Conservation of genetic resources

Introduction

So far in this course our focus has been on conservation of natural populations, species, communities, and ecosystems. I mentioned captive breeding in passing when we discussed management of endangered species, but we didn't discuss it at all. There is another strain of thought in conservation biology whose professional roots are as old as those of natural resource management and whose modern incarnation is a decade older than conservation biology — gene resource conservation.[1]

A brief history

The origins of gene resource conservation can be traced to the 1910's and the interest of agriculturalists in the origin of domesticated crops and in the use of wild relatives of crops in breeding programs. The interest was great enough that by 1924 the Russian botanist Nikolai I. Vavilov founded the All-Union Institute of Applied Botany and New Crops.[2] Before the Second World War the Institute sponsored 180 collecting trips in 65 countries. By 1940 it held about 200 thousand accessions of wheat, cotton, potato, legumes, vegetables, and other crops.[3] The number and size of crop gene banks has continued to grow dramatically ever since.[4]

[1] I'll focus almost exclusively on conservation of *plant* genetic resources, because it's what I know most about.

[2] Renamed the All-Union Institute of Plant Industry in 1930. Since 1967 it has been known as the N. I. Vavilov Research institute of Plant Industry.

[3] For more information on the Institute, visit `http://www.vir.nw.ru/`.

[4] Since plants have seeds that can be stored, gene banks have been much more extensively used for crop germplasm than for animal germplasm. Cryopreservation techniques have made sperm banks and egg banks possible for some animal species, but *in vitro* fertilization techniques are still quite inefficient and are available for only a few animal species.

Consequences of reduced diversity

In the early 1970's crop scientists began to worry that the genetic diversity plant and animal breeders was rapidly being lost. The corn leaf blight brought home to crop breeders in North America the extent to which genetic diversity in crop plants was being eroded.[5]

- By 1970 roughly three-quarters of the corn acreage was planted in "Texas T cytoplasm" corn.
  - The Texas T cytoplasm results in individuals that are male-sterile. This makes production of hybrid corn far less labor intensive than when seed companies had to hire young, midwestern farm boys to de-tassel corn plants in the field.
  - Individuals with this cytoplasm are susceptible to a leaf blight caused by *Helminthosporium maydis*. In 1970 this blight swept through fields of "Texas T cytoplasm" corn.
  - Yield was reduced by approximately 710 billion bushels. The cost to farmers was about $1 billion.
- Although the corn leaf blight is a recent example of the reduction in genetic diversity in crop plants, it is by no means the first.
  - In 1916 a rust fungus destroyed about 3 million bushels of wheat in the United States, roughly one-third of the crop.
  - In the 1840's an infestation of *Phytophora infestans* was precipitated by extensive planting of a single, genetically uniform potato in Ireland.[6] The reduction in the potato harvest associated with the potato blight was at least partially responsible for
    - the death of 1–2 million people and
    - the emigration of 2 million more.

[5]One could argue that if they'd been paying attention to history, they would have become worried much earlier, but some times it takes a dramatic event close to home to get people's attention.

[6]I should point out that my limited understanding of the Irish potato famine suggests that British government policies associated with land use and land tenure contributed to the famine. Most of the land in Ireland was owned by English, which was divided into small parcels and rented to Irish peasant farmers. Typical peasants were subsistence farmers renting fewer than 10 acres. Potatoes were a staple of their diet, providing the bulk of their calories and nutritional needs. Repeal of the Corn Laws, which imposed heavy tariffs on imported grain, did less to alleviate the food shortage than it might have, because their was great resistance to government intervention in economic activity.

Coining the term

As far as I can tell, the term "genetic resources" dates to 1970, when O. H. Frankel and E. Bennett edited a book entitled *Genetic Resources in Plants: Their Exploitation and Conservation* (Cambridge University Press). It is used to denote the genetic variation present in the plant and animal species upon which humans depend for survival, and there are two related aspects:

1. the diversity of species used and
2. the diversity within species necessary for continued use.

Diversity of species used

When you visit the supermarket it may seem as if we use an incredible variety of different plant species to provide food. In fact, we depend on a vanishingly small proportion of the existing diversity of plants.

