

Bio 112 Handout for Evolution 6

This handout contains:

- Today's iClicker Questions
- Handouts for today's lecture
- Information on Tree Building Survey
- Population Genetics Practice Problems and Solutions

iClicker Question #3A - before lecture

Which of the following statements is/are **true**?

- A. Evolution only happened in the past; it is not happening now.
- B. Humans are not evolving any more.
- C. A disadvantageous allele will always be removed from the population.
- D. Organisms which are more physically fit will always have more offspring.
- E. None of the above are true.

iClicker Question #3B - after lecture

Which of the following is/are examples of sexual selection?

- A. Semen (the fluid produced by males to carry sperm) produced by some species coagulates in the female's reproductive tract forming a plug that prevents further matings.
- B. Semen produced by fruit flies contains chemicals that reduce the female's interest in subsequent matings.
- C. Semen produced by some insects contains proteins that stimulate increased egg production in females.
- D. Male giraffes use their long necks in combat to determine which will mate with a female.
- E. All of the above.

Beaming in your answers

1. Figure out your answer and select the appropriate letter (A-E).
2. Turn on your iClicker by pressing the "ON/OFF" button; the blue "POWER" light should come on. If the red "LOW BATTERY" light comes on, you should replace your batteries soon.
3. Transmit your answer as follows:
 - a. Press the button corresponding to the answer you've selected (A thru E).
 - b. The "STATUS" light will flash green to indicate that your answer has been received. If the "STATUS" light flashed red, your answer was not received; you should re-send it until you get a green "STATUS" light.

Evolution Examples (3): Sickle-cell anemia

Trait controlled by one gene with two alleles:

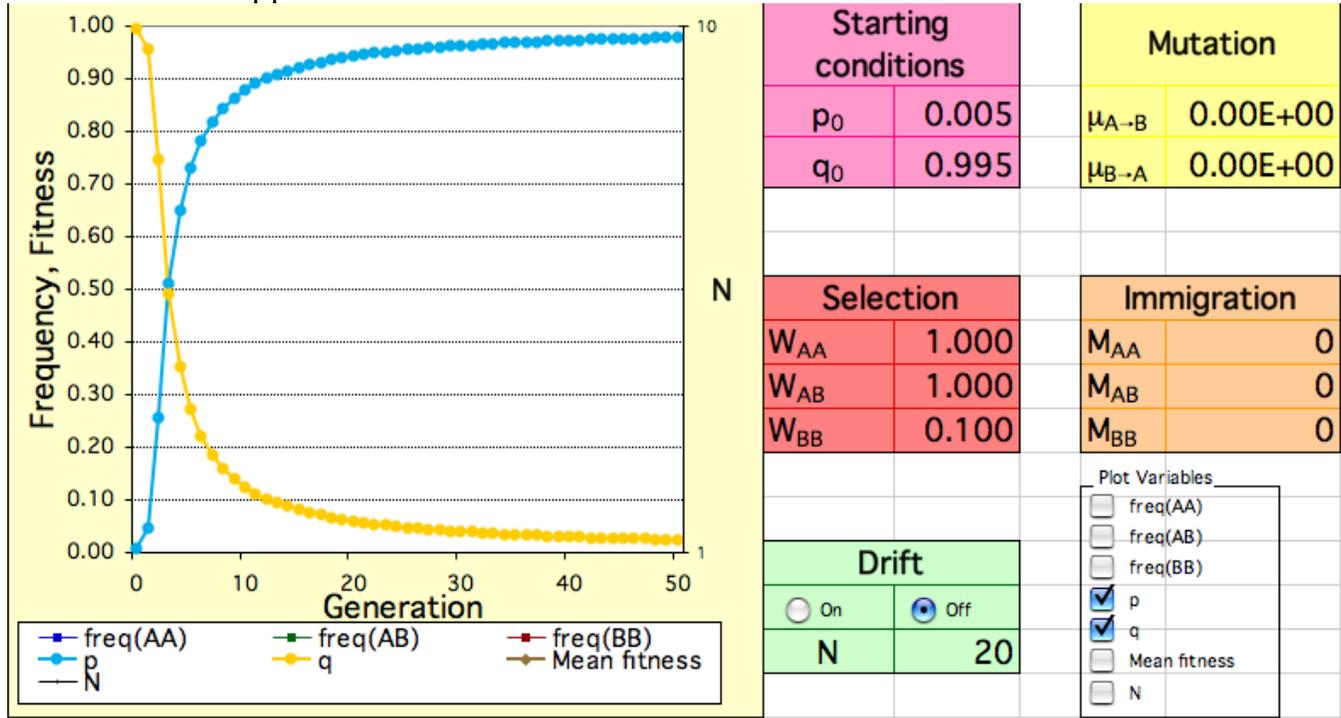
allele contribution to phenotype frequency

