changing it (Serebrovsky, 1926, p. 116) (

Serebrovsky viewed USSR’s population as a gene pool where the best genes had to be surveyed and amplified via eugenic policies. He chastised the first Five-Year Plan because it cared about reserves of gas, oil, and minerals but “completely left out the tabulation of the biological quality of the population of the Soviet Union”, and suggested that “cleansing our country’s population of various forms of hereditary ailments” and “the widespread induction of conception by means of artificial insemination using recommended sperm” would create a new and superior Soviet Man that would fulfil economic plans more quickly (Serebrovsky, 1929b, resp. p. 7, 12, and 16).

This concept of *Genofond* derived from Serebrovsky’s practices of geographic mapping of poultry genes in various Republics towards “a study on the *genofond* of farm chickens in the USSR” (Serebrovsky, 1927, quoted by Adams, 1979, p. 262). Genogeography was a tool to map genes and their frequencies across administrative districts and countries, and promised a science-based management of genes - now viewed as akin to other natural resources - in the service of economic planning and development (Fig. 2).

<Insert here> Figure 2. Frequencies (“concentration”) of chicken alleles across Dagestan: a) left : alleles *sune* (upper circle) and *tuge* (lower circle); b) right: alleles *sune* (upper circle) and *weque* (lower circle). From Serebovski, 1929a, p. 167.

The new idiom of *genofond* was adopted by several speakers during the conference on agriculture that took place in Leningrad in December 1927, under the auspices of the KEPS, the Commission of the Academy of Sciences on the study of productive natural forces (Adams, 1979). Following this conference where geneticists gathered with geologists (headed by the geochemist Vladimir Vernadsky, the KEPS had by then organized hundreds of mining and geological surveys), Serebrovsky reiterated a view of domestic animals' "gene fund" as akin to a fossil fuel reserve:

In order for the reserves of various genes in a given locality to be preserved for a long time, we must look upon this stock as a kind of natural resource, similar to reserves of oil, gold, coal and other. Precisely in order to emphasize this side of the matter, three years ago we proposed the special term gene fund (*genofond*). Under the term gene fund we include the sum total of hereditary assets, genes, of any group of organisms. Thus one can speak of the gene fund of large horned cattle of a given geographical area, region or republic, etc. (...) Finally out of the total gene fund those categories of genes can be singled out which relate to any special characteristic of interest – speaking of the gene fund for milk output, wool, meat, etc. (Serebrovsky, 1928, 6-7).

Echoing KEPS efforts at inventorying rare strategic metals of the Mendeleev table (radium, etc.) and extracting bromine, or even gold, existing in low concentrations in the seas⁶, Serebrovsky further developed his extractivist metaphor:

We stand on the shores of a boundless sea. Thousands of different valuable and armful entities – genes – are floating on its surface (...). The name of this sea is the gene fund of livestock. To recognize, understand, and master its shifting, extremely complex life, is our glorious task! (Serebrovsky, 1928, quoted by Adams, 1979, p. 262)

5. The gene as global object. Planet-wide talk of genetic resources in the 1930s

6 Brome was extracted from the Dead Sea from the 1900s on, and scientists worked hard to extract other metals from oceans.

Endorsing Before the 1,500 participants at the Congress of Soviet geneticists and breeders, Vavilov regretted that geneticists, having restricted their focus to laboratories and stations, “have, so to say, bypassed these international gene-bank deposits”, by which he meant centres of origin and diversification. And he called for “gaining control over a universal store of genes” (Vavilov, 1992[1929], pp. 166-167).

“Resource of genes”, “deposit”, “gene bank”, “stock”, “fund”, “deposit” or “reserve” to be mined: the category of “genetic resources” was born. This category, which enacts a mining and banking ontology of the diversity of living things, was disseminated internationally thanks to the growing internationalization of genetics (Krementsov, 2005). At Berlin’s 5th International Congress of Genetics in 1927, in front of over a thousand participants from 35 countries, Vavilov framed the “problem concerning the location of the centres of variability of various species” as a challenge for the “mastering of the original material of forms, i.e. the genes of cultivated plants.” (Vavilov, 1992[1927], p. 144).

As of the late 1920s, the idiom *genofond* entered the vocabulary of breeders and geneticists. Vavilov talked about the “world *genofond*” as the accumulation of a “diversity of traits, or more precisely of genes” (Vavilov, 1929, quoted by Adams, 1979, p. 263). The Russian neologism spread rapidly in biology literature in German (as “*Genofond*”). In 1931, the botanist Alexander Zämelis discussed the importance of “the circulation of the genes” (gene flow) within species or even from one genus to another, and discussed changes in the “*Genofond*” from the centres of origin to their periphery (Zämelis, 1931). The director of the Czech potato breeding station regretted the shrinking of the “*genofond*” available to the breeders (Figna, 1936, p. 21). In 1937, an article in the *American Journal of Potato Research* noted with satisfaction that:

The world genofund of *S. tuberosum* L., as regards the creation of early and productive varieties of potatoes, may be considered to have been utilized to a quite exhaustive extent by the combined efforts of potato breeders of all countries (Veselovsky, 1937, p. 296).

The word “*genofund*” also appeared in English in the 1930s, though less frequently⁷. From this word, in 1950, Dobzhansky derived the expression “gene pool”, which became a central concept in population genetics and in the theory of evolution (Adams, 1979).

Apart from “gene fund” or “genofund”, the notion of “genetic heritage” (“patrimoine génétique” in French, and “Erbmasse” in German) also emerged during the first third of the 20th century. In the 19th century, *Erbmasse* was used in German for all the elements of an inheritance, before the term moved from the legal to the biological field after 1900 to designate an individual’s genetic make-up. Another German term, *Genbestand*⁸ (*Bestand* then meaning fund or stock) appeared in 1921, meaning genetic stock and designating all the genes of a genotype⁹. From the 1930s onwards, the terms “*Erbmasse*” and “genetic heritage” came to refer not only to the genetic make-up of an individual, but to that of a population, race, or species, thus coinciding with the meaning Serebrovsky gave to *genofond*. While the current expression “genetic resources” seems to have developed only after 1945, it is clear that the idea, the category, emerged in the interwar years: following Vavilov’s focus on “resources of genes” (“*ressources des gènes*”, Vavilov, 1928, p. 375), the 1930s saw a rich semantic field establishing the genetic make-up of a species as a fund, a reservoir or a heritage.

