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Saving the gene pool for the future: Seed banks as archives

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Ensuring the salvage of future sources is a challenge for plant geneticists and breeders, as well as historians and archivists. Here, this suggestion is illustrated with an account of the emergence, in the mid-20th century, of seed banks. These repositories are intended to enable the conservation of the world's crop genetic diversity against the 'genetic erosion' of crops, an unintended consequence of the global uptake of new high-yielding Green Revolution agricultural varieties. Plant breeders and scientists advocated a strategy of freezing and long-term storage of seed which enabled the salvage of genetic diversity for future users without requiring the continual cultivation of old varieties: seed banking could preserve valuable genetic material and enable agricultural modernisation to proceed. This account of crop genetic conservation therefore shows how breeders and geneticists sought to create their own seed archives from whence the evolutionary history of crops could be made accessible in ways that are useful for the future. This analysis suggests that conservation practices are informed by ideas about the future use of material, indicating that there is value in exploring concurrently the archival and historiographical issues relating to the biomolecular big biosciences.

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1. Introduction

This special issue invites us to reflect on the links between the archiving of historical sources of the big molecular biosciences and methodological and historiographical issues relevant to the writing their histories. This account, that explores seed banks as archives of crop genetic diversity, demonstrates a similar interest in the relationship between preserving records and using them in the natural sciences suggesting that there are parallels between seed banking and ongoing efforts to preserve written and material records of genomic science (discussed by Shaw, this volume).

This account shows how matters of future use value are enmeshed in conservation strategies and structures; so, considering the connections between practices of archiving and the futures of archived materials is a helpful step when contemplating how best to preserve the future archives of the molecular biosciences (on archival collections as the result of forecasting and prediction of the necessities of 'future historians' see de Chadarevian, this volume). Hence, the emergence of seed banks as a method for genetic conservation represents an interesting case study for reflecting on the efforts to archive the records of the large, collaborative biomolecular biosciences which emerged later.

In this paper, I explore how seed banks were imagined as a response to the problem of genetic erosion and argue that seed banking was seen to both preserve and make available genetic diversity so that it could be used within the modern paradigm of scientific breeding, working with the shift to more globalised agricultural methods. Therefore, seed banks can be seen as archives of genetic diversity that made the past accessible as future sources for scientists and breeders by creating 'records' of the evolutionary history of crops through the freezing of seeds. In this way, the potential value of these resources could be accumulated for extraction at a later date through the use of contemporary technology. The case of seed banks demonstrates how strategies of conservation were also determined by the ways in which people expected to use these materials in the future.

Geoffrey Bowker (Bowker, 2005, p. 110) and Waterton and colleagues (Waterton, Ellis, & Wynne, 2013, p. 110) have identified

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seed banking as part of a broader drive to archive and represent biodiversity in databases of data and material in the 20th and 21st centuries. Drawing on Derrida's work in *Archive Fever* (Derrida, 1996), they point to the contradiction between our development of ever-greater memory stores and concurrent large-scale loss of biodiversity. Such repositories promise a comprehensive representation of life in databases of unprecedented breadth and integration, yet do not, and cannot, accommodate a complete set nor represent the complexity of biological diversity (Bowker, 2005; Waterton et al., 2013). As these databases become the source of knowledge for action to protect nature, that which is not represented on the database is beyond the scope of action, resulting in a process of convergence (Bowker, 2005) between the world and its representation. Thom van Dooren develops a similar critique of seed banks, arguing that '[t]heir objective has simply been to make genetic resources available for human use, not to conserve agricultural environments and diversity in any fuller sense of these terms.' (Van Dooren, 2009).

However, understanding the implications of seed banking as a conservation approach requires historical accounts that can show what banks *were* envisioned to do (and how), and contextualise their origin. In order to determine how seed banks have been imagined to do genetic conservation (strategically and in practice) I overviewed the arguments made for and against this approach. I focus especially on the vision of the plant breeder and emphatic advocate of gene banking, Otto H. Frankel (1900–1998). According to the plant geneticist J. G. Hawkes, Frankel 'really invented the concepts of the genetic conservation of plants useful to man' (Hawkes, 2002: xviii). He was central to the efforts to organise 'genetic conservation' from the 1960s onwards and is credited with bringing together the International Biological Programme (IBP) and FAO (the United Nation's Food and Agriculture Organization) 'in the common cause of halting 'genetic erosion' and conserving 'genetic resources' (Crute, 2004), Moreover, '[h]e was prominent in moves to establish a network of regional genetic resource centres under the aegis of the Consultative Group on International Agricultural Research, and the subsequent formation of the International Board for Plant Genetic Resources' (Crute, 2004).

Frankel's publications are sources of historical detail about the imaginary of seed banking: he was a prominent advocate for this strategy, expounded his view of its purpose and practices, and addressed others' critiques of this approach. The aim of this analysis is to bring to the fore actors' narratives about the purpose of genetic conservation, and how seed banking was assessed as a means to undertake such a project. This analysis therefore contributes towards the pool of work on the topic; where historical accounts remain relatively scarce (see Loskutov, 1999; Pistorius, 1997; Plucknett, Smith, Williams, & Anishetty, 1987, for accounts written by actors see, for instance, Scarascia-Mugnozza & Perrino, 2002).