A normal blood (dominant) p

B sickle-cell anemia (recessive) q

- BB individuals have sickle-cell anemia and greatly reduced fitness.

- What should happen to the B allele?



However, in areas with high incidence of Malaria (severe and often fatal parasitic infection of red blood cells), the frequency of B (q) is high (0.2) and constant (Campbell fig 23.17). In areas without Malaria, the sickle-cell allele is virtually unknown.

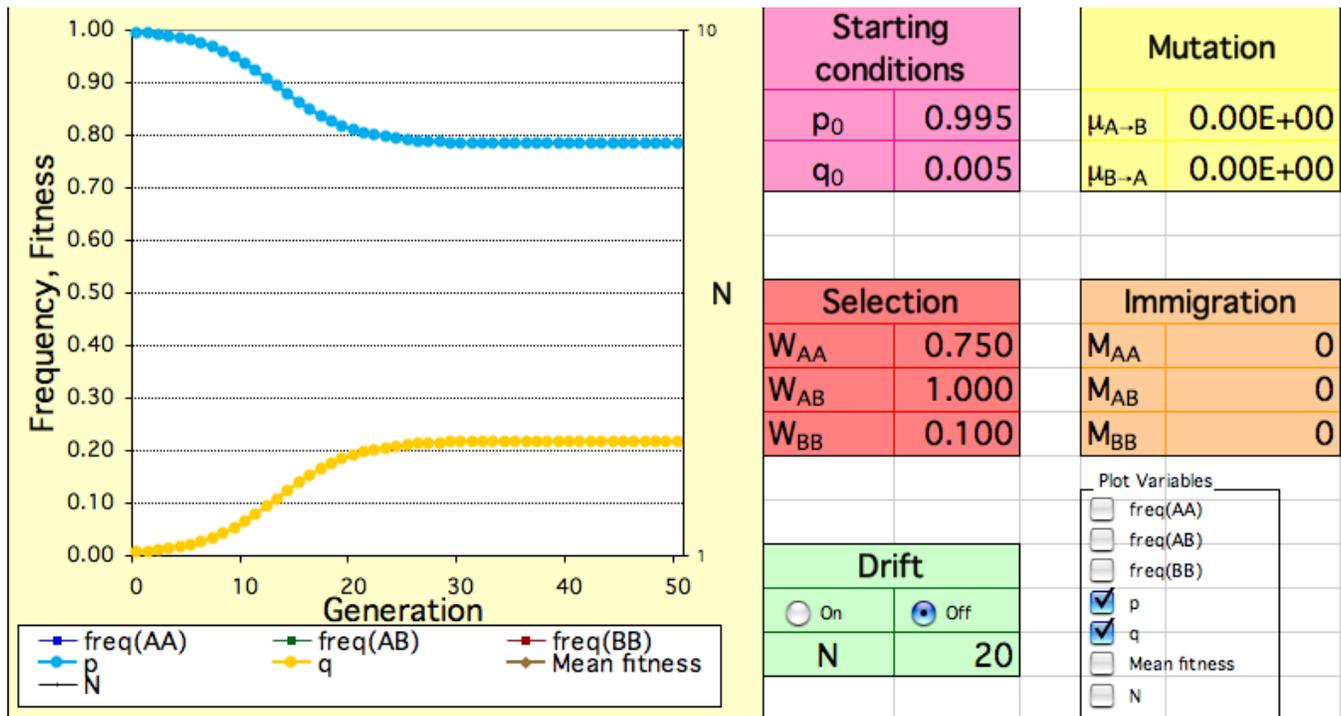
It turns out that the sickle-cell allele confers a dominant resistance to malaria:

allele	contribution to sickle-cell phenotype	contribution to malaria-resistance phenotype	frequency
A	normal (dominant)	none (recessive)	p
B	sickle-cell (recessive)	resistant (dominant)	q

therefore:

genotype	phenotype	fitness with malaria	fitness without malaria
AA	normal	low	high
AB	malaria-resistant	high	high
BB	sickle-cell (& malaria-resistant)	very low	very low

- Without malaria, the expected result is loss of the sickle-cell allele (previous page)
- With malaria, the advantage of being AB is balanced by the disadvantage of being BB.



Sexual Selection

Examples:

1) Advantages in competition with members of the same sex for mating with the opposite sex.

a) Peacock:



Males have ~170 eyespots on tail feathers

- remove 20 spots with scissors and females won't mate with them

b) Barn swallow:



Males have long tail feathers

- glue on longer tail feathers and females pick that male more often for mating

2) Sperm competition because females can mate with more than one male.
Garden spiders



Males lock their genitals onto the female's genitals, mate, and then die. The locked-on dead male prevents other males from mating.

Tree Bulding Survey

This is due by the start of the Evolution 7 lecture.

This survey is designed to see how well you understand the diversity of living organisms. There is no right or wrong answer; you will receive full credit for whatever you write. We are most interested in **your** understanding of these important biological issues.

Please do not consult any outside sources (textbook ,www, other people, etc,) when completing this survey!!

You will complete this survey on-line; once you have completed the survey, you will automatically receive 10 points for the "Tree Building Survey" whether your answers are correct or not.

How to complete the survey:

- 1) Go to any computer connected to the internet. Go to the Bio 111/112 home page:
<http://intro.bio.umb.edu/111-112/>
- 2) Go to the Bio 112 **Lecture Materials** and scroll down to the links for **Evolution 6** and click on the "Complete the Tree Building Survey" link.
- 3) Choose your name from the list and enter your UMS number as a password (leave off the "UMS"). If you do not see something like the screen shown below, your computer does not have Java installed; you should switch to another computer or download Java from the link on the **Lecture Materials** page (it is free).
- 4) Read the instructions carefully - you are to make a tree showing the relationships between the 20 organisms shown at the lower section of the web page.
- 5) Draw your tree: Move the organism labels to appropriate places on the page and connect them with lines as appropriate. **PLEASE DO NOT CONSULT ANY OUTSIDE SOURCES WHEN COMPLETING THIS SURVEY!!**

You should be sure to save your work often by clicking the Submit button.

- 6) Answer the questions that follow the tree.
- 7) Be sure to **Submit** your answers when you are done.
- 8) This assignment must be completed by 12:00 noon on Evolution 7; after that time, you will be able to see your survey but not save any changes or receive credit if you have not already.

Bio 112 Population Genetics Practice Problems

These are intended as practice for the exams; you should do them & write out answers before looking at the solutions. I will hand out solutions in a week or so.

1) In Shorthorn cattle, the genotype $C^R C^R$ is phenotypically red, $C^R C^W$ is roan (a mixture of red and white), and $C^W C^W$ is white.

a) Given that 108 red, 48 white and 144 roan animals were found in the central valley of California, calculate the frequencies of the C^R allele and the C^W allele in the gene pool of the population.

b) If all 5 assumptions for Hardy-Weinberg Equilibrium hold for this population, what is the expected frequency of each genotype in the next generation? Is the population represented in part (a) in Hardy-Weinberg equilibrium?

c) The rancher has observed that white Shorthorn cattle are sterile (unable to reproduce). What are the frequencies of the C^R and C^W alleles in the part of the population that is capable of reproducing? (this is harder than you'd likely find on an exam)

d) Taking into account the sterility of the white cattle, and assuming that the 5 assumptions of Hardy-Weinberg equilibrium hold for the breeding population, what are the expected frequencies of genotypes in the next generation? Would you expect this next generation to be at Hardy-Weinberg equilibrium? Why / why not?

