

# Genetic Drift

Mechanism, Founder Effect and Population Bottleneck

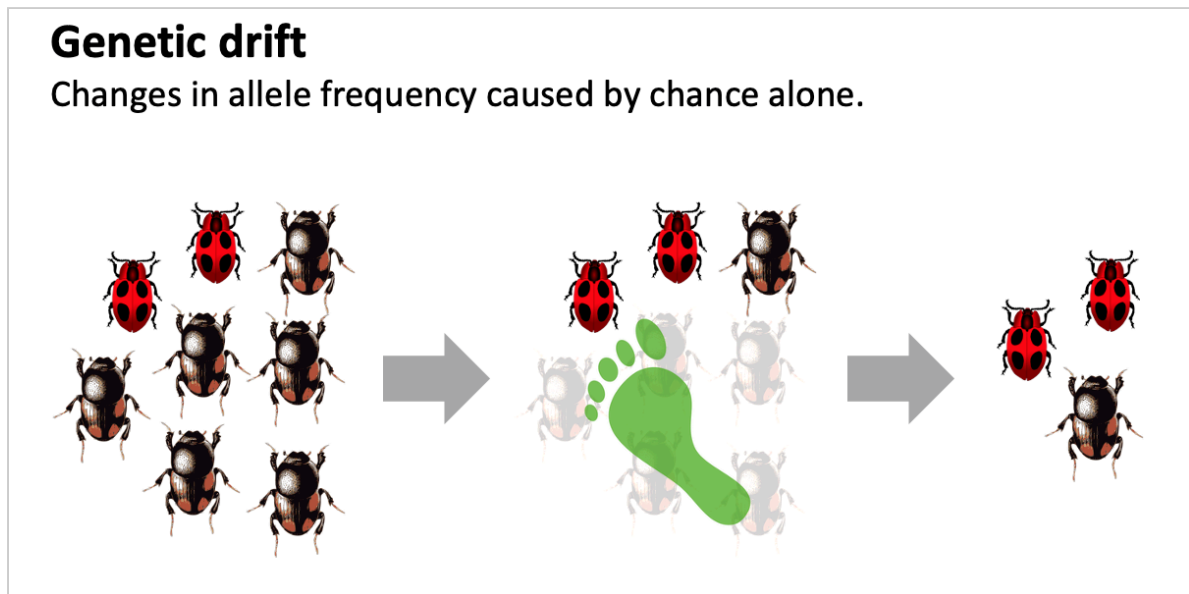


Figure 1 Genetic drift as random changes in allele frequency across generations in a small population (schematic diagram, Wikimedia Commons).

## 1 Introduction

Evolutionary change in populations occurs through several mechanisms such as natural selection, mutation, migration and genetic drift. Genetic drift refers to evolutionary change that is driven purely by chance. It is particularly important in small or isolated populations, where random sampling of gametes and individuals can substantially alter allele frequencies from one generation to the next.

### DEFINITION

**Genetic drift** is the random fluctuation of allele frequencies in a population across generations due to chance sampling of gametes and individuals, independent of their effects on fitness.

Unlike natural selection, which is a directional and environment dependent process that consistently favors genotypes with higher reproductive success, genetic drift is stochastic. It can increase or decrease the frequency of any allele, beneficial, neutral or even slightly deleterious. Over many generations in a finite population, drift can lead to fixation of one allele and loss of others.

## 2 Conceptual foundations

### 2.1 Gene pool and allele frequency

The **gene pool** of a population is the complete set of alleles present at all loci in all individuals. For a single locus with two alleles, for example A and a, the allele frequencies are usually denoted by  $p$  and  $q$  respectively, where  $p + q = 1$ .

In an infinitely large population with random mating, no selection, mutation or migration, allele frequencies remain constant through time. This is the Hardy Weinberg equilibrium. In real populations, however, the number of breeding individuals is finite, so sampling error in the formation of gametes and zygotes introduces random deviations from the expected frequencies.

#### KEY IDEA

Genetic drift arises because each generation is effectively a random sample of the previous generation. When sample sizes are small, random deviations from expected allele frequencies are large, so drift is stronger.

### 2.2 Strength of drift and effective population size

The magnitude of genetic drift depends on the **effective population size**, denoted  $N_e$ . This is the size of an ideal randomly mating population that would experience the same amount of drift as the population under study. In general, the variance in change of allele frequency per generation is approximately

$$\text{Var}(\Delta p) \approx p(1-p) / (2N_e)$$

Thus, smaller values of  $N_e$  produce larger random changes in allele frequencies. In very large populations, drift is weak and slow. In small populations, drift can rapidly fix or eliminate alleles.