This material indicates that collections of plant material were created in order to ensure that 'old' material would be kept available for future use. It shows historical actors planning a strategy for avoiding global genetic erosion through practices of collection and preservation of seeds that create records of genetic diversity, within the context of rapid changes in plant breeding. In this way, they argued, 'primitive' plant varieties which were endangered by changes in agricultural practices could be preserved by freezing their seeds.

Parry (2004) and Van Dooren (2009) have identified seeds as 'proxies', that is, components that can 'stand in' for the bulkier, more corporeal plants and that contain the essential aspect of the genetic material and thus are a way to record the genotypes and adaptations that would be valuable to future users. My narrative suggests that these proxies are particularly valuable for their ability to bridge the gap between the past and the future: they are, specifically, temporal proxies. Seeds' capacity for dormancy and reproduction was harnessed to ensure the conservation of seeds in a way that they could be used in the future, that is, they provide a way to create a stable record of the evolutionary past of crops. Banking seeds, then, is a form of committing to record important 'historical sources' in such a way that the evolutionary potential of crops is maintained, enabling their potential value to be realised.

In the next section, I introduce the concept of seed banking and genetic conservation. On Section 3, I suggest that the development and uptake of new crop varieties associated with the Green Revolution led to a new appreciation of the value of old, 'traditional' crop varieties, but simultaneously put them at risk. Then, I argue that seed banking was a promising strategy for conservation because it separated 'genetic conservation' from the continued cultivation of crops *in situ* (that is, in their original environment) hence providing a means to enact conservation that was not in tension with agricultural development. The next section details the ways in which ex situ conservation was seen to facilitate future use; and Section 6 shows how banking created 'records' of seeds, therefore enabling the recall of the evolutionary past of crops and its future retrieval.

2. Genetic diversity and its conservation

Genetic diversity, or the variation between different populations belonging to the same genus, resulted from the evolution of crops over millennia, in response to different environments and husbandry practices (Fowler, 2008) worldwide. Nikolai Vavilov's (1887–1943) work on the biogeography of crop plants provided a theoretical basis for understanding the relationship between a crop's 'centre of origin', or region where it originally evolved, and the amount of genetic variation displayed between its populations: he posited that the greatest amount of crop variation was to be found within 'centres of origin' (Vavilov, 1992).

Vavilov also conducted numerous collecting trips around the world. The resulting samples were assembled into a collection of germplasm, which now bears his name, at the All-Union Institute of Applied Botany and New Crops in Saint Petersburg (Loskutov, 1999). This repository stands out by its focus on the systematic representation of the variation *within* crop species. Here were assembled samples of many populations or varieties belonging to the same genus, with different traits, and drawn from the various populations spread around the world (by comparison, botanic garden collections showcase diversity at the level of the species; assembling representatives of many species together).

Vavilov's collection represented the variation between 'landraces' of crops: crop varieties which result from the gradual evolution of crop populations within a specific environment, over long periods of time, in response to artificial selection by farmers and natural selection processes (for a review of definitions, see Zeven, 1998). Because diversification happened as a result of the evolution of crop populations over time, it was the outcome of the adaptation process between a plant and its environment. Since these 'adaptive gene complexes' resulted from the ongoing relationship between a crop and its (physical and cultural) environment, the diversity of a crop's gene pool was the sum total of adaptations between a crop and the varying environments over its geographical range. Landraces therefore demonstrated 'genetic organization for productivity' (Frankel & Bennett, 1970, p. 11) which made them valuable: they would display particular traits—for instance, disease resistance—or characteristics (morphological or agronomical) that enabled them to survive within their environment.

Landraces were valued because they had been developed by farmers over time, and were thought to be 'organised' to be

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productive *within the parameters of a particular locality.* Their evolution was continuous and gradual; farmers certainly worked as breeders, but with the principle of maintaining adaptation to a particular environment. In this sense, the production of landraces was a local process.

The potential value of landraces as gene donors was known to plant breeders from the earlier 20th century (Zeven, 1998), as demonstrated in the writing of actors including Vavilov and the American agronomist Harry V. Harlan (Harlan & Martini, 1936). It is also evident from efforts to systematically collect them for breeding purposes. Several collections were made in the 20th century from which breeders could select material for use: for instance, in addition to Vavilov's collecting missions, the plant geneticist Erwin Baur collected potatoes in Asia, Europe and South America between 1926 and 1933 (Elina, Heim, & Roll-Hansen, 2005, p.165), while later the Office for Special Studies (directed by E. J. Wellhausen under instructions from the Rockefeller Foundation and the Mexican Government) collected maize germplasm between 1943 and 1959 (Taba et al., 2005; see also Wellhausen, 1965). The use of 'back-crossing' as a breeding technique (breeding a crop variety with its wild or 'primitive' relatives) provided a way to introduce valuable adaptive traits into new crop varieties (Elina et al., 2005).

Thus, collections which existed until then as 'working collections' for breeders, (that is, constituted of material that was kept according to criteria of immediate or obvious usefulness) were now used as a conservation method. The preservation of seeds in repositories known as seed banks emerged, as a conservation strategy, in the 1960s–70s, as an approach to protect agricultural genetic diversity against 'genetic erosion' of landraces.

