Who Needs Seeds?
New Genetic Technologies and Old Seed Morgues

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I. Introduction

Who needs seeds?

Why store seeds?

- Seeds are dirty, messy things.
- Small and fiddly to handle.
- A tendency to spoil.
- Long-term storage is costly and uncertain.
- Users are increasingly interested in genomic information, perhaps linked to data from characterization and evaluation.
- Seed morgues (Raeburn 1995): little used, filled with non-viable material.

Dematerialization

- Why not get rid of seeds and store digitized genomic data?
  - If not today, then in the near future...
  - Gene editing plus emerging technologies will dramatically alter plant breeding.
- Little need for seed.
- Perhaps store seeds as a temporary measure.
- Perhaps use sequencing to identify a much smaller subset of material that encompasses all the genes without all the seeds.

My argument

- In the short to medium run, seeds will continue to be valuable and to be used in breeding and research.
- In the long run, seeds contain an enormous amount of potential meta-data beyond the DNA sequences.
  - Seed physical and chemical properties may offer information of value.
  - Seeds may be valuable for purposes that we cannot fully anticipate (a kind of option value).
- Long-term storage is not especially costly.
- Long-term management strategies may differ from today's practices.

With apologies to Shakespeare

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- Mark Antony, *Julius Caesar*: 'I come to bury Caesar, not to praise him.'

With apologies to Shakespeare

- Mark Antony, *Julius Caesar*: 'I come to bury Caesar, not to praise him.'
- I come to bury seeds (possibly in Svalbard), and to praise them.

Svalbard Global Seed Vault

- Capacity for 2.5 billion seeds (4.5 million varieties of crops).

II. Why Seeds?

Seeds as productive input for agriculture

- Seeds (along with other forms of genetic resources) are obviously a key input to agricultural research.
- A well-documented role in supporting agricultural innovation.
- Recent economic analyses find very large effects of agricultural innovation on productivity growth and overall economic and health outcomes Gollin et al. (2021); von der Goltz et al. (2020); Bharadwaj et al. (2020).
- Breeding depends fundamentally on the availability and accessibility of useful genes.
- Seeds remain (for now; for many crops) the most useful form of genetic material to store and exchange.

Seed stores as insurance

- Seeds stored in gene banks represent a valuable form of insurance, beyond the immediate goal of productivity improvement:
  - Insurance against loss of genetic material *in situ*
  - Insurance against biotic stresses for which current (narrower) breeders' collections have limited resistance
  - Insurance against catastrophic losses of genetic material through disasters.

Costly activities

- Gene banks are expensive.
- Main costs include:
  - Collection, cleaning, and cataloging
  - Capital costs for gene banks
  - Energy costs for refrigeration
  - Staff costs for managing collections
  - Regeneration and multiplication of materials (primarily for seeds)
  - Costs associated with use: distribution and documentation
- Global budget for gene banks?? Perhaps in the hundreds of millions of dollars?

Complex legal framework

- Ownership and control of genetic resources is increasingly a complex issue.
- Management of seeds in gene banks has become legally and politically sensitive.
- But this does not detract from the underlying value of the resources.

III. Lessons from Economics?

Theory of genetic resources conservation

- A good literature on the economics of genetic resources; especially on the benefits of diversity; e.g.,
  Dasgupta (2000); Brock and Xepapadeas (2003); Kassar and Lasserre (2004); Di Falco and Chavas (2008); Perrings et al. (2009); Pascual et al. (2010).
- Thoughtful analysis of the uses of genetic resources for R&D and the divergence between private incentives and social values; e.g.,
  Goeschl and Swanson (2002, 2003); Sarr et al. (2008).
- Useful discussions of property rights regimes for genetic resources; e.g., Swanson and Goeschl (2000).
- But little guidance in this literature for specifics of exactly what to conserve or how to conserve it.

Economic questions

- Scarce funding; potentially unlimited needs for conservation
- Big questions:
  - What to collect?
  - How to conserve?
  - How to manage?
  - How to finance?
- Important questions with relatively little theoretical or empirical evidence.

How to conserve?

- Do we still need to conserve seeds?
- As the tools of bioscience advance, can we move to other forms of dematerialized conservation?
  - Cheaper
  - More easily shared
  - Less reliant on physical reproduction and regeneration
- Perhaps maintain smaller collections that can be used for characterization and evaluation or genomic research.

