

chapter 23 the evolution of populations answer key

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Understanding Chapter /23: The Evolution of Populations – A Comprehensive Answer Key

When studying evolutionary biology, Chapter 23 often stands out as the core of population genetics. It bridges theory with real world data, explaining how genetic variation is maintained, altered, or lost over time. This article offers a thorough walk through of the chapter's essential concepts, typical exam questions, and a detailed answer key. Whether you're a student preparing for a midterm or a teacher looking for a quick refresher, this guide is designed to help you master the material with clarity and confidence.

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Chapter Overview

Chapter 23 delves into the dynamics that shape genetic variation within populations. It begins with a discussion of the Hardy–Weinberg equilibrium, a foundational principle that provides a baseline against which evolutionary forces can be measured. The chapter then explores four primary mechanisms that drive evolutionary change: natural selection, genetic drift, gene flow, and mutation. Each mechanism is illustrated with mathematical models, empirical data, and real life examples.

In addition to theoretical explanations, the chapter includes a series of problem sets designed to test students' ability to apply concepts to data analysis. The answer key we present here aligns with those problems, offering step by step reasoning and highlighting common pitfalls.

Key Concepts and Definitions

Hardy–Weinberg Equilibrium

Under ideal conditions—no mutation, migration, selection, genetic drift, and random mating—allele and genotype frequencies remain constant across generations. The equilibrium equations are:

- Allele frequencies: $p + q = 1$
- Genotype frequencies: $p^2 + 2pq + q^2 = 1$

These equations provide a null model. Deviations from Hardy–Weinberg proportions indicate that at least one evolutionary force is at work.

Genetic Drift

Random fluctuations in allele frequencies, especially pronounced in small populations. Two classic forms:

- Founder effect: a new population founded by a few individuals carries only a subset of the original genetic variation.
- Bottleneck effect: a drastic reduction in population size temporarily lowers genetic diversity.

Gene Flow

Movement of alleles among populations through migration. Gene flow tends to homogenize allele frequencies, counteracting the diversifying effects of drift and selection.

Mutation

The ultimate source of new genetic variation. While most mutations are neutral or deleterious, a small fraction may be advantageous, providing raw material for natural selection.

Fitness

A measure of an organism's reproductive success relative to others in the population. Fitness is often denoted by w , with relative fitness values compared to a reference genotype.

Selection Coefficient (s)

The reduction in fitness of a genotype relative to the most fit genotype. For a deleterious allele with fitness $1 - s$, s quantifies its selective disadvantage.

Effective Population Size (N_e)

The number of individuals in an idealized population that would experience the same amount of genetic drift as the actual population. It is typically smaller than the census size due to factors like unequal sex ratios or variance in reproductive success.

Mechanisms of Evolutionary Change

Natural Selection

Natural selection operates through differential survival and reproduction. The chapter discusses two main forms:

- Directional selection favors one extreme phenotype, shifting allele frequencies in one direction.
- Stabilizing selection favors intermediate phenotypes, reducing variation.
- Disruptive selection favors both extremes, potentially leading to speciation.

Mathematically, selection changes allele frequencies according to:

$$p' = \frac{p w_A}{\bar{w}}$$

where w_A and w_a are the fitnesses of the two alleles, and $\bar{w}$ is the mean fitness of the population.

Genetic Drift

Because allele frequencies fluctuate randomly, the probability of fixation of a neutral allele is simply its initial frequency (p). Drift is most powerful in small populations and can lead to loss of rare alleles or fixation of deleterious alleles.

Gene Flow

When individuals migrate between populations, allele frequencies change according to:

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where m is the migration rate. High gene flow can prevent local adaptation by introducing maladaptive alleles.

Mutation

In a large population, the equilibrium frequency of a deleterious allele under mutation–selection balance is $q \approx \frac{\mu}{hs}$ where μ is the mutation rate. For neutral mutations, the fixation probability equals the allele's initial frequency.

Mathematical Models in Population Genetics

Hardy–Weinberg Calculations

Given observed genotype counts, calculate allele frequencies and test for equilibrium using chi square:

$$\chi^2 = \sum \frac{(\text{Observed} - \text{Expected})^2}{\text{Expected}}$$

A significant chi square indicates deviation from equilibrium.

Fixation Probability

For a beneficial allele with selection coefficient s in a diploid population, the fixation probability is approximately:

$$P_{\text{fix}} \approx \frac{2s}{1 + 2s}$$

provided that s is small and N_e is large.

Effective Population Size

Calculated from variance in reproductive success:

$$N_e = \frac{4N}{V_k + 2}$$

where V_k is the variance in the number of offspring per individual.

Migration-Selection Balance

When selection against a foreign allele (s) balances gene flow (m), the equilibrium frequency is:

$$q_{\text{eq}} = \frac{m}{s + m}$$

Common Exam Questions

1. Explain the difference between directional, stabilizing, and disruptive selection, providing examples.
2. Using a given genotype table, test for Hardy–Weinberg equilibrium and interpret the results.
3. Describe how genetic drift can lead to the loss of genetic variation in a small population.
4. Calculate the expected allele frequency change due to migration between two populations with different allele frequencies.
5. Discuss the role of mutation in maintaining genetic diversity, referencing mutation–selection balance.
6. Interpret a graph showing allele frequency change over time under different selection scenarios.
7. Explain the concept of effective population size and its significance in conservation genetics.
8. Analyze a case study where gene flow has prevented local adaptation in a plant species.
9. Derive the fixation probability of a new beneficial mutation in a population of size $N_e = 10,000$ with selection coefficient $s = 0.01$.
10. Discuss how the founder effect can influence the genetic structure of isolated island populations.

Answer Key with Explanations

Question /1: Types of Natural Selection

Answer: Directional selection favors one extreme phenotype, shifting allele frequencies toward that phenotype. For example, in a population of beetles, if darker coloration confers better camouflage, alleles for dark color will increase. Stabilizing selection favors intermediate phenotypes, reducing variation; a classic example is human birth weight, where both very low and very high weights are selected against. Disruptive selection favors both extremes over the intermediate; consider the case of finches with either very large or very small beaks in a dry environment, where intermediate beak sizes are less efficient at accessing food.

Question /2: Hardy–Weinberg Test

Suppose observed genotype counts: AA = 120, Aa = 80, aa = 100. Total N = 300. Allele frequencies:

- $p = (2 \times 120 + 80) / (2 \times 300) = (240 + 80) / 600 = 320/600 = 0.533$
- $q = 1 - p = 0.467$

Expected genotype frequencies:

- AA: $p^2 \times N = 0.533^2 \times 300 \approx 85$
- Aa: $2pq \times N = 2 \times 0.533 \times 0.467 \times 300 \approx 149$
- aa: $q^2 \times N = 0.467^2 \times 300 \approx 66$

Chi square calculation:

- $(120 - 85)^2 / 85 \approx 13.7$
- $(80 - 149)^2 / 149 \approx 29.1$
- $(100 - 66)^2 / 66 \approx 18.1$
- $\chi^2 = 60.9$

With 1 degree of freedom, the critical value at $\alpha = 0.05$ is 3.84. Since $60.9 > 3.84$, we reject the null hypothesis of Hardy–Weinberg equilibrium. This suggests that at least one evolutionary force (e.g., selection, non random mating, or migration) is acting.

Question /3: Genetic Drift in Small Populations

Answer: In small populations, random sampling of alleles each generation can cause allele frequencies to fluctuate dramatically. Rare alleles may be lost simply by chance, reducing

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