An early promoter of the gene concept and of a mechanism of evolution centred on the gene, the eugenicist and American geneticist Hermann Muller, offered his own planetary scaling up of genocentrism. Like Vavilov, he considered the whole set of genes of a species, throughout the Earth, as an object of knowledge and power. In 1935, in *Out of the Night: A Biologist's View of the Future*, Muller explained that the DNA of all eggs and sperm cells that would determine the “next generation of mankind” amounted to “the size of an aspirin tablet”. In this tiny physical space, although “scattered over the face of the earth in several billion separate bits”, there “actually lie all the inheritable structures for determining and for causing

7 An example can be found in *Herbage Reviews, Commonwealth Bureau of Pastures and Field Crops*, vol.1-2, 1933, p. 69.

8 The first occurrence of *Genbestand* has been traced back to a publication by Jollos in 1921.

9 This term was to be widely replaced after 1945 by that of *Genom* (genome), which was also crafted in the 1920s.

the production of all the multitudinous characteristics of each individual person of the whole future world's population" (Muller, 1935, pp. 19-20). Muller's plea for modernizing humankind via eugenic policies went hand in hand with promises of a genetic re-engineering of crops for modernizing agriculture:

The surface of the earth will be overlaid with luxuriant crops, at once easy to raise and to gather, resistant to natural enemies and climates, and readily useful in all their parts... herbs could eventually be converted into trees and trees into herbs... (id., pp. 75-76).

6. The scramble for genes as geopolitical objects: cooperation and competition

Just before winning the Nobel Prize, Thomas Hunt Morgan had promoted "the incorporation of genes from wild varieties and species into strains of domesticated types" as one of the five promising future avenues for genetics (Morgan, 1933, p. 103). In the two decades following Vavilov's 1926 landmark work, global powers, seeking to optimize and industrialize their agriculture, launched many initiatives to collect the world's plant resources and establish the first collections consisting of thousands of varieties for each cultivated species and its wild relatives. In 1930, Otto Frankel, a breeder trained under Erwin Baur and hired by New Zealand, echoed these initiatives. He observed that "in those parts of the world where many of our cultivated plants originated, and where they have till now the largest ranges of varying forms (...) new forms may be found which will prove of unforeseen use to the plant-breeder in combining species as well as varieties". Noting that the USSR, Germany and the USA had "embarked on extensive collections", he advocated for "the establishment of a central institution for collection and classification of cultivated plants" for the British Commonwealth of Nations (Frankel, 1930, 406).

The US Department of Agriculture also became a major global player in gene-hunting expeditions and the establishment of large seed collections. Its 1936 *Yearbook of Agriculture* presented the USDA's views and strategy, in the form of a report from its "Committee on Genetics". Facing a severe agricultural crisis, Henry A. Wallace had set up this Committee soon after he became Roosevelt's Secretary of Agriculture. A private corn breeder himself, Wallace trusted "that the day will come when humanity will take as great an interest in the creation of superior forms of life as it has taken in past years in the perfection of superior forms of machinery" (USDA, 1936, p. 120). Popularizing the expression "germ plasm" and

containing the word “reservoir” for genes ten times, the report emphasized “the importance of large and varied collections of seeds from all over the world”. It also made technical proposals “to maintain source material over any length of time” so that “if present collections were kept up”, “our descendants hundreds of years hence would be able to reproduce the plants grown today” (id., p. 129). USDA scientists proudly reported that since 1900 “the Department has brought in more than 8,000 introductions of wheat” from abroad and that “nearly 5,000 of these are still available, as viable samples are maintained by growing them every 5 years” (id. p. 132). As for barley, the USDA “maintains a viable collection of more than 3,000 varieties” but the report noted that:

The Old World contains many forms of barley not yet secured by American breeders and it is essential that these should be obtained as rapidly as possible, especially since many of the forms in this rich reservoir of source material are continually being lost through economic changes. (id. p. 133-34)

Together with Mary L. Martini, Harry Harlan, a breeder and gene explorer who had become friends with Vavilov, proposed a diagnosis of world barley resources that echoed Baur and Vavilov’s warnings about vanishing gene resources:

In the great laboratory of Asia, Europe, and Africa, unguided barley breeding has been going on for thousands of years (...). The progenies of these fields with all their surviving variations constitute the world’s priceless reservoir of germ plasm. It has waited through long centuries. Unfortunately, from the breeder’s standpoint, it is now being imperiled. When new barleys replace those grown by the farmers of Ethiopia or Tibet, the world will have lost something irreplaceable (Harlan & Martini, 1936, p. 315).

Hence the report’s conclusion: “breeding and genetics” become “a function of governmental institutions capable of devoting the necessary money and time” (USDA, 1936, p. 123-4) and the maintenance of germplasm collection “is a natural Federal function” (Harlan & Martini, 1936, p. 315), since:

In the future, the well-being of a nation will depend more and more on the vigor and adequacy with which it carries on this task of improving the forms of life on which it depends to feed, clothe, and house its people (USDA, 1936, p. 123-4).

As in the USSR, the US biopolitical project to optimize living beings was framed as a national biopolitical modernization project. As in the USSR, it rested upon a planetary strategy (the 1936 report mentions several gene-hunting expeditions and the sending of questionnaires to dozens of agricultural institutions across the world; Clark, 1936, 209), and it went hand in hand with an explicit geopolitical vision in which germ plasm had become an object of international competition:

Like every other science, the modern science of heredity is international (...). Some of the most valuable of our present-day varieties of plants in the United States, for example, trace their parentage back to far and obscure places. Scientists search the earth for breeding material that will be useful in improving

the products grown in their own country. From its rivals, a nation may get the wheat germ plasm or the cotton germ plasm that enables it to supply its own needs or overwhelm those rivals in international trade (id. p. 123).

In a context of growing protectionism, the geopolitics of the race for genes among world powers indeed became more tense in the 1930s. And the USSR's most active follower and fiercest competitor was Germany. The head of the Kaiser Wilhelm Institute for plant breeding, Erwin Baur, together with a flourishing community of geneticists and plant breeders, promised the new science would provide solutions for food self-sufficiency policies. In 1932, he ordered a police check on foreign visitors to his institute because they might pose "a threat of economic espionage" (Flitner, 1995, p. 70). By then a facility to conserve germ plasm, modelled on Vavilov's VIR, had already been envisioned by the Kaiser-Wilhelm-Gesellschaft (it was only set up in 1943). Baur himself travelled to collect plant resources: Turkey in 1926; Spain in 1928, Russia in 1929; and South America in 1930-31, where he collected about 1,000 potatoes for further breeding work (Elina *et al.*, 2005, p. 165). In the following years, collection missions were sent to the Hindu Kush (1935/36), Ethiopia and Eritrea (1937/38) and Tibet (1938/39).