## 3 Mechanism of genetic drift

Genetic drift operates each generation through several sampling steps.

1. Adults produce gametes with allele frequencies approximately equal to those present in the adult population.
2. Only a finite number of gametes participate in fertilization. This introduces binomial sampling error so that the allele frequencies among zygotes differ slightly from the expectations based on the adult gene pool.
3. Some zygotes fail to survive to reproductive age for reasons unrelated to genotype, for example accidents or random environmental effects, introducing further stochasticity.
4. The resulting adult generation has allele frequencies that have shifted randomly compared with the previous generation.

Repeated over many generations, these random shifts resemble a random walk. Eventually one allele may reach frequency 1 (fixation) and the alternative allele is lost. The probability

that a neutral allele ultimately becomes fixed is equal to its current frequency.

### 3.1 Genetic drift versus natural selection

Natural selection and genetic drift frequently act together. Selection tends to increase the frequency of alleles that confer higher fitness, whereas drift introduces random noise. In very small populations, drift can overpower selection and cause the loss of slightly advantageous alleles or the fixation of mildly deleterious alleles.

Feature	Genetic drift	Natural selection
Cause	Random sampling of gametes and individuals	Systematic differences in survival or reproduction among genotypes
Dependence on population size	Stronger in small populations, weaker in large populations	Can be strong in any population size if fitness differences are large
Directionality	Directionless, can increase or decrease any allele frequency	Directional, pushes allele frequencies toward higher fitness combinations
Outcome over many generations	Fixation or loss of alleles irrespective of their effect on fitness	Increase of beneficial alleles and removal of strongly deleterious alleles
Role in evolution	Reduces genetic variation, can cause divergence between small isolated populations	Drives adaptive evolution and fit between organisms and environments

## 4 Special cases of genetic drift

Two particularly important scenarios of strong genetic drift are the **founder effect** and the **population bottleneck**. Both involve a drastic reduction in the number of breeding individuals, but they differ in context.

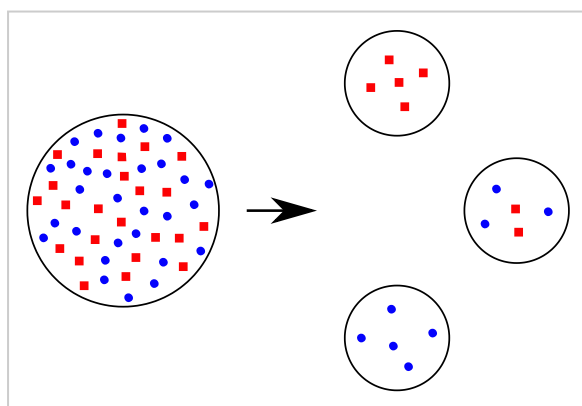


Figure 2 Founder effect. A small group leaving a larger population carries only a subset of alleles into a new habitat.

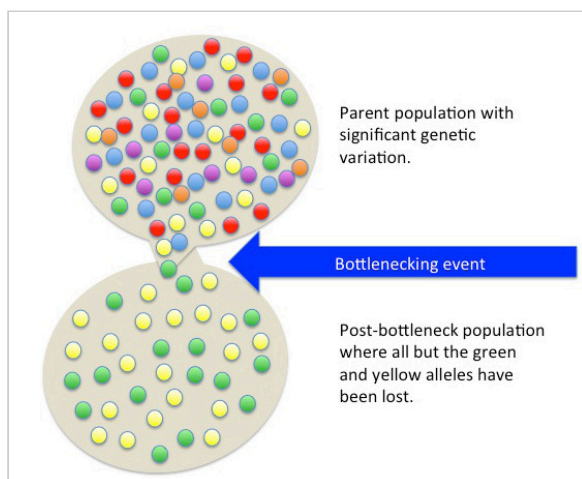


Figure 3 Population bottleneck. A temporary crash in population size sharply reduces genetic diversity.

## 4.1 Founder effect

The founder effect occurs when a small number of individuals colonize a new area or become isolated from the main population. The new population is founded by only a few genotypes, which may not be representative of the original gene pool.

### FOUNDER EFFECT

The **founder effect** is a type of genetic drift that occurs when a new population is established by a small number of individuals from a larger population, causing the new population to have allele frequencies that differ from the source population.

### Characteristics

- Begins with a small group of founders separated from a larger ancestral population.
- Allele frequencies in the founders are a random sample of those in the source population.
- Rare alleles can become common if they are present in one or more founders.
- Genetic diversity in the new population is typically lower than in the source population.