Seed banks are a form of *ex situ* conservation, that is, where material is kept somewhere other than its original environment. They are generally organised by crop, showcasing material from a broad geographical area, and contain a systematised representation of the variation at the genetic level, and within crop populations. The aim is the conservation of variation at the genetic level through storage of genetic material, so that the purpose of seed banks is 'not so much to preserve seeds as to preserve diversity, the variation within populations.' (Fowler & Mooney, 1990, p. 167). In this sense, they share ground with biomedical biobanks. They also differ from other projects of nature conservation—including *ex situ* repositories, such as botanical gardens—with the exception of banks of animal semen and/or embryos (Plucknett et al., 1987, p. 92; on the history of animal germplasm banks see Polge, 2007), since the purpose of seed banks is the conservation of *germplasm*, that is, genetic material that is the physical basis of inherited characteristics, and which can be passed on to the next generation as germ cells; in the case of plants, through seeds (Aubry, Shoal, & Erickson, 2005, p. 44). Even if seeds are produced by individual plants, the conservation unit is an 'accession' comprised of seeds from multiple individuals;[1] so, in most cases, it represents the genotypes of a population rather than of an individual.[2]

This paper focuses on seed banks, that is, repositories for the storage of seeds. Yet not all crops can be stored as seed; some plants do not produce them and others yield 'recalcitrant' seed which cannot tolerate storage (Berjak, Farrant, & Pammenter, 1989). Hence, other kinds of conservation repositories exist for the conservation of other kinds of plant material. Collectively, they are known as genebanks.[3] These include tree 'field genebanks' (but these are seen as costly and vulnerable to pests and diseases [Engelmann & Engels, 2003, p. 91]); and what Withers and Engels (1990) once described as 'test tube genebanks', i.e., collections of tissue culture samples. Increasingly, purified DNA can also be kept, although this format does not enable the replication of whole plants from the sample (Frankel, Brown, & Burdon, 1995). Seed banks constitute circa 90% of contemporary gene bank holdings (FAO, 2010) and seed preservation is 'the best researched, most widely used and most convenient method of *ex situ* conservation' (Engels & Visser, 2003, p. 65). It involves the reduction of the moisture content of seeds followed by storage at low temperatures (FAO, 2014; Harrington, 1970). The type of banked material, and the method and conditions of storage all influence the timespan of viability for a sample. Cryopreserved material might be indefinitely stable, whereas trees in field genebanks are limited to their natural lifespan. Seeds, if not cryogenically frozen, will also eventually lose viability. For long-term conservation, however, a seed sample can be 'regenerated' by germinating some of the sample for fresh seed for storage and distribution.

Genebanks vary greatly in terms of scope, specialising in one or in multiple crops, and storage capacity, from a few to hundreds of thousand samples. The largest public genebanks are those established within the agricultural research institutes of the Consultative Group on International Agricultural Research (now CGIAR) such as the rice collection at the International Rice Research Institute (IRRI, Philippines) and wheat and maize at the International Centre for the Improvement of Wheat and Maize (CIMMYT, Mexico). Between 1972, when FAO and the CGIAR envisioned a World Network of seed banks (see Pistorius, 1997: 55 and following) to 2010, 7.4 million samples (of which 1.5–2 m are thought to be unique) were stored in 1,750 genebanks around the world (FAO, 2010).

Next, I show how the need to develop a genetic conservation strategy to prevent the loss of older, traditional varieties of crops (and consequently the 'genetic erosion' of their gene pool) was related to the spread of the cultivation of new, high yielding varieties worldwide.

3. Genetic erosion and plant breeding

The emergence of genetic conservation happened concurrently with the modernisation and intensification of agricultural practices known as the Green Revolution (Frankel & Bennett, 1970, pp. 8–9). These programmes of agricultural development, funded by the Rockefeller Foundation, were designed to increase agricultural production of maize and wheat with the aim of reducing hunger through a combination of new, high-yielding varieties with the use of fertilisers (on the history of the Green Revolution see Harwood, 2009, 2012, 2013; Perkins, 1997). Breeders created more productive varieties of cereals through novel techniques, such as shuttle breeding, and embraced the breeding of varieties suitable for cultivation across different climates (Baranski, 2015):

> Before the advent of science-based agriculture, plant breeding was strictly a local activity. Farmers selected genotypes according to their own needs and preferences and for adaptation to a particular place. With the creation of agricultural research programs in the 19th century, the scope of plant breeding broadened considerably, though still confined to relatively limited areas of individual countries. Against that background

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[1] Not to be confused with the database of sequences, GenBank, discussed by Bruno Strasser (2011)—although this presents an interesting comparison—as discussed in the Conclusion.

[2] Which is variable, depending on the number of plants available and the calculated genetic variability among them (Crossa & Vencovsky, 2011); yet Allard (1970) suggests 50–100.

[3] The reproductive method of a crop also determines how many individuals are represented within a gene bank sample: it may be composed of a number of seeds from different individuals in the case of sexually reproduced crops, or correspond to individual plants (or cell cultures thereof) when they are clonally reproduced.

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> the development of crop varieties for global distribution came as a radical amendment to the timeworn principles of plant breeding. The first article of this new creed called for genotypes with broad adaptation, expressed as high yield across a wide range of climates (Russell, Harris, & Wolf, 1992)

This 'radical amendment' resulted in significant differences between the crop varieties being produced in the agricultural stations in Mexico and elsewhere and 'traditional' landraces, which were bred and cultivated by farmers. Firstly, 'scientifically bred' varieties were far more genetically homogeneous than the seeds saved by farmers; secondly, they were bred to be productive in a broad range of environments, rather than have specific adaptations to any particular one. In this sense, one can contrast the local, farmer-bred varieties with the scientific, higher-yielding varieties that can be expressed temporally as pre-modern (it was still common in the 1970s to describe landraces as "primitive" varieties) versus modern.