IV. Lessons from Libraries?

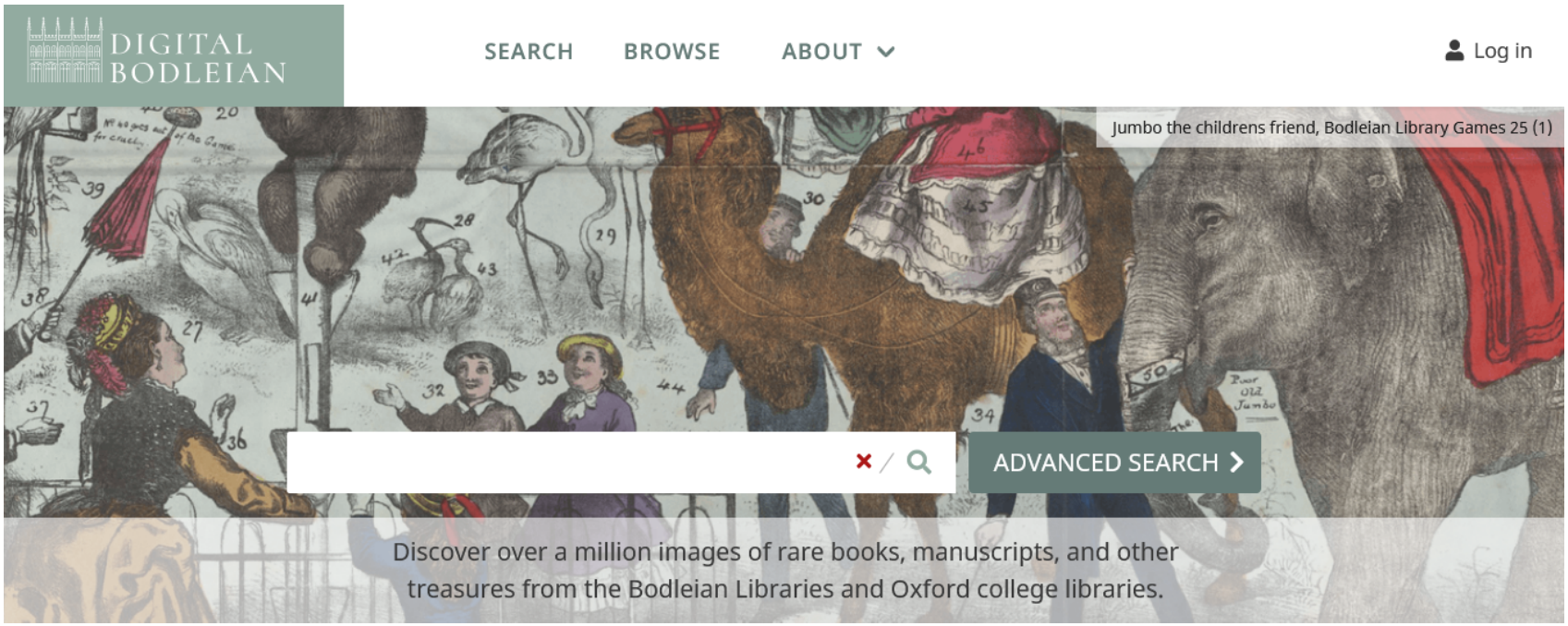
Gene banks as libraries

- A metaphor attributable to Gardner Brown Jr (1991); elaborated by Koo and Smale (2003)
- Not hard to assign value to books we have already read...
- But we shouldn't throw out those books that haven't been used in a while.
- The challenge is to identify those books we should keep.
  - Maybe reduce duplicates?
  - Thin out collections in certain subject areas?