- There are roughly 250,000 species of land plants currently extant.
- Of those, roughly a quarter (60,000) are thought to possess some food value for humans.
- Over the course of human history, about 3,000 have actually been used by one or more cultures as a regular source of foodstuffs (about 1% of the total).
- Only about 150 have been commercially cultivated.
- In 1974[7] only seven of the 30 major cultivated crops had harvests in excess of 100 million tons.
  - wheat
  - rice
  - corn
  - potato
  - barley
  - sweet potato

[7] and it hasn't changed much since

- cassava

- Only three species account for over two-thirds of the world's total grain crop:
  - wheat
  - rice
  - corn

Many minor crops (and "heritage varieties" of major crops) are in danger of economic extinction, e.g.,

- tarwi (*Lupinus mutabilis*)
- relatives of swordbean (*Canavalia plagiosperma*, *C. regalis*)
- African yeheb nut (*Cordeauxia edulis*)

A similar pattern is seen with domesticated animals. Over 3000 breeds of donkey, cattle, horse, pig, sheep, and water buffalo are known, and over 1000 are at risk of extinction [1]. I'll focus on genetic resource of crop plants, because that's what I am most familiar with.

Concern about the narrow base species and the narrow base of diversity within those species[8] on which human welfare depends led to the formation of the

- International Board for Plant Genetic Resources (IBPGR) within the framework of the
- Consultative Group on International Agricultural Research (CGIAR)
- to promote the collection, conservation, documentation, evaluation and use of crop plant genetic resources.

What does such an organization do? What problems does it face? To answer these questions we must address the following questions first:

- What are the consequences of domestication?
- What are the uses of genetic resources?
- What are the techniques that can be used to conserve them?

[8] More on this in a moment.

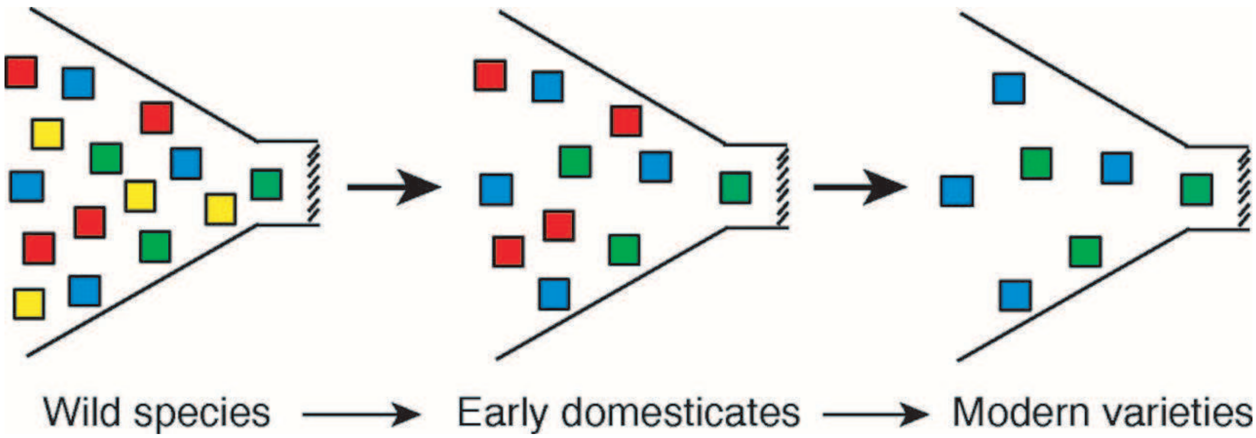

Figure 1: Loss of genetic diversity during crop domestication (from [4])

Consequences of domestication

Just as the diversity of species we depend on is a small fraction of the species available to us, so is the genetic diversity with those species a small fraction of the genetic diversity actually present in them. The species we depend on have become more and more genetically uniform. Well over half of the soybean crop in the United States is genetically engineered, and it's likely that the diversity of soybean germplasm in Iowa is less now than it was even five years ago.[9] Tanksley and McCouch [4] have a figure that illustrates this nicely (Figure 1):

I mentioned some extreme examples at the beginning of this lecture. Let's consider the more typical case of barley. As with many other crop plants, the genetic resources can be divided into five categories:

1. "Advanced" varieties in current commercial use and bred varieties no longer in commercial use.