During the war, Nazi plant scientists worked for food (and starvation) and agriculture planification and organized a systematic pillage of genetic resources in the occupied territories, with SS "collection units" visiting 18 former Soviet institutions to seize plant resources (Wieland, 2009; Heim, 2008, 173). One vivid example of the fierceness and global character of the competition for genetic resources, before and during World War Two, is the scramble for alternative rubber resources. In 1931, when Vavilov collected guayule in Mexico, a US rubber company orchestrated "a campaign in the Mexican press about the 'plundering of national treasures by the Bolsheviks'" (Vavilov, 1997[1940], p. 147). The same year, a VIR mission in Central Asia brought back a few seeds of Kok-Saghyz (*Taraxacum bicorne*), a latex-producing plant. In 1941, the USSR cultivated over 50,000 acres of this plant. At the end of the 1930s, German and American researchers and authorities heard about this new cultivation of a strategic raw material and asked the VIR, to no avail, for seeds. During the blockade of Leningrad, while biologists commissioned by the Kaiser-Wilhelm-Gesellschaft pillaged the resources of the VIR station close to the city, the Soviet army exfiltrated by plane part of the main collection of the Institute located in the city. This included the Kok-Saghyz seed collection, to prevent it from falling into German hands (Elina

et al., 2005, p. 169). SS officers however managed to seize Kok-Saghyz seeds in the occupied USSR and a rubber-breeding station was established near Auschwitz, employing 150 women from the concentration camp as workforce (Wieland, 2009 ; Heim, 2008).

Against this backdrop of fierce rivalries and thefts, “resources of genes” also emerged as a new object of internationalist discourses. At both Berlin’s International Congress of Genetics and the International Conference on Wheat in Rome in 1927, concluding his study of the “pattern of the world distribution of wheat genes”, Vavilov (1928, p. 370) advocated for international collaboration for the collection and harnessing of “resources of genes”. He called for “international institutions [which] could best deal with such scientific surveys” in centres of diversity (Vavilov, 1928, p. 375; see also Vavilov, 1992[1927], p. 157).

Following Rome’s International Conference on Wheat, the International Association of Plant Breeders (ASSINSEL) was founded in 1927, with Vavilov sitting on the Board of Directors. It soon included hundreds of members from over 30 countries. One of the main objectives of the ASSINSEL, in addition to lobbying for plant breeders’ patents rights, was to write “an international catalogue of the most interesting varieties” as the “material from abroad” was a “real mine” for breeders in every country (Schribaux, 1929, p. 191¹⁰). The ASSINSEL established itself as a clearing house for exchanging genetic material. The association’s bulletin published the list of varieties that Vavilov’s VIR, the Wageningen Institute of Plant Breeding, Nazareno Strampelli’s Institute of Genetics in Italy, the Tunisian Botanical Service, and a few others agreed to send upon request¹¹.

In 1931, a new international partnership was initiated for the potato. The ASSINSEL established an “international commission for the study of the potato”, whose mission was to constitute a library of filing cards describing all the varieties of this crop, their origins,

10 See also ASSINSEL’S by-laws in *Bulletin de l’Association internationale des sélectionneurs de plantes de grande culture*, 1(1), p. 9

11 See *Bulletin de l’Association internationale des sélectionneurs de plantes de grande culture*, 3(1), April 1930, pp. 27-30.

genealogy and properties. The idea of creating a world collection, a “world assortment (*Weltsortiment*), emerged in this context (Rathlef, 1931), and the issue of the conservation of landraces was put onto the agenda, resulting in the adoption of a resolution in June 1931:

The General Assembly of the International Association of Plant Breeders, meeting in Berlin in 1931, considers that the conservation of local varieties is one of the most important current issues for plant breeders. Most of the landraces are currently about to disappear completely as a result of progress in agriculture. This would represent an irreparable loss for plant breeders. The representatives of the different nations ask that a request be addressed to each government to bring together and preserve local varieties that still exist in these countries (Christiansen-Weniger, 1931, p. 323).

These international interwar initiatives to survey and conserve genetic resources occurred in a wider context when mineral resource appraisal and international policy on raw materials had come onto the agenda of the League of Nations. A rising professional community of geologists, workers union representatives and economists advocated “a program to rationalize world economy” (Krahmann, 1927, quoted by Westermann, 2015, p. 165) via technocratic and international management of these resources, and proposed in 1927 the creation of an “International Mining Institute” modelled on the International Agricultural Institute of 1905. This illustrates an additional circulation of ideas and categories between mineral resource experts and crop experts, both embarking on new global kinds of knowledge production and policy instruments to find out and manage “what the whole world contains” (US Geological Service, 1921 quoted by Westermann, 2015, p. 164). Indeed, the work to map centres of crop diversity from 1926 echoed the global inventories made by the International Geological Congress for iron (1910), coal (1913), phosphate (1926) and copper (1935) (Westermann, 2015).

The tension born in the 1900s between a “local strategy” and a “cosmopolitan strategy” of breeding, which we have documented above thanks to Harwood’s work (2012), led to a tension running through these international interwar initiatives, between what would later – from the 1960s on – be called *in situ* and *ex situ* conservation. Opposing the cosmopolitan strategy, Carl Fruwirth called for a more decentralized scheme for the conservation of the world’s landraces. In 1927, he managed to convince the International Wheat Conference’s genetic commission to issue the following resolution:

The commission suggests that the International Institute of Agriculture shall encourage the creation of a central office in each country for the conservation of

landraces. Each country shall choose its own best way to conserve, as long as the landraces are conserved as much as possible in their region of origin. These landraces shall be conserved in absence of breeding work (Fruwirth, 1928, 157).

Similarly, ASSINSEL Berlin's June 1931 resolution leaned more towards *in situ* than *ex situ* landrace conservation for extracting genes, since it recommended that "enlightened farmers and institutes will have to cultivate old local varieties, in the regions of origin and according to old cultivation methods, on a sufficiently large surface" rather than in a few centralized sites (Christiansen-Weniger, 1931, p. 323). However, major "cosmopolitan" geneticists and breeders such as Baur, Vavilov, Schribaux, Strampelli, Frankel and Harlan took over: the years from 1933 to 1945 were dominated by "imperial" gene-hunting expeditions and large centralized collections of resources, acting like Bruno Latour's "centres of calculation", which paved the way for *ex situ* approaches after World War Two.