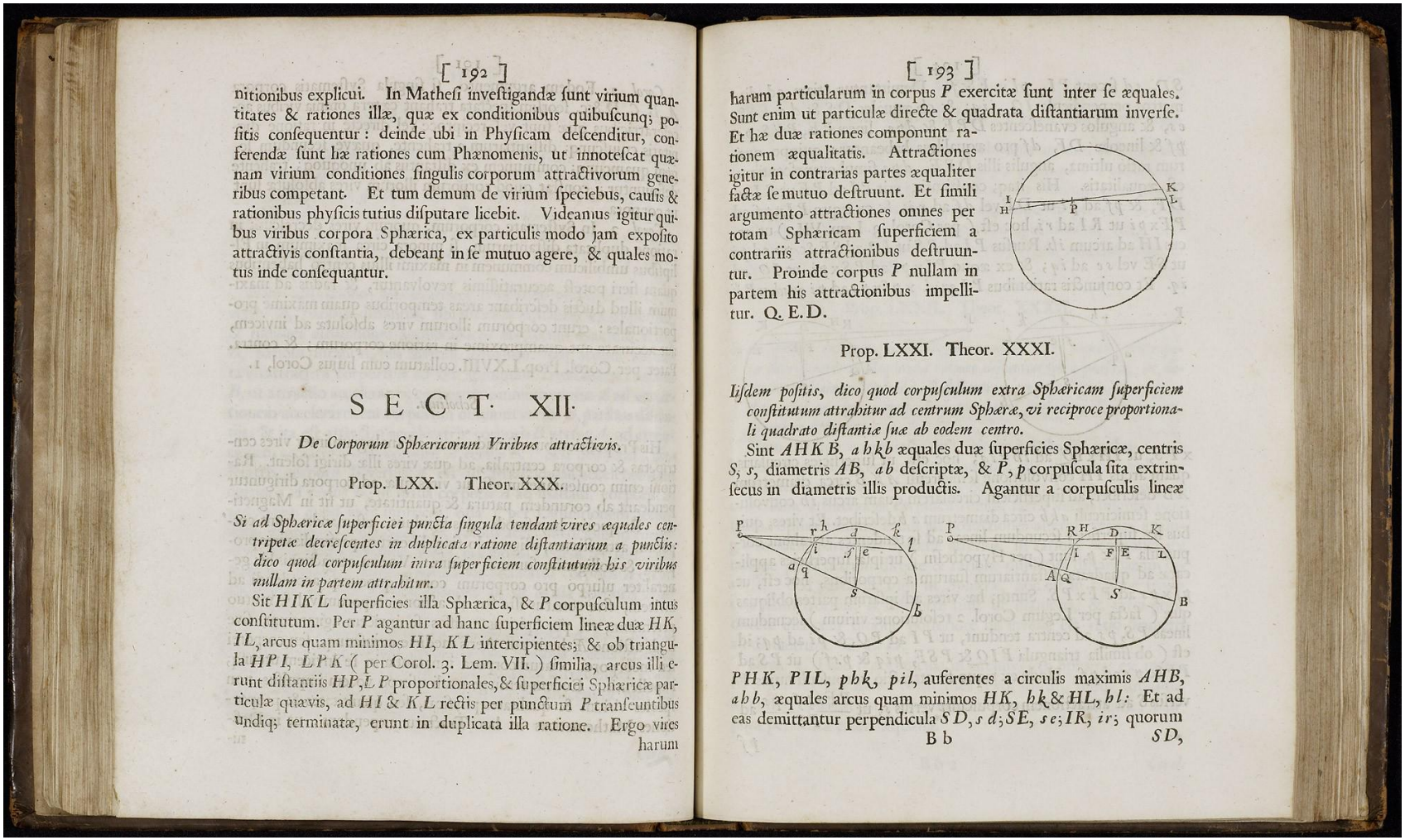
Gene banks as libraries, cont.

- How do our library collection and maintenance strategies change with the arrival of new technologies?
- When old books have been digitized, should we get rid of the hard copies?
  - Digital copies make search easier.
  - Can be accessed simultaneously by many users.
  - Perhaps keep some hard copies as backups?
  - Hard copies may be convenient for certain uses...
- But is that an adequate approach?

Digital technologies open new possibilities



Newton's *Philosophiæ naturalis principia mathematica*



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nitionibus explicui. In Matheſi inveſtigandæ ſunt virium quantitates & rationes illæ, quæ ex conditionibus quibuſcunq; poſitis conſequentur: deinde ubi in Phyſicam deſcenditur, conferendæ ſunt hæ rationes cum Phænomenis, ut innoteſcat quænam virium conditiones ſingulis corporum attractivorum generibus competant. Et tum demum de virium ſpeciebus, cauſis & rationibus phyſicis tutius diſputare licebit. Videamus igitur quibus viribus corpora Sphærica, ex particulis modo jam expoſito attractivis conſtantia, debeant in ſe mutuo agere, & quales motus inde conſequantur.