### Examples

- **Island colonization** colonization of remote islands by a few birds or insects can produce populations whose genetic composition differs strongly from that on the mainland.
- **Human isolates** some human populations, such as isolated island communities or religious isolates, show high frequencies of otherwise rare genetic disorders because their founding individuals carried those alleles.
- **Endemic species** many endemic species on archipelagos originated from one or a few colonization events followed by drift and selection.

## 4.2 Population bottleneck

A population bottleneck occurs when an existing population experiences a sudden, severe reduction in size, for example due to habitat destruction, overexploitation, disease outbreaks or natural disasters. Only a small number of individuals survive and contribute genes to subsequent generations.

### POPULATION BOTTLENECK

A **population bottleneck** is an episode during which population size is drastically reduced for one or more generations, causing loss of alleles and increased genetic drift in the surviving lineage.

### Phases of a bottleneck

1. **Pre bottleneck phase** a large, genetically diverse population with many alleles at most loci.
2. **Bottleneck event** a sharp decline in population size often to only dozens or hundreds of individuals.

3. **Post bottleneck recovery** population size may increase again, but from a reduced genetic base. Lost alleles are not spontaneously restored except through new mutation or migration.

### Consequences of bottlenecks

- Loss of alleles, especially rare ones, leading to reduced genetic diversity.
- Increased homozygosity and potential exposure of deleterious recessive alleles.
- Greater susceptibility to further random fluctuations in allele frequencies, because post bottleneck populations are usually small.
- Potential reduction in adaptive potential in the face of future environmental change.

### Real world examples

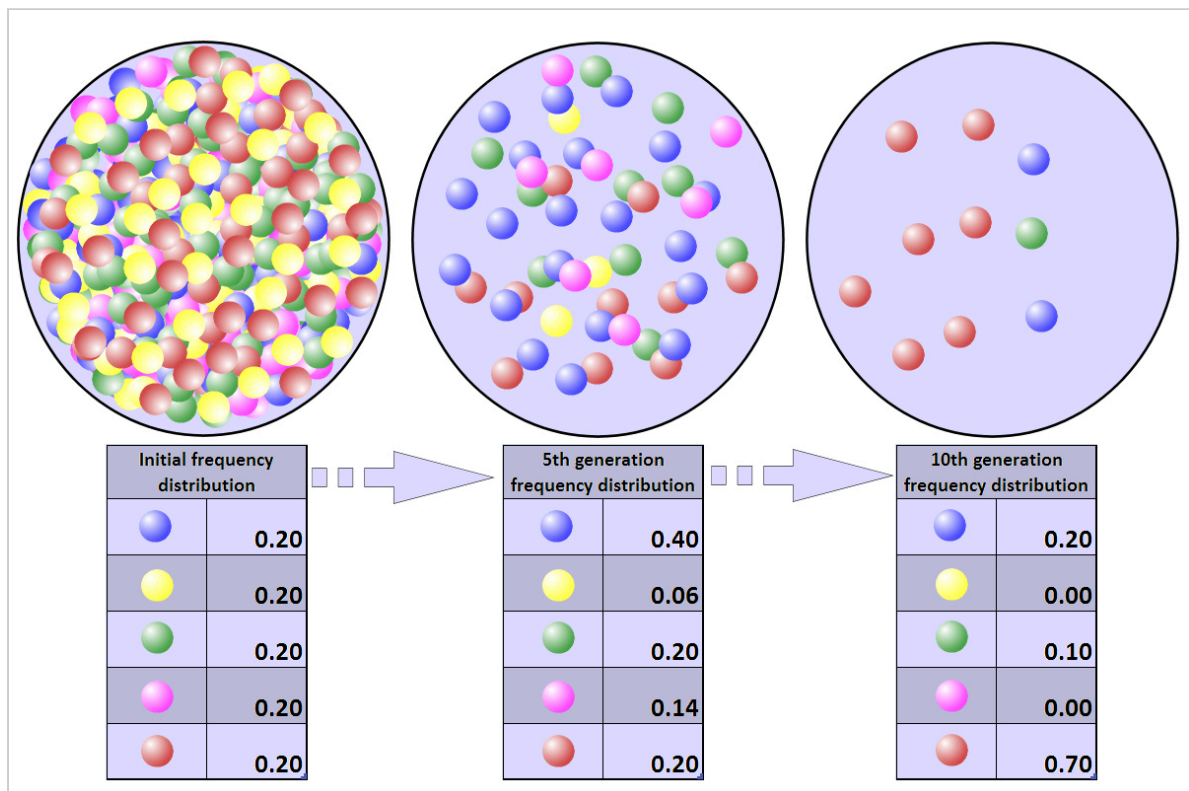


Figure 4 Population bottleneck schematic showing a sharp temporary crash in population size and subsequent recovery.