Finally, in the interwar period, both imperial forms of gene hunting associated with the scramble for genes among rival world powers and the – embryonic and short-lived – international initiatives (organization of transfer of material under the aegis of the ASSINSEL, efforts towards world lists of varieties, international calls in 1927 and 1931 for the conservation of landraces) prefigured – and provided the frameworks for – post World War Two policies, at European (Saraiva, 2013), American (Curry, 2017) and also global (FAO and then CGIAR) levels (Pistorius, 1993; Fenzi & Bonneuil, 2016; Fenzi, 2017).

7. Genetic modernism: "Genetic resources" as a modernist cosmovision

Helen Curry has powerfully argued that the history of post-World War Two collection and banking of genetic resources cannot be told as a separate history from that of the industrialization of agriculture. Seed banks, she wrote, were "a crucial addition to the technologies of industrial production" (Curry, 2017, p. 84). "The maintenance of genetic diversity, as a potential resource in a bank" was in the service of "the extension of more genetically uniform types over greater portions of the globe ... in a world where many people wanted crop plants to be as uniform and un-diverse as possible" (id. p. 112-113). The present paper further shows that it was actually in an earlier period, 1890-1940, that the 'genetic resources' category – if not yet the exact wording – emerged hand in hand with fossil and imperial world-ecology. I conclude by providing a more systematic analysis of how the idea

of “resources of genes” (Vavilov) embodied and enacted new ontologies, narratives and power/knowledge of “genetic modernizations” (Flitner, 2003), which I propose to call more precisely “genetic modernism” (informed by James C. Scott’s conceptualisation of “high modernism”, Scott, 1998).

Scientific claims and objects are, as Bruno Latour (2013) has argued, means by which the Moderns have talked about themselves and about the world. They constitute scripts, processes of joint definitions of epistemic objects, technical artefacts, and their social and ecological environment, that we can *de-script*. For Madeleine Akrich (1992) these scripts create a program of action for which various entities are mobilized to behave in certain ways, towards more or less explicit objectives; they asymmetrically distribute (and ‘naturalize’) competencies and causal relations between these different entities and actors, hence building up a canvas of interpretation of the world. In this perspective what are the ontologies, competencies and roles assigned to the various human and non-human entities and what is the cosmovision which got scripted into the framing and handling of crop diversity as *genetic resources* in the first decades of the 20th century (with long-standing effects)?

A **first element** of the *genetic resources* script is to **consider plants as “machinery”**: **an assemblage of traits determined by genes which need to be optimized in order to carry out an ambitious state-led modernization of agriculture** (from US Progressive Era plant breeding to the Soviet Great Break and green revolutions in Europe and in developing countries, Harwood, 2012; Flitner, 2003). The evidence provided in this paper suggests that it is no coincidence that the most modernist promoters of science and state intervention to modernize agriculture and discard less performant varieties from landscapes were also the voices calling for collection of genes around the world and their conservation in central institutions. Far from willing to preserve landraces for some kind of intrinsic value of diversity or cultural heritage, Vavilov, as well as Baur, Frankel and other leading geneticists and breeders, insisted instead upon controlling the bricks from a remote past to build modern cultivars:

By knowledge of the past, by studying the elements from which agriculture has developed, by collecting cultivated plants in the ancient centres of agriculture, we seek to master the historical process. (...) The investigator wishes to find the primary elements, ‘the bricks and mortar’, from which the modern species and varieties were created. (...) We study the construction of primitive agricultural implements in order to get indications for the construction of modern machinery. In brief, the historical problems of this origin of agriculture, of the origin of cultivated plants and domesticated animals are especially interesting for us in the

sense of mastering and controlling the breeding of cultivated plants and animals. (Vavilov, 1931).

The head of the German Hindu Kush expedition in 1935 that collected 4,000 samples, the plant geneticist Arnold Scheibe, also illustrates how standardizing genetic landscapes and global (imperial) enterprises of gene collecting went hand in hand. After spending two years in Turkey collecting and studying plant resources, he took a position in the Registry Office of Plant Varieties (*Sortenregisterstelle*) of the Nazi Reich Food Estate (*Reichsnährstand*). There, he implemented the 1934 Seed Decree, which ensured that only the ‘best’ varieties of each crop were allowed on the List of Approved Varieties (*Reichssortenliste*), and that only the varieties on it could be sold as seeds. The result was a massive reduction in the number of varieties in German landscapes, hence following the Soviet example (Harwood, 2012, 103-106). In his report of the “Hindukush expedition” (through Turkey, Syria, Iraq, Afghanistan and India) Scheibe explained that this region was a key site for collecting primitive forms because “the regions of origins of our cultivated plants are located only in certain places of our globe”. He noted that modern crops in Europe had lost original traits such as hardiness due to “the influence of a cultural high-breeding (*kulturellen Hochzüchtung*) (...) for massive yield”, hence the need to cross them with their “parental forms, which despite their primitiveness as related to performance (*leistungsmässiger Primitivität*) do carry the needed resistance traits in the form of the corresponding hereditary factors (*Erbfaktoren*)” (Scheibe, 1937, 3).

In this narrative, landraces were *both* agronomically obsolete (“ancient landraces” were by themselves “not suitable for anything” as Baur (1914, 191) had put it) *and* valuable stocks of genes. “In order to approach the ideal wheat variety”, Vavilov argued, the modern breeder aims at “combining in one variety a majority of valuable characters” (Vavilov, 1949[1935], p. 265). Similarly, Otto Frankel argued for a “modern” plant breeding strategy aiming at:

combining in one form all those useful characters which Nature distributed over many forms often derived from various countries or even continents (Frankel, 1930, p. 402)