SECT. XII.

De Corporum Sphæricorum Viribus attractivis.

Prop. LXX. Theor. XXX.

Si ad Sphæricæ ſuperficiei puncta ſingula tendant vires æquales centripetæ decreſcentes in duplicata ratione diſtantiarum a punctis: dico quod corpuſculum intra ſuperficiem conſtitutum his viribus nullam in partem attrahitur.

Sit *HIKL* ſuperficies illa Sphærica, & *P* corpuſculum intus conſtitutum. Per *P* agantur ad hanc ſuperficiem lineæ duæ *HK*, *IL*, arcus quam minimos *HI*, *KL* intercipientes; & ob triangula *HPI*, *LPK* (per Corol. 3. Lem. VII.) ſimilia, arcus illi erunt diſtantiis *HP*, *LP* proportionales, & ſuperficiei Sphæricæ particulæ quævis, ad *HI* & *KL* rectis per punctum *P* tranſeuntibus undiq; terminatæ, erunt in duplicata illa ratione. Ergo vires harum

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harum particularum in corpus *P* exercitæ ſunt inter ſe æquales. Sunt enim ut particulæ directe & quadrata diſtantiarum inverſe. Et hæ duæ rationes componunt rationem æqualitatis. Attractiones igitur in contrarias partes æqualiter factæ ſe mutuo deſtruunt. Et ſimili argumento attractiones omnes per totam Sphæricam ſuperficiem a contrariis attractionibus deſtruuntur. Proinde corpus *P* nullam in partem his attractionibus impellitur. Q. E. D.

Prop. LXXI. Theor. XXXI.

Iiſdem poſitis, dico quod corpuſculum extra Sphæricam ſuperficiem conſtitutum attrahitur ad centrum Sphæræ, vi reciproce proportionali quadrato diſtantiæ ſuæ ab eodem centro.

Sint *AHKB*, *ahkb* æquales duæ ſuperficies Sphæricæ, centris *S*, *s*, diametris *AB*, *ab* deſcriptæ, & *P*, *p* corpuſcula ſita extrinſecus in diametris illis productis. Agantur a corpuſculis lineæ

PHK, *PIL*, *phk*, *pil*, auferentes a circulis maximis *AHB*, *ahb*, æquales arcus quam minimos *HK*, *hk* & *HL*, *hl*: Et ad eas demittantur perpendicula *SD*, *sd*; *SE*, *se*; *IR*, *ir*; quorum

SD,

Newton's *Principia*, cont.

Relinquitur adeo tertium genus, qui philosophiam scilicet experimentalem profitentur. Hi quidem ex simplicissimis quibus possunt principiis rerum omnium causas derivandas esse volunt: nihil autem principii loco assumunt, quod nondum ex ph_enomenis comprobaturn fuerit. Hypotheses non comminiscuntur, neque in physicam recipiunt, nisi ut quastiones de quarum veritate disputetur. Duplici itaque methodo incedunt, analyfica & synthetica. Naturae vires leg.esque virium simpliciores ex selectis quibusdam phaenomenis per analysin deducunt, ex quibus deinde per synthesin reliquorum constitutionem tradunt. Haec illa est philosophandi ratio longe optima, quam prae caeteris merito amplectendum censuit celeberrimus auctor noster.