Yet, landraces were used as progenitors in the breeding of Green Revolution varieties, donating traits that were directly involved in the characteristics that made them so productive. With the development of scientific breeding techniques came the possibility of introducing specific traits of interest from landraces into newer varieties. The wheat varieties bred by Norman Borlaug (active 1944–2009)[4] for instance, inherited a semi-dwarfing gene from the Japanese landrace Daruma, via a Norin-10xBrevor 14 cross sent to him by the breeder Orville Vogel in the U.S. (Gale & Youssefian, 1985, p.3–7; Hoisington et al., 1999).

The very success of the scientific breeding and its homogeneous, broad varieties now put at risk the traditional varieties that were progenitors and gene donors for these same varieties. The rapid uptake of new, Green Revolution varieties by farmers previously growing landraces—particularly in centres of origin—meant that other locally adapted, diverse (but less productive) landraces would no longer be cultivated, thus imperilling diverse crop varieties in their original environment.

Thus, '[t]he transition from primitive to advanced cultivars (…) had the effect of narrowing the genetic base' (Frankel & Bennett, 1970, p. 10) as new varieties were uniformly bred, aiming for high yields and broad geographical coverage.

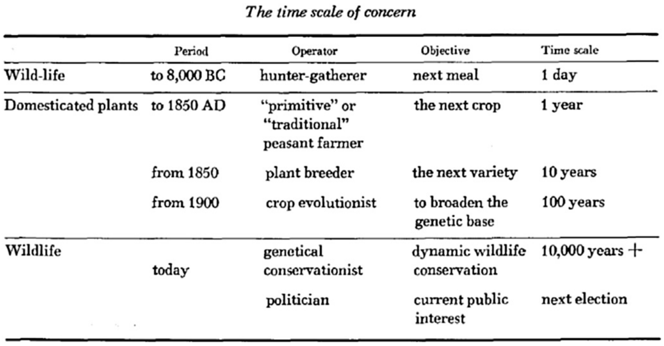
> When the application of science to agriculture, and especially the advent of scientific plant breeding, ushered in the second agricultural revolution, modern varieties, bred for high production and uniformity, absorbed only a small proportion of the ancient stores of variation. Today the same, or closely related, varieties are grown in many parts of the world. (…) No doubt the dramatic improvement of food production has saved mankind from extensive starvation, at least for the time being; but it also has deprived the world of valuable genetic resources, and (…) much of what remains is now acutely threatened (Frankel, 1974, p. 55)

The loss of genetic variation at the level of crop populations was called 'genetic erosion'. Although reported as early as 1914 by Baur (van de Wouw et al., 2010), it became a more pressing concern from the 1960s onwards, as a result of the spread of improved varieties to crop centres of origin. Awareness of this shift led to heightened 'interest in, and concern about "natural gene pools" with the recognition of both the 'immense value of representative germplasm collections', and 'the growing threat to the[ir] continued existence' (Frankel & Bennett, 1970, p. 1). Their disappearance, Frankel argued, 'may turn out to be an irreparable loss to future generations' as it meant 'the extinction of the natural sources of adaptation and productivity represented by primitive varieties' that had evolved over millennia and were irreplaceable (Frankel & Bennett, 1970, pp. 11–12).

So, it was important to look beyond the current success of agricultural production to ensure that the *adaptability* of populations or species was maintained for the future: this was Frankel's concept of 'evolutionary potential' (Frankel, 1974; Frankel & Soule, 1981). Notably, he developed this concept by analogy with other sorts of cultural heritage, thus eliciting a sense of a common past that deserved protection:

> The widespread concern with the fate of the natural and cultural heritage now exposed to a hurricane of change is finding expression in the concept of the national estate. This concept denotes landscapes, sites or objects (…) which are or should be preserved. By analogy, one can recognise a genetic estate which comprises the biological heritage, the genetic endowment of organisms (…). The latter is conservative and static, whereas the genetic estate is forward looking and dynamic: its essence is its evolutionary potential. Accordingly it has a more meaningful time scale. Since it deals with processes it has at least a national [sic—means notional, see Frankel & Soule, 1981] time dimension. This may be relatively brief, as for the breeding of crops or livestock, or it may be infinite, as for the evolution of species in natural communities. Thus genetic conservation has a time scale of concern, which extends from a day or a year when there is no need (or plan) for conservation, to infinity. (Frankel, 1974, p. 53)

In summary, the conservation of old landraces was essential in order to ensure the future production of new crop varieties. Even if the newer crop varieties of the Green Revolution were very productive in the present, the long-term success of agricultural production depended on being able to access genetically diverse material. Frankel developed the idea of different 'timescales of concern' (see Fig. 1) that needed to be taken into consideration in order to ensure this potential, and suggested that the objectives of plant breeders and farmers may work against the cultivation of landraces. Along with these more immediate concerns, crop evolutionists were aware of the need to maintain the evolutionary potential of a crop, and consequently had a longer 'timescale of concern' relative to breeders or farmers. As a result, they were able to identify the relationship between the past and future of crops and, consequently, call for and enact what Frankel had called 'our evolutionary responsibility':