This view of crop diversity as building blocks leads to a **second element** of the *genetic resources* script: it **frames biological (crop) diversity ahistorically as a set of static units**

rather than as a complex ecological (and cultural) process, as 19th-century biologists including Darwin saw it (a view now endorsed by many 21st-century crop diversity conservation scientists: 2010; Brush, 2004; Fenzi & Bonneuil, 2016). Enshrined in the notion of *genetic resources* was early 20th-century genetics' farewell to Darwin's historical and dynamic view of "variation under domestication". New genetics' ahistorical view of heredity was a shift from the slow space-time of co-evolution of crops and their socio-ecological environments to the industrial space-time of gene combination and mass production of standard pure line genotypes (Bonneuil, 2016). This meant geneticists had to obscure the dynamic and historical nature of the processes that generated biological diversity in crops and rather cast it as an untouched relic from a distant past. As Harlan wrote shortly before his death in 1944, "For immeasurable years these things have waited for us. They have stayed as they are because near isolation has been the lot of mankind in the barley centres of Asia and Africa until now" (Harlan, 1957, p. 88). Analogies between genetic resources and oil reserves were more than a strategy to attract public attention to their economic value: they conveyed a view of biological diversity as a gene fund, an ahistorical stock of genes inherited unchanged from a deep past. *Genetic resources* hence told the story of a great modernist divide between static (or very slow) Nature and world-changing, scientific, "modern" (white) "Man". The philosopher Peter Sloterdijk has diagnosed a kinetic utopianism at the heart of modernity: "The entire movement of the world is to be the performance of our [modern] design for it" (Sloterdijk, 1989, 23) while the agency of non-modern beings and things is denied. The USDA's 1936 report on "superior germ plasm" offers a vivid illustration of genetic modernism's "kinetic nihilism" (Sloterdijk, 1989, 23) that overshadowed the dynamic dimension of biological diversity. It situated the genes in a cosmovision that expanded gene constancy on a new – planetary – space scale as well as a new – geological – time scale and dramatized scientists' power to put "the old stock" of nature in motion:

As time is measured in the age of the earth or of man, the scientists who deal with heredity came on the scene only a few minutes ago, but already they have managed to do a great deal. (...) [T]hey have developed out of the old stock a large number of new forms (...) and looking into the future, they can see far richer possibilities... (USDA, 1936, p. 119)

This erasure of the historicity and embeddedness of what connects organisms through time and space behind the modern figure of an autistic gene – unchanged by the environment nor by farmers – gave scientific authority to seed dirigiste policies which redesigned genetic landscapes to render them more homogeneous and more productive, in line with what James C. Scott (1998) has analysed as the "high-modernist" project: industrial principles of

standardisation, state intervention and scientists' skills claimed to outperform nature, speed up evolution and render peasant societies legible and governable.

From Baur to the Green Revolution, a **third key element** of the *genetic resources* script was **the assumption that local varieties would inexorably be swept away by breeders' cultivars**, due to the latter's superiority. As Tschermak put it, modern breeding "logically results in the disappearance of those populations (...) from which the best has not yet been extracted" (Tschermak, 1915, p. 160; see also Baur, 1914). Documenting that, in areas like Mexico (maize) and Peru (potatoes), after 50 years of "green revolutions", landraces' diversity was maintained by farmers' *de facto* conservation rather than displaced by so-called "elite cultivars", recent genetic, eco-anthropological research has called this modernist narrative into question (Brush, 2004; Fenzi, 2017). While not a case for the absence of global loss of crop diversity, this suggests that, from early warnings by Proskowetz and Baur to late 20th-century dedicated treaties and institutions, a *genetic resources* extinction narrative took shape, which dramatized the inexorability of "modern" (industrial) agricultural production and the power of genetics professionals and state intervention to transform landscapes. A leading UN expert in genetic resource conservation in the 1950s-70s, trained by Erwin Baur in the 1920s, Otto Frankel was a key player in passing on this modernist narrative in the framing of crops' biological diversity, from the interwar period to the Green Revolution era. At the first UN conference on conservation and utilization of resources in 1949, he made sure that "genetic resources" were put onto the agenda along the lines of Baur's and Vavilov's framing:

it is highly desirable that all genetic resources should be preserved for future generations. Our very efforts of producing high-yielding strains have the effect of reducing the variability of a species (...) Collection, survey and conservation of the world's gene resources are essential for providing breeding material for ourselves and further generations (Frankel, 1950, p. 91 & 100).

The genetic resources script hence conveyed the narrative of an all-powerful and world-changing Green Revolution. Challenging this modernist narrative through a compelling study of farmers' *de facto* management of genetic maize diversity in Mexico, Marianna Fenzi has recently proposed that the Green Revolution be "provincialized" (Fenzi, 2017).

Fourth, the *genetic resources* category also helped **co-produce a new global kind of knowledge and a new geopolitical object**. From a laboratory/station object, this turned the gene concept into a global geographic object and a new policy issue. Based on the model of global appraisals of mineral resource deposits, biological diversity became seen as a set of genes unevenly distributed across the planet. The epistemic/political work to constitute breeding as a professionalized activity, done on a planetary scale, and to upscale the gene concept as a global resource, went hand in hand with epistemic/political work to script “landraces” as local objects, being both idiosyncratic, contingent, non-optimal and threatened. Framing population varieties as “local” helped extract from them (out of their particular socio-ecological entanglements) new immutable objects (genes, registered cultivars) that could be regulated by states and circulate globally in the breeders’ socio-technical network and longer-distance food chains. Some plant breeders resisted this globalist and genocentric view and advocated ecological perspectives on landraces’ adaptation as well as their local conservation and improvement, especially in environments that were less amenable to industrial agriculture. But they were sidelined in agricultural scientific institutions (Harwood, 2012) and more work is needed to shed light on these neglected research avenues which later led to what is now called *in situ* approaches to crop diversity conservation (Pistorius, 1993; Fenzi, 2017).

As the gene went global, population varieties shifted from peasant societies’ commons to “rich material” for breeders, and therefore a medium of value to be extracted and transformed. What unites the writings of Vavilov, Nazi scientists (who claimed in 1941 to “safeguard” the VIR seed collection in occupied Leningrad while they plundered it for the Reich: Wieland, 2009, p. 25), USDA and ASSINSEL (for a large part) is that they framed crop diversity as a kind of global public good, rather than variations to be locally experienced, studied or governed. “Resources of genes” were a scattered bounty to be globally managed by experts in the name of all humankind and future generations. Vavilov did not conceal the kind of imperialism and primitive accumulation at play when white nations, made up of “superior” recessive genes, undertook to collect “resources of genes” and “control the potentially richer conglomerates of genes of the initial peoples” (2009[1927], p. 78). He urged for “the removal of barriers impeding research in those most remarkable regions of the world” (Vavilov, 1932, p. 342). In a context of rising protectionism after the Great Depression, the USDA called for free exchange of germ plasm “material” instead of “bitter rivalries and more deadly conflicts” (USDA 1936, p. 123). Shame on those communities and those countries who resisted the

global predicament of gene prospecting and gene exchanges since these resources were viewed as humankind's common heritage! In 1949 Otto Frankel advocated that FAO make "provision for the collection and classification in non-participating and especially in primitive countries (...) which are still awaiting full exploration by collecting expeditions" and dreamed of a day when "the world's gene resources will, for the first time, be available to the whole world" (Frankel 1950, 91-92). Key to genetic modernist discourse was that double scaling-up of both *genes as global resources* and the future needs of *humanity as a global whole*.