Some questions

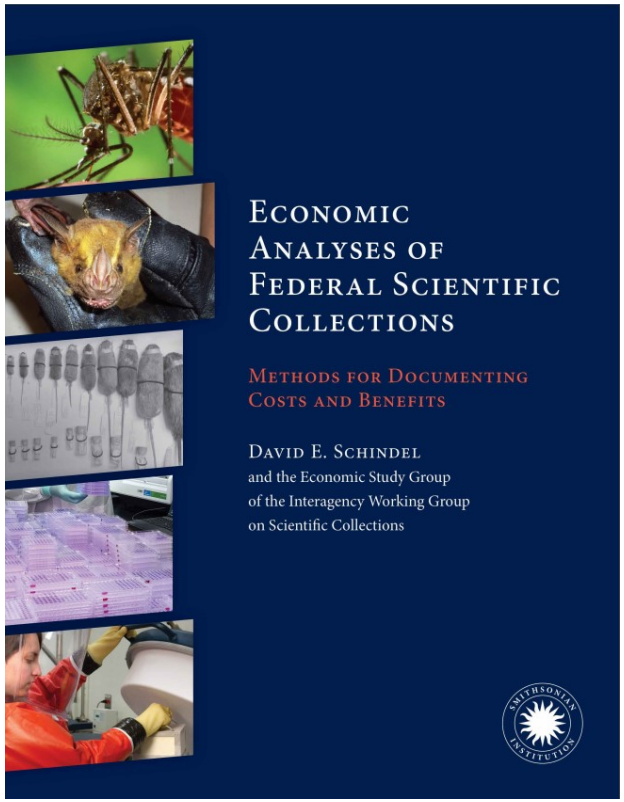
- To what extent does the text version substitute for the hard copy?
- Is there any reason, beyond sentiment, to keep a first edition of the book?
- Are there reasons to keep multiple copies or subsequent versions?
- How should we view the 'imperfections' that arise from the handling of the book over centuries?
- These questions all have analogies in the world of seeds.

V. Lessons from Scientific Collections?

Scientific collections frequently have unanticipated uses

- Gene banks are only one type of scientific collection.
- Many other collections: medical specimens, geological samples, herbarium records.
- Recent studies have documented the many and fascinating ways in which these collections turn out to have uses beyond their original purpose.
- Example: herbarium records used to document long-term climate changes, based on documented flowering dates.
- "If you build it, they will come..." (or "If you collect it, you will find uses that you didn't expect.)

The value of scientific collections



- Recent report from Smithsonian Institution, produced by a multidisciplinary study group.Schindel et al. (2020)

VI. Lessons from Archaeology?

Lessons from archaeology: the need for intellectual humility

- In archaeology, it has become a standard practice to leave sites (or portions of sites) unexcavated.
  - We don't know what questions will be of interest in the future.
  - We don't know what tools and technology future researchers will have at their disposal.
  - What we know for certain is that well-intentioned scientists, digging in the past, have destroyed material that we would now value highly.
  - Example: past archaeologists looked for artefacts and discarded the dirt; present-day researchers analyse the dirt for biological and chemical data.

Hattusha

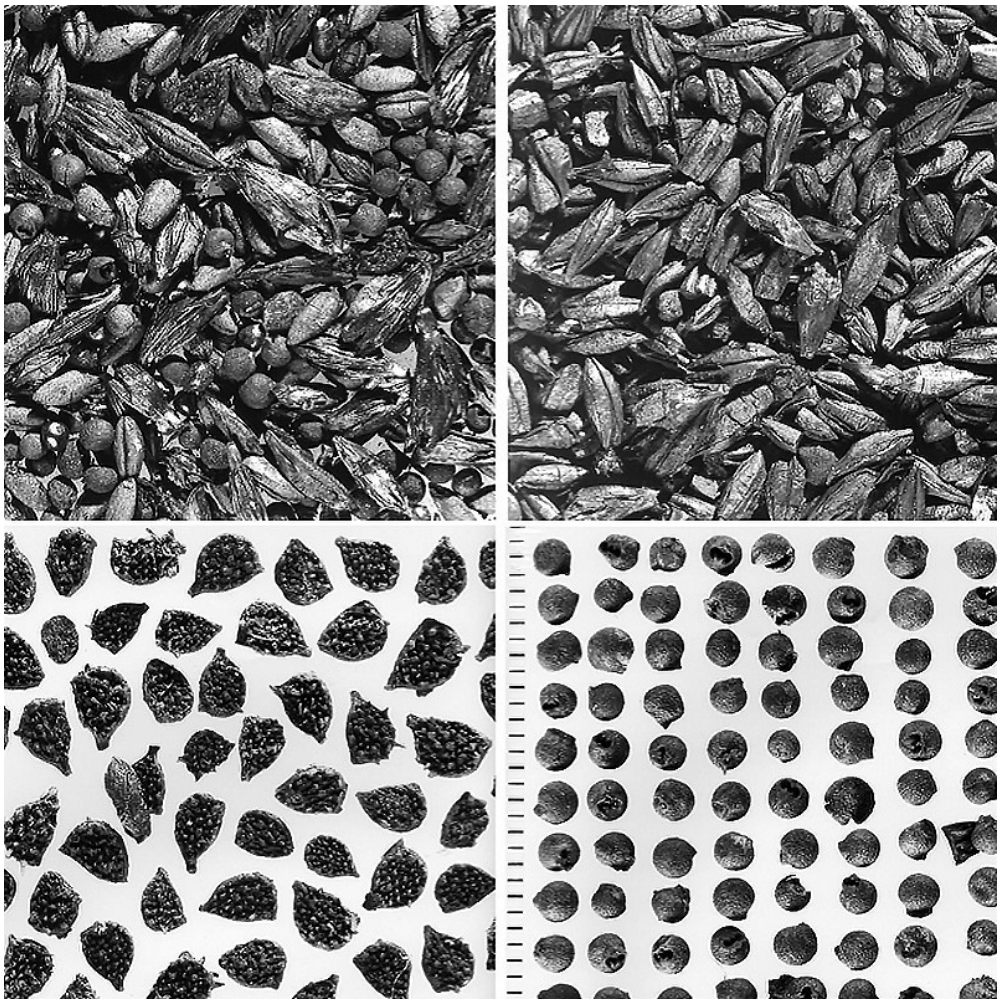
Hattusha: the Hittite Capital Aslanlı Kapı, Lion Gate