Figure 5 Cheetah *Acinonyx jubatus*, a species with very low genetic variability that has experienced historical bottlenecks.



Figure 6 Southern elephant seal *Mirounga leonina*, whose populations recovered from severe overhunting but retain reduced genetic diversity.

- **Cheetahs** cheetahs show remarkably low genetic variation at many loci, consistent with one or more historical bottlenecks. Individuals are so genetically similar that skin grafts between unrelated cheetahs are often not rejected.

- **Northern elephant seals** nineteenth century hunting reduced northern elephant seal numbers to a few dozen individuals. Although the species has since recovered numerically, genetic diversity remains low.
- **Human history** various genetic and archaeological data suggest that human populations have undergone bottlenecks associated with climatic events and migrations.

## 5 Founder effect versus bottleneck

Founder events and bottlenecks are both situations where genetic drift is intense, but they arise under different circumstances. The table below summarizes the main differences.

Feature	Founder effect	Population bottleneck
Typical trigger	Small group migrates or is isolated and forms a new population	Existing population experiences drastic mortality or failure to reproduce
Change in geographic location	Usually involves colonization of a new area or habitat	Usually occurs in the same geographic area
Population size dynamics	Starts small and may grow rapidly in the new location	Large population shrinks severely, then may recover in size
Source of alleles after the event	Alleles present in the founders, a random subset of the source population	Alleles carried by the survivors of the bottleneck
Genetic consequences	Low diversity, potential high frequency of rare alleles carried by founders	Loss of many alleles, especially rare ones, increased homozygosity
Examples	Island colonization, formation of small human isolates	Cheetahs, elephant seals, species reduced by overhunting or habitat loss

## 6 Long term effects of genetic drift

### 6.1 Loss of genetic variation within populations

Genetic drift steadily erodes genetic variation within a population. Each fixation event removes alternative alleles from the gene pool. In the absence of mutation or migration, a finite population will eventually become monomorphic at all loci.

### 6.2 Divergence among populations

Different populations of the same species experience independent random fluctuations in allele frequencies. Over time, genetic drift can cause populations to diverge from one another even if they live in similar environments. This divergence provides raw material on which natural selection and other processes can act during speciation.

### 6.3 Interaction with inbreeding

Small populations that have gone through bottlenecks or founder events often show high levels of **inbreeding**. Drift and inbreeding together increase homozygosity and can expose

deleterious recessive alleles. This can lead to **inbreeding depression**, a reduction in fitness due to the expression of harmful alleles.

## 7 Genetic drift in conservation biology

Conservation biologists pay close attention to genetic drift because many threatened species exist in small, fragmented populations. When numbers are low, genetic drift can rapidly remove variation that might be needed for adaptation to future environmental changes, such as new diseases or climate shifts.

- Small, isolated populations are at high risk of losing adaptive potential through drift.
- Management strategies such as establishing habitat corridors or translocating individuals can increase gene flow and counteract the effects of drift.
- Captive breeding programs must avoid repeated bottlenecks and maintain sufficiently large breeding populations to minimize loss of diversity.

### PRACTICAL GUIDELINE

For many conservation programs, maintaining an effective population size of at least a few hundred individuals is recommended to limit short term loss of heterozygosity due to drift, and larger sizes are desirable for long term evolutionary potential.

## 8 Summary

- Genetic drift is random change in allele frequencies due to chance sampling of gametes and individuals.
- Drift is strongest in small populations, where sampling error is large.
- Over time, drift can lead to fixation or loss of alleles and reduction of genetic variation within populations.
- Founder effects occur when a small group establishes a new population whose allele frequencies differ from the source population.
- Population bottlenecks are sharp reductions in population size that intensify drift and reduce genetic diversity among survivors.
- Both founder events and bottlenecks can increase the frequency of rare alleles and influence patterns of disease and adaptation.
- In conservation, limiting the strength of genetic drift by maintaining large, connected populations is essential for long term viability.

## 9 Review questions

1. Define genetic drift and explain how it differs from natural selection in terms of cause and directionality.
2. Why is genetic drift stronger in small populations than in large populations? Explain using the concept of sampling error.
3. Describe a realistic example of a founder effect in nature. How might this event alter allele frequencies compared with the source population?
4. Outline the stages of a population bottleneck and explain why genetic diversity remains low even if the population size later recovers.
5. Compare and contrast founder effect and population bottleneck with respect to trigger, geography and genetic consequences.
6. Explain why species that have undergone severe bottlenecks can be more vulnerable to diseases or environmental change.