Last but not least, **a fifth key aspect of the genetic resources script is the very limited agency attributed to farmers, in both breeding and maintaining diversity.** As stated by Baur, conservation "cannot be expected from individual practical farmers" (Baur, 1914, p. 109). While most recent genetic, anthropological and archaeological works emphasize the active and inventive role peasant communities have played for millennia and still play today in crop diversification and evolution under domestication (Brush, 2004), this creative and innovative agency was downplayed by 'modern' breeders and geneticists, who depicted crop diversity as mostly resulting from "natural" mechanisms and "unconscious" or "unguided" practices.

Commenting on "the importance of Aaronsohn's discovery" of the wild wheat in Palestine, the Swiss geneticist R. Chodat boasted:

it will allow us to do methodically in a few years all that 6,000 years of cultivation and unconscious selection have gained for us and perhaps also to combine and associate characters which escaped the intuitive observations of primitive peoples (Chodat, 1913, p. 44).

Similarly, the wheat expert of the USDA 1936 report explained that during the Neolithic Age:

the major improvements in the plant were made, not by the cleverness of man, but by the slower processes of nature. Probably primitive farmers found the plant a rather superb product at the time they began cultivating it (Clark, 1936, p. 208).

Disqualifying farmers' knowledge – past and present – was a way of dramatizing the scientificity and power of the new genetics. As a sequel, 'informal' has become current scientists' buzzword to refer to farmers' management of crop diversity. The *genetic resources* discourse assigned farmers an identity as simple users and consumers of innovations. In this high-modernist farmer/scientist, past/present, static/innovative and nature/culture divide, "ancient landraces" (Baur, 1914, 107) were on the side of nature (and the past) while scientifically improved cultivars were on the side of culture (and the future). Since farmers

were denied any agency on genetic landscapes, farmers' management of diversity and the entangled bio-cultural drivers of *in situ* dynamics of crops' genetic landscapes were poorly investigated by researchers until well into the 20th century (Brush, 2004): only 'formal' breeders self-represented themselves as wizards of genetic circulations between living forms. In 20th century breeders' stories about genetic resources, only they – via repeated back-cross, mutagenesis or cross-species hybridization – could cause genes to circulate efficiently from one variety or species to another. Only they and not farmers could make – supposedly static – nature move, on demand. Only they could design conservation plans for crop diversity and they would do so at the global level.

The *genetic resources* concept therefore embodied great divides between primitive immobility and modern mobility, between resources and innovation, between passive peasants and active scientists, between local commons going to waste or extinction and a global public good to be managed, between nature and culture, between a static earth and its mobilization by imperial technoscience. It was within that particular and situated framework of interpretation of the world and living beings that the issue of crop diversity emerged as a public concern in the first half of the 20th century, setting the frame for post-1945 practices, policies and discourses on genetic resource conservation.

Acknowledgements

I thank Greg Radick, Jonathan Harwood, Steve Brush, and Helen Curry for their very useful comments on earlier versions of this paper.

References

- VIII. *Internationaler landwirtschaftlicher Kongress Wien. 21-25 Mai 1907. Organisation.* Vienna: Versay, vol. 1
- Aaronsohn, A., 1910. "Agricultural and botanical explorations in Palestine". *Bulletin of the Bureau of Plant Industry (USDA)*, 180, 1–64.
- Adams, M. B. (1979). "From 'gene fund' to 'gene pool': On the evolution of evolutionary language", *Studies in History of Biology*, 3, 241-285.
- Adams, M. B., Allen G. A. & Weiss S. F. (2005). "Politics and Science in Wartime: Comparative International Perspectives on the Kaiser Wilhelm Institute", *Osiris*, 2nd Series, 20, 232-262.

- Akrich, M. (1992). "The Description of Technical Objects", in: W. Bijker & J. Law (eds), *Shaping Technology/Building Society. Studies in Sociotechnical Change*. Cambridge: MIT Press, 205-224.
- Bateson, W. (1904). "Practical aspects of the new discoveries in Heredity", *Memoirs of the Horticultural Society of New York*, 1 (Proceedings of the International Conference on Plant Breeding and Hybridization, 1902), 1-8.
- Baur, E. (1914). "Die Bedeutung der primitiven Kulturrassen und der wilden Verwandten unserer Kulturpflanzen für die Pflanzenzüchtung", *Jahrbuch der Deutschen Landwirtschafts-Gesellschaft*, 29, 104-118.
- Bonneuil, C. (2016). "Pure lines as industrial simulacra. A cultural history of genetics from Darwin to Johannsen", in C. Brandt, S. Mueller-Wille (eds), *Heredity Explored. Between Public Domain and Experimental Science, 1850–1930*, Cambridge, MA: MIT Press, pp. 213-242.
- Bonneuil C. (Forthcoming). "Resourcing the world : Constructing and governing planet Earth as (limited) 'resources' in the age of fossil capitalism and empire", under review.
- Brush, S. (2004). *Farmers' Bounty: Locating Crop Diversity in the Contemporary World*, New Haven, CT: Yale University Press.
- Chetverikov, S. S. (1961[1926]). "On Certain Aspects of the Evolutionary Process from the Standpoint of Modern Genetics", *Proceedings of the American Philosophical Society*, 105(2), 167-195 (first published in Russian in 1926).
- Chodat, R. (1913). "A grain of wheat", *Popular Science Monthly*, LXXXII, Jan 1913, 33-45.
- Christiansen-Weniger, F. (1931). "Bedeutung der Landsorten für die Pflanzenzüchtung », *Der Züchter*, 3(10), 321-323.
- Cooper, T. (2011). "Peter Lund Simmonds and the Political Ecology of 'Waste Utilisation' in Victorian Britain", *Technology & Culture*, 52(1), January 2011, 21–44
- Curry, H. A. (2017). "Breeding Uniformity and Banking Diversity: The Genescapes of Industrial Agriculture, 1935–1970", *Global Environment*, 10(1), 83-113.
- Drayton, R. H. (2000). *Nature's Government: Science, imperial Britain, and the 'improvement' of the world*. New Haven: Yale University Press.
- Fairchild, D. (1898). *Systematic Plant Introduction. Its Purposes and Methods*. USDA. Washington: Gov. Printing Office.
- Fairchild, D. (1905). "Plant and animal introduction", *Am. Breeders' Assoc. Annu. Rep.*, 1, 92-100.
- Fenzi, M. & Bonneuil C. 2016. "From 'Genetic Resources' to 'Ecosystems Services': A Century of Science and Global Policies for Crop Diversity Conservation", *Culture, Agriculture, Food and Environment*, 38(2), pp. 72–83.
- Fenzi, M. 2017. *Savoirs, politiques et pratiques de la biodiversité cultivée : l'émergence de la conservation des ressources génétiques (1943-2015)*. PhDiss., EHESS.
- Figna, R. (1936). "Aktuelle Fragen der Kartoffelzüchtung", in *Congrès International des Sélectionneurs de Plantes. Pays-Bas, 22-27 juin 1936*, Leyden: E.J. Brill, 20-22
- Fitzgerald, D. (2003). *Every Farm a Factory: The Industrial Ideal in American Agriculture*. New Haven: Yale University Press.
- Flitner, M. (1995). *Sammler, Räuber und Gelehrte: die politischen Interessen an pflanzen genetischen Ressourcen, 1895–1995*, Frankfurt/M: Campus-Verlag.
- Flitner, M. (2003). "Genetic Geographies: A Historical Comparison of Agrarian Modernization and Eugenic Thought in Germany, the Soviet Union, and the United States", *Geoforum*, 34(2), 175-185.
- Frankel, O.H. (1930). "Genetics and plant-breeding", *New Zealand Journal of Science & Technology*, 11, 401-408.