Author: Umut Özdemir Copyright: © Ministry of Culture and Tourism
Permanent URL: whc.unesco.org/en/documents/131602

Hattusha

- In the early 1990s, researchers from the German Archaeological Institute uncovered at Hattusha underground silos with hundreds of tons of intact carbonised grain.
- They sampled the grain but deliberately left most of it *in situ*, unexcavated, for future generations to explore further.
- Last year, Amy Bogaard and team from Oxford analysed chemical profiles and weed seeds from the samples:
  - Found that separate chambers held grain from different communities.
  - Possibly tribute from locations under the rule of the Hittites
- More seeds await analysis using future tools...

Hattusha, cont.



Clockwise from upper left, wheat kernels mixed with weed seeds; barley; and two types of weed seed.
Credit: C. Diffey et al./*Antiquity*

Shifting questions and tools

- Earlier excavations sought artefacts, gold, solutions to historical mysteries:
  - Schliemann's excavation's of Troy in the 19th century.
  - Howard Carter's excavation of Tutankhamun's tomb in the 1920s.
- Today's archaeologists are studying different questions:
  - Climate change - based on pollen residues and sediments
  - Historical patterns of human migration – based on chemical and physical analysis of bones
- Shifting questions and improved tools...
- There is no 'end of science' !

VII. Conclusions

Current breeding uses are only the beginning...

- The purpose of gene banks is precisely to conserve genes for future uses.
- Some of those uses can be anticipated... but some are not yet clear.
- Gene banks are indeed a resource for current breeding and research – but that is only a subset of their value.
- The bulk of the value lies in much longer time horizons and possibly in uses that are not yet apparent.

How valuable is information?

- Gollin et al. (2000) argued that information about the materials in a gene bank is of great value.
  - Allows for more targeted searches and reduces both search costs and time lags.
- What information should we collect?
  - Passport data and characterization / evaluation data are important.
- Seeds as meta-data
  - But we need to recognize that the seed itself is a form of meta-data.
  - Potentially enormous amounts of information contained in the *seed as medium*.
  - Should we alter collection, handling, or storage practices to maximize the value of this meta-data?

Basic economic lessons remain

- Weitzman (1992; 1993; 1998)and Simpson et al. (1996):
  - Avoid duplication.
  - Recognize the potential for redundancy.
- We want to conserve relatively rare genes.
- We also want to conserve valuable genes.

How close is the future?

- What is the realistic ability of scientists to work *usefully* with dematerialized DNA?
  - Differs from the technical capabilities of genetic modification or gene editing.
- Many traits are multigenic, and moving gene complexes remains challenging.
- Many genes are themselves not simple; expression of genes is not straightforward.
- Conserving dematerialized DNA will not be a useful strategy for some time.
- Technology is moving rapidly...
- But the horizon also recedes!