2. Genetic stocks, i.e., lines that carry particular mutations, cytogenetic rearrangements, or linkage markers.

3. Bulk populations or composite crosses developed from crosses from a wide variety of cultivars.

4. "folk" varieties of land races associated with traditional, pre-scientific agriculture

5. wild progenitors or relatives of potential use in crop breeding (or as new crops)

[9] To be honest, I'm not sure that anyone's actually looked.

	Within samples	Total collection
32 Swedish cultivars	0.005	0.095
C.C.–21, F_17		0.100
C.C.–31, F_4		0.140
12 Iranian land races	0.081	0.170
28 Israel wild populations	0.118	0.230

Table 1: Genetic diversity in barley as based on allozyme loci.

As illustrated in Table 1, a single, wild population of barley in Israel harbors more electrophoretic diversity than an advanced generation of a composite cross. A relatively small number of populations from a small part of the wild range contains far more electrophoretic diversity than a broadly based composite cross. Notice that about half of the diversity present is due to differences *among* populations. There is, of course, an important few caveat: patterns of variation at electrophoretic loci need not match those of economically or agronomically important traits. And barley is not unique. Rice and tomatoes show much the same pattern (Figure 2).

Use of genetic resources

The need to avoid complete genetic uniformity over a long period is obvious from the examples of agricultural pathogens I've already mentioned — corn leaf blight, wheat rust, potato blight. Are there more immediate concerns about conservation of genetic resources? Yes. Consider how important use of genetic resources has been in increasing agricultural production.

- Yields of many crops increased dramatically in the half century from 1930 to 1980.
  - Rice, barley, soybeans, wheat, cotton, and sugarcane — doubled
  - Tomato — tripled
  - Corn, sorghum, potato — quadrupled
- Plant breeders use of genetic diversity accounted for at least one-half of that doubling [3]
- Even maintaining productivity requires constant input of new genetic material to overcome crop losses due to pests that become pesticide resistant.

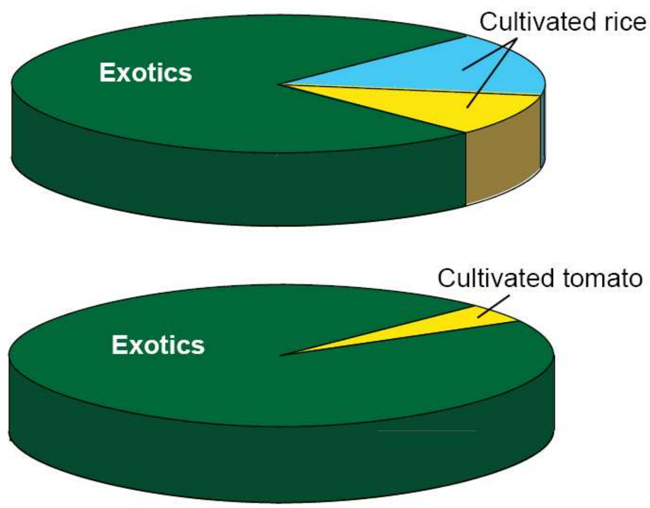

Figure 2: Relative amounts of genetic diversity in cultivated rice and tomato and wild relatives ("exotics") with which they are cross-compatibile (from [4]).

- Consider the humble tomato
  - Resistance to at least 32 major tomato diseases have been discovered in wild relatives of the cultivated tomato.
  - Genes responsible for promoting resistance to 16 of these have been bred into commercial cultivars, allowing tomato production in areas where they could not otherwise have grown.
  - Insect resistance, tolerance to temperature extremes, salinity tolerance, drought tolerance, and tolerance of waterlogging are among the traits expressed in wild relatives that may be useful in breeding commercial tomatoes.
  - The potential economic value is great.
    - High fruit solids are important for processing-type tomatoes because less water is processed and more paste is manufactured from each ton of tomatoes.
    - Each 0.1% increase could be worth as much as $10,000,000 per year to the California tomato processing industry.
    - Breeding lines between cultivated tomato and *Solanum chmielewskii* have the potential to increase fruit solids from 6.2% to 8.6%, an increase of 2.4% which would be worth nearly $250,000,000 per year.