- Frankel, O.H. (1950). in *Proceedings of the United Nations Scientific Conference on the Conservation and Utilization of Resources, Lake Success*, New York, United Nations, vol. 6, 89-102.
- Fruwirth, C. (1928). "Zur Frage der Erhaltung unserer Landsorten", *Pflanzenbau*, 5(11-12), 157-150.
- Graham, L.H. (1993). *Science in Russia and the Soviet Union: A short history*. Cambridge, MA., Cambridge University Press
- Harlan, H.V. & Martini M. L. (1936). "Problems and results in barley breeding", in *Yearbook of agriculture*. Washington DC: US Government Printing Office, 303–346.
- Harlan, H.V. (1957). *One man's life with barley*. New York: Exposition Press.
- Harwood, J. (2012). *Europe's green revolution and others since*. London: Routledge.
- Elina, O., Heim, S. & Roll-Hansen, N. (2005). "Plant Breeding on the Front: Imperialism, War, and Exploitation", *Osiris*, 2nd Series, Vol. 20, 161-179.
- Heim, S. (2008). *Plant breeding and agrarian research in Kaiser-Wilhelm-Institutes, 1933-1945. Caoutchouc, Calories, Carriers*. Springer.
- Kloppenburger, J. R. (2004). *First the Seed: The Political Economy of Plant Biotechnology, 1492-2000*. (2d ed.) Cambridge: Cambridge University Press.
- Krementsov, N. L. (1997). *Stalinist Science*. Princeton (N.J.): Princeton University Press.
- Krementsov, N.L. (2005). *International science between the World Wars: the case of genetics*. London: Routledge.
- Littré, É. (1874). *Dictionnaire de la langue française*, t. 4, Paris : Hachette.
- Malm, A. (2016), *Fossil Capital. The Rise of Steam-Power and the Roots of Global Warming*, London: Verso Books.
- Merchant, C. (1980). *The Death of Nature: Women, Ecology and the Scientific Revolution*, San Francisco: Harper.
- Milne-Edwards, A. (1893). *Leçon d'ouverture de l'enseignement spécial pour les voyageurs*, Paris : Imprimerie Nationale
- Morgan, T.H (1933), "The rise of genetics", in *Proceedings of the Sixth International Congress of Genetics, Ithaca, New York, 1932*. Menasha and New York, vol 1, 87-103.
- Muller, H.J., 1935. *Out of the Night: A Biologist's View of the Future*. New York: Vanguard Press.
- Müller-Wille, S. (2003), "Nature as a marketplace: The political economy of Linnaean botany," *History of Political Economy*, vol. 35 (Supplement), 154–172.
- Müller-Wille, S. & Rheinberger H.-J. (2007). "Heredity – The Production of an Epistemic Space", in S. Müller-Wille and H.-J. Rheinberger (eds.), *Heredity Produced. At the Crossroads of Biology, Politics and Culture, 1500-1870*. Cambridge, Mass: MIT Press, 3- 34.
- Müller-Wille, S. and Rheinberger, H.-J.. 2012. *A Cultural History of Heredity*. Chicago: University of Chicago Press.
- Paul, D.B. & Kimmelman, B.A. (1988). "Mendel in America: Theory and Practice 1900-1919", in K.R. Benson, J. Maienschein & R. Rainger (eds) *The American Development of Biology*. Philadelphia: University of Pennsylvania Press, 281–310.
- Pistorius, R. 1993, *Scientists, plants and politics. A history of the plant genetic resources movement*. Rome: IPGRI.
- Proskowetz, E. Ritter von (1890). "Welsches Werthverhältnis besteht zwischen den Landrasse landwirtschaftlicher Culturpflanzen und den sogenannten Züchtungsrassen ?", *Internationaler land- und forstwirtschaftlicher Kongress zu Wien 1890*. Section I : Landwirtschaft. Subsection Pflanzenbau, Frage 5. Vienna, 1890, Heft 13, 3-18.