Conclusion

- Conservation of genetic resources is an important frontier for economics.
- Worthwhile re-evaluate conservation strategies that may (or may not) be out of date.
- Current breeding uses do not reflect an end state of scientific knowledge.
- But the pandemic reminds us that the insurance uses of gene banks should not be overlooked.
- Loss of diversity has the potential to cause crises; ecosystem vulnerability; food system impacts.
- Keep the seeds!

Keep the seeds!

International Rice Gene Bank

VIII. References

References I

Bharadwaj, P., J. Fenske, N. Kala, and R. A. Mirza (2020). The green revolution and infant mortality in india. *Journal of Health Economics 71*, 102314.

Brock, W. A. and A. Xepapadeas (2003). Valuing biodiversity from an economic perspective: a unified economic, ecological, and genetic approach. *American Economic Review 93*(5), 1597–1614.

Dasgupta, P. (2000). Valuing biodiversity. *Unpublished Working paper. Available from http://www. econ. cam. ac. uk/faculty/dasgupta/index. htm*.

Di Falco, S. and J.-P. Chavas (2008). Rainfall shocks, resilience, and the effects of crop biodiversity on agroecosystem productivity. *Land Economics 84*(1), 83–96.

Goeschl, T. and T. Swanson (2002). The social value of biodiversity for r&d. *Environmental and Resource Economics 22*(4), 477–504.

Goeschl, T. and T. Swanson (2003). Pests, plagues, and patents. *Journal of the European Economic Association 1*(2-3), 561–575.

Gollin, D., C. W. Hansen, and A. Wingender (2021). Two blades of grass: The impact of the green revolution. *Journal of Political Economy 0*(ja), null.

Gollin, D., M. Smale, and B. Skovmand (2000). Searching an ex situ collection of wheat genetic resources. *American Journal of Agricultural Economics 82*(4), 812–827.

Kassar, I. and P. Lasserre (2004). Species preservation and biodiversity value: a real options approach. *Journal of Environmental Economics and Management 48*(2), 857–879.

References II

Pascual, U., R. Muradian, L. Brander, E. Gómez-Baggethun, B. Martín-López, M. Verma, P. Armsworth, M. Christie, H. Cornelissen, F. Eppink, et al. (2010). The economics of valuing ecosystem services and biodiversity.

Perrings, C., S. Baumgärtner, W. A. Brock, K. Chopra, M. Conte, C. Costello, A. Duraiappah, A. P. Kinzig, U. Pascual, S. Polasky, et al. (2009). The economics of biodiversity and ecosystem services. *Naeem, S., Bunker, DE, Hector, A., Loreau, M. and Perrings, C., Biodiversity, ecosystem functioning, and human wellbeing: an ecological and economic perspective. Oxford University Press, Oxford*, 230–247.

Sarr, M., T. Goeschl, and T. Swanson (2008). The value of conserving genetic resources for r&d: A survey. *Ecological Economics 67*(2), 184–193.

Schindel, D. E. et al. (2020). Economic analyses of federal scientific collections: Methods for documenting costs and benefits.

Simpson, R. D., R. A. Sedjo, and J. W. Reid (1996). Valuing biodiversity for use in pharmaceutical research. *Journal of Political Economy 104*(1), 163–185.

Swanson, T. and T. Goeschl (2000). Property rights issues involving plant genetic resources: implications of ownership for economic efficiency. *Ecological Economics 32*(1), 75–92.

von der Goltz, J., A. Dar, R. Fishman, N. D. Mueller, P. Barnwal, and G. C. McCord (2020). Health impacts of the green revolution: Evidence from 600,000 births across the developing world. *Journal of Health Economics 74*, 102373.

Weitzman, M. L. (1992). On diversity. *Quarterly Journal of Economics 107*(2), 363–405.

Weitzman, M. L. (1993). What to preserve? an application of diversity theory to crane conservation. *Quarterly Journal of Economics 108*(1), 157–183.

Weitzman, M. L. (1998). The noah's ark problem. *Econometrica*, 1279–1298.