- Overall crop breeding programs add at least $1 billion per year to the value of U.S. agricultural production.
- But the most spectacular example has to be associated with the "Green Revolution."[10]
  - A cultivar of wheat, "Norin 10," from Japan was of shorter stature than typical varieties of wheat being grown because of two genes, *Rht1* and *Rht2*, that caused dwarfing. These genes were derived from a Japanese landrace "Shiro Daruma."
  - Norman Borlaug speculated that by breeding these genes into Mexican wheat lodging would be reduced and the plants would respond to fertilizer application.
  - As it turns out, these genes not only reduce lodging through reduced height, they have direct effects on yield as a result of more efficient nutrient uptake and enhanced tillering.

The potential of seed banks to contribute to increased agricultural production is probably much greater than what has already been realized [4]. The old paradigm for use of gene banks was simple, look for the phenotype:

1. Screen entries from a gene bank for a desired characteristic.
2. Cross with an elite cultivar to introduce the genes.

While simple, it works well only for simply inherited traits, i.e., those associated with only one or two genes. There are, of course, many traits that are agronomically important that are also influenced by more than one or two genes. Because of the severe bottlenecks associated with production of today's elite cultivars, it is unlikely that modern cultivars retain all of the genes that could contribute to high yield. The new paradigm is to look for the genes:

1. Use molecular markers to map loci that contribute to agronomically important traits, like yield.
2. Use the markers that have been identified to enhance the introgression of these multi-locus traits into an elite background.

Using this approach in cultivated tomato, genes from *Solanum hirsutum* were introgressed and resulted in lines that yield 48% more, have 22% greater soluble solids content, and 33% "better" color (even though *S. hirsutum* is green). The normal yearly improvement from traditional breeding techniques is less than 1%.

[10] This discussion is drawn from [2].

Techniques for conservation of genetic resources

There are two major alternatives for the conservation of genetic resources: *in situ* and *ex situ*.

- *In situ* conservation refers to the conservation of important genetic resources in wild populations and land races, and it is often associated with traditional subsistence agriculture.
  - If the focus is only on *agricultural* varieties, the approach is only partially effective because traditional crop varieties, though much more diverse than elite varieties, are themselves much less diverse than wild populations and wild relatives.
  - An attractive approach is to combine nature reserves focused on protection of wild races and wild relatives with traditional agricultural practices. Note: we shouldn't expect traditional farmers to forgo the substantial economic benefits that may attend the switch to elite varieties. This may require direct economic subsidy or conservation of traditional varieties in some other way.
- *Ex situ* conservation refers to the conservation of genetic resources off-site in gene banks, often in long-term storage as seed.
  - Seeds of many important tropical species are recalcitrant, i.e., difficult or impossible to store for long periods.
  - Many crop plants are clonally propagated. Storing seed does no good, and tissue culture techniques for long-term storage are poorly developed.

The story of rubber

Vulcanization of rubber was developed in 1839, and the development of this process led to a huge increase in the exploitation of Amazonian trees. Supplies were soon inadequate to meet the demand. Sir Clements Markham and Sir Joseph Hooker arranged for a collection of seed from Brazil to be sent to the Royal Botanical Gardens at Kew in 1873.

- Twelve small plants grown from these seed were dispatched to India and promptly died.
- A second consignment (1875) also failed.

In 1875 Hooker commissioned H. A. Wickham to collect 70,000 seeds, and they were sent by chartered ship to Liverpool and thence to Kew.

- By June, 1876 fewer than 4% of the seed had germinated.
- In August, 1876 the British Colonial Office shipped nearly 2000 seedlings in specially constructed glass cases to Ceylon. Kew sent an additional 22 to the Singapore Botanical Garden.
- In 1888, 20,000 seeds were harvested from the tress planted in Ceylon and shipped to Singapore.
- The first rubber plantation was established in Malaysia using these seeds in 1898, and Malaya quickly became the principal source of rubber for the world's industry.
- Attempts to establish plantations in South America have failed, because of a leaf blight.

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