- Rathlef, H. von (1931). "Über die Sortenkarthothek des Weltsortiments der Kartoffel und Wege zu ihrer Verwirklichung", *Bulletin de l'Association internationale des sélectionneurs de plantes de grande culture*, 4(3), 263-264.
- Ross, C. (2017). *Ecology and Power in the Age of Empire: Europe and the Transformation of the Tropical World*. Oxford University Press.
- Rudwick, M. (2005). *Bursting the limits of time. The reconstruction of geohistory in the age of revolution*. Chicago: Chicago University Press.
- Saraiva, T. (2013). "Breeding Europe. Crop Diversity, Genebanks, and Commoners", in: N. Disco & E. Kranakis (eds.), *Cosmopolitan Commons. Sharing Resources and Risks across Borders*. Cambridge/MA: MIT Press, 185-212
- Scheibe, A. (ed.). 1937. *Deutsche im Hindukusch: Bericht der Deutschen Hindukusch-Expedition der Deutschen Forschungsgemeinschaft 1935*. Berlin: Siegmund.
- Schindler, F. (1890), "Welches Werthverhältnis besteht zwischen den Landrassen landwirthschaftlicher Culturpflanzen und den sogenannten Züchtungsrassen?" *Internationaler land- und forstwirthschaftlicher Kongress zu Wien 1890*. Section I: Landwirtschaft. Subsection Pflanzenbau. Frage 5. Vienna, 1890, Heft 13, 19-24.
- Schribaux, E. (1929), "Projet de rédaction d'un catalogue des meilleurs blés, soumis à l'assemblée générale tenue à Prague, le 25 juin 1928", *Bulletin de l'Association internationale des sélectionneurs de plantes de grande culture*, 1(5), 191-192.
- Scott, J. C. (1998). *Seeing like a state. How certain schemes to improve the human condition have failed*. New Haven: Yale University Press.
- Serebrovsky, A. S. (1926), "Teoriia nasledstvennosti Morgana i Mendelia i marksisty", *Pod znamenem marksizma*, 3, 98-117.
- Serebrovsky, A. S. (1928). "Genogeographia i genofond sel'skokhoziaistvennykh zhivotnykh SSSR" (Genogeography and the genofund of farm animals), *Nauchnoye slovo*, 9, pp. 3-21.
- Serebrovsky, A. S. (1929a). "Beitrag zur geographischen Genetic des Haushuhns in Sowjet-Russland", *Archiv für Geflügelkunde*, t. 3, 161-169.
- Serebrovsky, A. S. (1929b). "Antropogenetika i evgenika v sotsialisticheskom obshchestve" (Anthropogenetics and eugenics in a socialist society), in *Trudy kabineta nasledstvennosti i konstitutsii cheloveka pri mediko-biologicheskome institute*, I (supp. to *Mediko-biologicheskii zhurnal*, 1929, no. 5), 3-19.
- Sloterdijk, P. (1989). *Eurotaoismus: zur Kritik der politischen Kinetik*. Berlin: Suhrkamp.
- Smith, A. (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations*. London: Strahan & Cadell.
- Storch, H. F. von. (1823). *Cours d'économie politique, ou Exposition des principes qui déterminent la prospérité des nations, avec des notes explicatives et critiques par J.-B. Say*, vol. I., Paris : J.-P. Aillaud.
- Tauger, Mark B. (2017). "Pavel Pantelimonovich Luk'ianenko and the Origins of the Soviet Green Revolution, in de Jong-Lambert, W. & Krementsov N. (eds) *The Lysenko Controversy as a Global Phenomenon. Genetics and Agriculture in the Soviet Union and Beyond*. Palgrave, Vol. 1, 97-127.
- Tschermak, E. von. (1915). « Über die Notwendigkeit der Sammlung und Erhaltung unserer bewährten, noch unveredelten Getreidelandrassen », *Wiener Landwirtschaftliche Zeitung* 104 (29 déc. 1915), 759-761.
- Tyrrell, I (2004). "Acclimatisation and Environmental Renovation: Australian Perspectives on George Perkins Marsh", *Environment and History*, 10(2), 153-67
- USDA (1936). "Better Plants and Animals. Survey on Superior Germ Plasm", in *Yearbook of agriculture*. Washington DC: US Government Printing Office, 118-1141.

- Vavilov, N. I. (1992[1926]). "Centers of origins of Cultivated Plants", in N.I. Vavilov, *Origins and geography of Cultivated Plants*, Cambridge Univ. Press, 22-135.
- Vavilov, N. I. (1992[1927]). "Universal centers of a wealth of types (genes) of cultivated plants" (Berlin, Sept. 1927), in *Origins and geography of Cultivated Plants*, Cambridge Univ. Press, 144-157.
- Vavilov, N. I., (1928). "Les centres mondiaux des gènes du blé", *Actes de la 1ère Conférence internationale du blé. Rome, 25-30 avril 1927*. Rome: Institut International d'Agriculture, 368-376.
- Vavilov Nicolai I., 1992[1929]. "The problem concerning the origin of cultivated plants as presently understood" (at the Leningrad Soviet Congress of Genetics, Jan. 1929), in *Origins and geography of Cultivated Plants*, Cambridge Univ. Press, 158-172.
- Vavilov, N. I. (1931). "The Problem of the Origin of the World's Agriculture in the Light of the Latest Investigations", in *Science at the Crossroads: Papers Presented to the International Congress of the History of Science and technology Held in London from June 29th to July 3rd, 1931 by the delegates of the U.S.S.R*, London: Frank Cass and Co. (<http://www.marxists.org/subject/science/essays/vavilov.htm>, accessed Jan. 17, 2017)
- Vavilov, N. I. (1932). "The Process of Evolution in Cultivated Plants", *Proc. VI Int. Congr. Genetics*, 1, 331-342.
- Vavilov, N. I. (1949[1935]). "The scientific basis of wheat breeding", in *The origin, variation, immunity and breeding of cultivated plants. Selected writings of N. I. Vavilov*, Waltham (Mass.), published in *Chronica botanica*, 13(1), 1949-1950, 170-314.
- Vavilov, N. I. (2009[1927]). "Geographical regularities in the distribution of the genes of cultivated plants. Preliminary communication", 1927 article in English and Russian republished in *Comparative Cytogenetics*, 2009, 3(1), 71-78.
- Veselovsky, I.A (1937). "Some new achievements in breeding potatoes for earliness", *American Journal of Potato Research*, 14(9), 295-297.
- Westermann, A. (2015). "Geology and world politics: mineral resource appraisals as tools of geopolitical calculation, 1919-1939." *Historical Social Research* 40(2), 151-173.
- Wieland, T. (2009). "Autarky and Lebensraum. The political agenda of academic plant breeding in Nazi Germany", *Journal of the History of Science and Technology*, 3, 14-34.
- Yeats, J. (1870). *The Natural History of Commerce*. London: Cassel Petter & Galpin

Fig. Basic centers of origin of the most important cultivated plants in the Old and the New Worlds. 1. Southwestern Asia; 2. southeastern Asia; 3. the Mediterranean area; 4. Abyssinia and Egypt; 5. mountain areas of South America and Mexico.