The time scale of concern

	Period	Operator	Objective	Time scale
Wild-life	to 8,000 BC	hunter-gatherer	next meal	1 day
Domesticated plants	to 1850 AD	"primitive" or "traditional" peasant farmer	the next crop	1 year
	from 1850	plant breeder	the next variety	10 years
	from 1900	crop evolutionist	to broaden the genetic base	100 years
Wildlife	today	genetical conservationist	dynamic wildlife conservation	10,000 years +
		politician	current public interest	next election

Fig. 1. The 'time scale of concern' (Frankel, 1974). Note the difference in timespan between the concerns of the plant breeder and that of the 'crop evolutionist'.

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[4] A plant breeder, Borlaug worked at CIMMYT and was awarded a Nobel Peace Prize in 1970 in recognition of the effect improved varieties had on ensuring the food supply in Mexico, India and Pakistan.

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genetic conservation. In the next section, we turn to how seed banks were imagined as the way to carry it out.

4. Salvaging “primitive” varieties through *ex situ* conservation

‘The time scale of concern’, wrote Frankel, ‘must not be confused with the time for action, which clearly is *now*.’ (Frankel, 1974, p. 53). Prompt action was needed to prevent the erosion of the ‘genetic estate’, in the form of a collaborative, internationally coordinated effort to prevent genetic erosion. A Joint Meeting on Plant Exploration and Conservation[5] was convened in 1967 with a view to developing a strategy for genetic conservation, sponsored by the International Biological Programme (IBP) and the United Nations Food and Agricultural Organization (FAO). In the publication that resulted from the Joint Meeting (Frankel & Bennett, 1970)—the first to focus on genetic resources conservation issues—Frankel and Bennett argued that long-term seed storage, that is, seed banking, was ‘the most urgent single measure at the present time to ensure genetic conservation’ (Frankel & Bennett, 1970, p. 16).

Given that what was valuable about traditional landraces was their evolutionary relationship with a particular environment, why was an *ex situ* strategy such as seed banking (that relied on the storage of crop genetic diversity away from the evolutionary pressures that shaped it) identified as the most urgent measure?

Geneticists and plant breeders did hold different views on how genetic conservation should be done, resulting in a long-running debate (described in Pistorius, 1997; Plucknett et al., 1987) over what constituted the best strategy: *in situ* or *ex situ* conservation, or a combination of the two. These different perspectives are instructive in terms of the arguments put forward for seed banks, and how they expected to ensure the safety and future availability of these landraces.

Some scientists, including the plant geneticist Erna Bennett (director of the Crop Ecology and Genetic Resources Unit at FAO between 1967 and 1982) argued it was necessary to maintain populations in continued, dynamic evolution in response to the selective pressures (human and natural) of the surrounding environment.

In contrast, Frankel saw the *in situ* strategy as expensive and ‘impracticable in view of the large numbers [of accessions] involved and the technical and social problems to be met’ (Frankel, 1985, p. 31 in Pistorius, 1997, p. 28). He called it a ‘social and economic impossibility’ (Frankel, 1974), believing it was not possible to expect farmers in developing countries to abstain from cultivating high-yielding varieties for the sake of continuing to grow landraces. At most, *in situ* conservation could be helpful only ‘from the point of view of preservation for current utilisation during the next 20 years or so’ (Frankel in Bennett, 1968: 111), and so fell short of the ‘timescale of concern’ he envisaged for crops of circa 100 years (see Fig. 1).

Frankel therefore considered *in situ* conservation to be incompatible with the contemporary modernisation of agriculture. Genetic erosion could not be avoided in farmers’ fields on any large scale. Instead, Frankel and others suggested the long-term banking of seeds as a strategy for conserving genetic diversity. In maintaining crop genetic diversity through preserving seed, rather than as populations in the field, its long term future was assured, since crop samples could be sheltered from potential damage and adverse selective pressures. *Ex situ* collections therefore provided an alternative space where ‘primitive’ landraces could be preserved.

Frankel believed that the storage of seeds under appropriate conditions of low temperatures and moisture would extend their longevity (see also Roberts, 1972). Collected samples would therefore be kept physically and metaphorically ‘frozen’ (Frankel et al., 1995, p. 5).[6] He saw seed collections as technologically feasible; especially for crops producing ‘orthodox seeds’ (that is, seeds that could withstand storage) (see also Harrington, 1970). Proponents saw this as a ‘convenient and cost-effective’ collection of the greatest diversity of material, and the economic factor did matter: ‘on economic grounds—quite an important proviso—seed banks have the advantage’ (Frankel, in Bennett, 1968: 111; quoted in Pistorius, 1997: 28).

Significantly, this strategy worked within the context of the Green Revolution. It was appealing as a means to conserve ‘traditional’ varieties, compatible with the ongoing agricultural modernisation and shift towards improved varieties. It enabled access to the same germplasm independently of the continuous cultivation of these populations *in situ*: genetic diversity could be conserved even if varied populations ceased to exist in their original environment. So, the geographies of crop variation and of agricultural development were invoked as part of the argument for seed banking. The geographical distribution of genetic diversity and agricultural production brought up questions regarding how to fund and carry out conservation, and who should shoulder the costs given the global distribution of benefits. With *ex situ* storage, different countries’ interests could be aligned: ‘gene-rich’, developing countries in centres of origin would not be restricted in their development. Instead, it would be in the international common interest that ‘the genetic diversity that they still possess should be preserved’ (Frankel & Bennett, 1970: 13). Hence, seed banking arguably enabled the (re)distribution of conservation costs.

This conservation strategy privileged the preservation of *genetic* material contained within frozen samples, rather than the maintenance of dynamic populations of plants, evolving within their bio-cultural context (Van Dooren, 2009). In this sense, it mirrored contemporaneous projects, also sponsored by the IBP, focusing on the ‘salvage’ of blood samples from indigenous peoples considered to be at risk of disappearing (Radin, 2013).

Seed banks therefore provided an alternative way to access crop diversity: instead of collecting samples *in situ* or acquiring them from another person or organisation, they could be sourced from an *ex situ* collection. The feature that enabled this to happen was the storage of different varieties of plant as seeds, to which I now turn.

5. Recording and recalling evolutionary history

Preserving genetic material as seed meant that it would be possible to make use of plants’ own biological mechanisms for conservation purposes, due to their ability to contain genetic material. This made them proxies: objects which decorporealize the important parts of an organism—generally, the genetic information—and make it more fungible, manageable, and readable (Parry, 2004).

On the one hand, it would be possible to create further copies of the stored germplasm as required. In that sense, they were indeed a ‘convenient form of gene storage’ (Van Dooren, 2009) for the conservation of genotypes and traits of interest (as will be further discussed in the next section). On the other hand, the natural dormancy of seeds could be used to extend the lifespan of this information to the appropriate ‘timescale of conservation’ through the technological control of the storage conditions, in terms of temperature and

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[5] Attended, amongst others, by Bennett, Frankel, Hawkes, and the botanist Jack Harlan; all of whom would be later in the FAO ‘Panel of Experts’ convened to continue to develop this project (see Pistorius, 1997).

[6] In contrast, seeds in shorter-term collections would lose viability more rapidly, requiring periodical ‘rejuvenation’ (or ‘regeneration’) to produce fresh seed.

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moisture levels. In this case, the biological characteristics of seeds that enable them to lie dormant were harnessed for the purpose of conservation, because it meant they could be 'archived and conveyed intact over space and time for future reutilization' (Parry, 2004, p. 74). Seed banking was grounded on the ability to retrieve seeds from the bank and, from these, the locally adapted traits and characteristics that were encoded within. Thus, the materiality and biological capacity of seeds enabled the purification of the 'essential' parts of the plant: their genetic material.

In this case, seeds appeared as particularly *temporal* proxies, in that they were put to use to ensure the continued conservation of genetic diversity. Seed banks might then be described as repositories that would enable the 'recall' of crop genetic diversity as and when required. Moreover, the genome of seeds represented within its genetic code the gradual adaptations of diverse populations to their environments. Frankel's vision for seed banking was therefore that in sampling and freezing germplasm of crops it would be possible to preserve genetic diversity statically and for posterity, thus creating records of the evolutionary past of a crop in the form of seeds.

To exemplify, I turn to another point of contention between supporters and non-supporters of genebanks: whether it was possible to avoid genetic erosion within the seed bank itself. Was it indeed possible to maintain the stability of the genetic constitution of accessions? For Frankel, careful management of the banked material and good curation practices meant it was possible. Yet for the plant breeder N. W. Simmonds (Simmonds, 1962, p. 452), they

> '…neither effectively preserve[d] nor… exploit[ed] variability' because 'a major collection (…) is virtually certain to contain a proportion of ill-adapted genotypes which can either not be preserved at all or can be preserved only with great difficulty and uncertainty. However careful the maintenance, some strains are lost to disease, others succumb to [the] weather and others again fall victim to the inevitable accidents'

Essentially, Simmonds disputed that it was possible to undertake genetic conservation of adaptations outside of their own environment because the composition of the sample would inevitably change over time, that is, its genetic integrity could not be maintained. He went on to characterise *ex situ* collections as 'wasting asset[s]' (Simmonds, 1962), suggesting that the success of *ex situ* collections were related to their ability to keep material static. This debate, then, indicates the fundamental importance of maintaining a stable set of records, even if the seeds themselves might age and the accession undergo regeneration.

Such recording could take place because the material process of archiving structured the gene pool into distinct and static accessions, therefore providing snapshots of genetic diversity as it was at a particular time so that seed bank material could serve as an unchanging source from whence the evolutionary history of crops could be 'read' with 20th century techniques of genetic analysis and interpreted with recourse to Vavilov's theory of plant evolution. So, cold storage was significant not only because it extended the longevity of the stored material, but also for its ability to produce static representations of gene pools by stopping (or at least, slowing) the decay of seeds.

The success of genetic conservation depended on its ability to maintain the 'genetic integrity' of the sample when it entered the seed bank because this would allow researchers and breeders to draw on a stable reference: a sample that would be, as much as possible, genetically unchanged since its storage. It was essential that the material kept in the seed bank was an accurate representation of the evolutionary past of the crop, both for those using seed bank material for research (for instance, into the evolutionary relationships between varieties of the same crop) and for breeders, ensuring that the conserved material, once germinated, would show the expected traits of interest. Seed bank material is, in this sense, different from other plant laboratory resources such as the standardised research lines of the plant model organism *Arabidopsis thaliana*, where the material is 'domesticated' into homogeneous laboratory research lines that are made available for genetics research around the world (Leonelli, 2007).

It was precisely the static nature of seed banking that led to critiques (inclusively by Erna Bennett and N. W. Simmonds) challenging the merit of *ex situ* collections in evolutionary terms:

> 'I see no special advantage in conservation in the form of seed apart from the very eminent one of convenience, and I think that attempts to find other merits in the 'steady state' which seed storage represents, seem to come dangerously near to adopting museum concepts. The purpose of conservation is not to capture the present moment of evolutionary time, in which there is no special virtue, but to conserve material so it will continue to evolve. Such 'continued evolution' could only be possible in *in situ* collections' (Bennett, 1968, p. 63 in Pistorius, 1997, p. 27).

From this perspective, the value of seed bank accessions was limited to a matter of convenience in terms of future accessibility, rather than potentiating further *in situ* adaptation. For its advocates, ensuring the accessibility of material in the future was no small achievement, as we now turn to.

6. Conserving valuable genetic resources for the future

Arguments related to the needs of users featured prominently on the case for seed banking. This strategy was appealing because its imaginary included both the conservation of genetic diversity *and* its future availability. The latter aspect was important because the conservation of genetic resources was based on utilitarian grounds, that is, on the 'significance of the genetic resources which are of immediate or long-term value, bearing in mind not only present, but also possible future needs' (Frankel & Bennett, 1970, p. 10).

Genetic resources were seen as 'insurance' that kept options open for the future of agriculture (Fowler, 2008), inasmuch as having access to a more diverse gene pool amplified the probability of finding a trait or genotype in response to unpredictable future requirements.

> Apart from resistance, new needs for specific characteristics arise from advances in science and technology. These may be difficult to predict but are nevertheless likely to multiply in years to come. Who could have predicted a decade ago that extensive gene pools would be screened for high-lysine stocks, or for restorer genes for pollen fertility? There is general agreement among plant breeders that large and diverse gene pools are increasingly required to meet the ever-changing demands, opportunities and challenges of the future. (Frankel & Bennett, 1970, p. 11)

In practical terms, this meant that conservation practices should be organised with a view to maintaining genetic material so that it was retrievable and so that it would be a suitable resource for the potential future uses to which it might be put.

In this sense, an *ex situ*, proxy-based approach to conservation would be advantageous. The static nature of seed banking which *in situ* advocates found problematic was beneficial from a user's perspective, since it was easier to select traits from samples that had been abstracted from their environment and grown under controlled conditions rather than from populations in the field. For Frankel, '*ex situ* facilities provide[d] ease of access for study and use, and the convenience of a *stable reference* under direct control' (Frankel et al., 1995, p. 86) [my italics].[7]

In addition, this approach would make it possible to *accumulate* accessions in a few large repositories. The centralisation of genetic diversity within the reach of potential users (especially breeders) would increase the amount of samples that could be searched. Conserving the gene pool of the crop *ex situ* made it possible to assemble collections of seeds that represented a broad variety of environments or geographical regions, for the same crop genus. Therefore, the diversity of material available for screening would be more wide-ranging than in the case of *in situ* approaches, where all the variation on show would be adapted to a specific geographical area. This could be particularly helpful at a time when the uses for this genetic diversity, too, were changing from the local adaptation paradigm to the breeding of broad-adaptation varieties.

Through the creation of collections, evolutionary potential could be stored for posterity, creating a repository of potentially valuable traits and genotypes available as resources for future users. In this, they resemble other archives of human and animal tissue (Landecker, 2007; Parry, 2004; Radin, 2013) where the development of freezing and cell culture technologies during the 20th century made living materials such as brain or blood manageable, and usable, in new ways. Like the frozen blood stored by the IBP, the genetic constitution of plants was envisioned as having the capacity for *latency*: their value could be realised at some future point, and mediated by the use of contemporary technologies (Radin, 2013) which made possible the extraction of valuable traits, or the derivation of new knowledge. In other words, the value of genetic resources remained potential until it was recalled from the seed bank: the 'enormous' evolutionary potential of genetic diversity had to 'be realised through recombination, genetic engineering, and selection' (Frankel et al., 1995, p. 5). So, the imaginary of seed banking incorporated particular concepts about the future uses of genetic diversity within modern plant breeding approaches and innovations in the plant sciences.

Seed banks can therefore be imagined as repositories that enabled the 'recall' of genetic diversity, both by committing it to memory and by allowing it to be recovered from cold storage for use. By evoking both these meanings, the concept of recall conveys how the conservation of old landraces is entangled with concerns regarding their future use. Seed banks thus function as archives that make records of the past of crops accessible in the future.

7. Conclusions

This account shows how the imaginary of seed banks as method of genetic conservation was grounded on the need to conserve genetic diversity for the sake of ensuring future availability, indicating that the development of strategies for the conservation of historical sources (in this case, as frozen seed) was influenced by ideas about their future use.

Seed banks contained frozen germplasm that embodied genomes which, assembled together, amounted to a representation of the gene pool and, consequently, the evolutionary history of crops. They can therefore be understood as archives, making possible the 'recall' of that evolutionary history. With the aid of the banks' material practices of memory, such history can be 'remembered', or recorded in the external memory device that is the collection, and 'retrieved', that is, recovered from the seed bank for future use.

The emergence of these repositories as a form of conservation was contextualised within the significant changes to plant breeding that were taking place in the mid-20th century. At this time, the Green Revolution had a globalising effect on agriculture and plant breeding, bringing broadly adapted new crop varieties to regions of high crop genetic diversity where locally adapted landraces grew and, with it, the erosion of the 'genetic estate' on which future crop development depended.

Storage in seed banks was therefore a way to preserve the 'valuable aspects of the past', that is, the genotypes that plant breeders see as useful, in a manner that worked within the new requirements and techniques available to plant breeders. Techniques of seed freezing fixed genotypes (and consequently, the inheritable traits and adaptations therein) by stabilising them through seed proxies (Parry, 2004; Van Dooren, 2009). In this case, the outcome was a novel way of recording the genetic constitution of crop plants so that they could be committed to memory and retrieved from cold storage as required.

Conservation in seed banks meant that 'traditional' varieties such as landraces could be preserved within this collection, even if genetic erosion proceeded in farmers' fields. By uncoupling the object of conservation from its place of origin, this strategy avoided the tension between conservation and agricultural development and enabled the organisation of genetic conservation at the international level. The importance of maintaining the fidelity of the record shows how seed banks, emerging a a time of significant change, were seen to provide a space where it would be possible to access varieties that would *not* ordinarily be found in the same region. This approach enabled the accumulation of the 'evolutionary potential' of crops in large collections of material originating from around the world. The scale of these repositories could therefore matched the increasingly broad scope of plant breeders, and where it was possible to compare material from around the world in order to derive knowledge or useful traits. Storage of material as seed enabled the collocation of varieties from around the world. As Bruno Strasser (2012) argued, collections (be they 19th century natural history collections or the databases of the following century) make the collected material comparable because it is standardised, and this process can be discerned in the vision underpinning seed banking.

Seed banking can therefore be understood as an attempt to salvage the latent value of genetic diversity. Much like the archives of blood from indigenous groups that appeared at the same time (Radin, 2013), the seed bank was an instrumental tool for the preservation of valuable resource material, rather than an effort to keep the population itself. Instead, in making proxies scientists created static 'snapshots' of the gene pool. This process made the evolutionary past of crops available for 'recall'. This meaning is twofold: firstly, that the evolutionary history could be 'remembered', that is, read or investigated, through genetic analysis of the material stored. Secondly, it meant that a new resource was created—the archive—from whence such genetic resources were retrievable.

The genetic resources represented in the seed bank existed in a particular form because plant breeders and other interested parties understood the evolution of crop plants from a particular paradigm, informed by Mendelian genetics and Vavilov's work. Consequently, what was represented, and how it was remembered, was defined in relation to these theories, thus favouring Mendelian inheritance patterns and a geographically broad representation of the crop's genetic diversity.

Frankel's vision for genebanks was one where good curation practices mean that this genetic material could be preserved into the future with (nearly) no change to its genetic constitution: a kind

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[7] Pistorius points out that Frankel's view was more centred on single genes and Mendelian inheritance than that of *in situ* advocates such as Bennett (Pistorius, 1997).

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of ‘perfect memory’. So, the idea that new technologies provide a way to fix and draw on the genotypes of crops therefore brings with it the promise of unlocking the great ‘evolutionary potential’ of crops; presuming that such potential could be saved from erosion, it could also be highly productive. In this context, concerns about conservation are inseparable from ideas about what future use is desirable. The continuity between the past and future of crops was thus safeguarded. Moreover, this effort of preserving past data or observations for envisioned future users from the same community draws a parallel between genetic conservation and the ‘sciences of the archive’ described by Lorraine Daston (2012).

Considering banking as a means to commit to record these particularly valuable aspects of the past evolutionary history of crops brings to the fore a set of questions regarding the technical, social and theoretical practices that make this act possible, and that Bowker calls ‘memory practices’ (2005). They ‘are what carries the past along with us into the future: they are what makes our current reality true and our future—in will if not in deed—controllable’ (Bowker, 2005, p. 229–230). The concept of memory practices thus expresses the particular orientation of seed banks towards both past and future. This analysis suggests that cold storage techniques, too, may have a role as memory practices, in that they enable the organisation and standardisation of crop samples. A study of the interaction between this and other memory practices at work in *ex situ* conservation could lead to a better understanding of the way the temporalities of plant breeding and plant evolution were interacting in the 20th century.

In the present case, the strategies of conservation are concerned with the maintenance of the economically and agriculturally valuable aspects of genetic resources; and this account suggests that the way the archive is structured has implications for the way “the past” is organised. This interplay makes particular stories about the past more or less accessible. As we seek to think ahead and make choices about how to create and make use of the archive for the histories of the future molecular biosciences, the case of seed banks suggests that that conservation is always, already, about future use; because we use particular historiographical and theoretical tools to define what it is that is important. This insight, then, provides an example from the natural sciences that supports the relevance of doing the methodological work (how will these sources be used?) and the decisions about what and how to archive, together. Awareness of the implications of archival techniques for the kinds of records that can be kept and the futures that they enable is, therefore, a valuable effort. Decisions about how to salvage the past are always, necessarily, about how we value the future.

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