2) Populophobia is a dreaded (but hypothetical) autosomal recessive condition in humans that causes genetics students to go into convulsions whenever they see the Hardy-Weinberg formula. That is: D is the normal allele; d is the populophobia allele (recessive phenotype), so DD and Dd are normal

dd are populophobic - go into convulsions when they see the H-W formula

In a class of 200 genetics students, 32 had convulsions during their first population genetics lecture. Assume that students are a representative sample of a population at Hardy-Weinberg equilibrium.

a) What is the frequency of the populophobia (d) allele in this population? How many students in this class are heterozygous (Dd) for this condition?

b) During the second population genetics lecture, the professor decided to derive the Hardy-Weinberg formula for a population having 10 alleles at a given locus. The trauma induced by the derivation caused 75% of the students with populophobia to spontaneously combust...

POOF!

What is the frequency of each allele in the surviving population of genetics students? What are the frequencies of each genotype and phenotype?

c) The devious professor planned to rid the world of populophobia by forcing all young science students to derive the Hardy-Weinberg formula. Why was he a poor geneticist (besides being insane)?

3) You are studying an obnoxious weed in your backyard. These weeds are sexually-reproducing, freely-interbreeding, diploid organisms. They are either tall, medium, or short; the height is determined by one gene with two codominant alleles:

<u>Genotype</u>	<u>Phenotype</u>
HH	tall
Hh	medium
hh	short

a) Last year, you counted all the weeds in your yard and got the following results:

<u>Height</u>	<u>Number</u>
tall	16
medium	48
short	36

i) What are the frequencies of the two alleles (H and h) in this population? Show your work.

ii) Is this population at Hardy-Weinberg equilibrium? Justify your answer.

b) This year, after a particularly harsh winter, you count all the weeds in your yard again and get the following results:

<u>Height</u>	<u>Number</u>
tall	2
medium	57
short	41

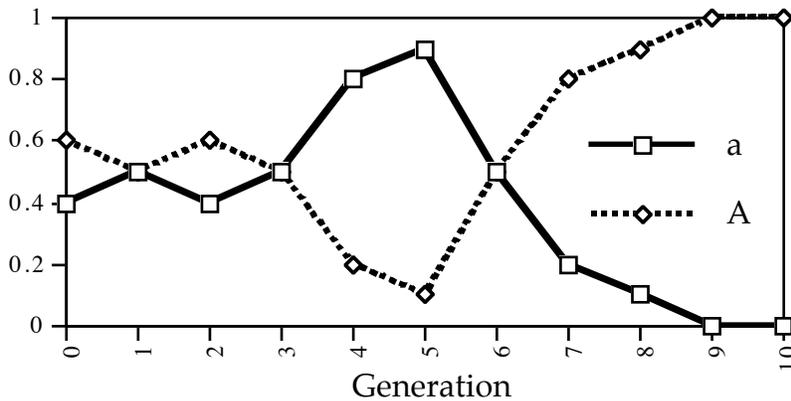
i) What are the frequencies of the two alleles (H and h) in this population? Show your work.

ii) Is this population at Hardy-Weinberg equilibrium? Justify your answer.

c) Offer a reasonable hypothesis to explain the changes in the genetic structure of the population from last year to this year assuming that the changes are **due to natural selection**.

d) Offer a reasonable hypothesis to explain the changes in the genetic structure of the population from last year to this year assuming that the changes are due to **some factor other than natural selection**.

4) Shown below is a graph similar to what you constructed in lab. It is the result of randomly killing 95% of the population in each generation.



Notice that the A allele takes over the population completely and the a allele goes extinct in generation 9. Is this the result of the A allele increasing the fitness of the organisms? Explain your reasoning briefly.

5) Microevolution

You are a time-traveling evolutionary biologist studying a particular species of snake on an island off the coast of Massachusetts. You travel 100,000 years into the past and observe that the snakes are a variety of colors (red, blue, yellow, green) and that most of the snakes are blue. This same species of snake and the same mix of colors are found on the mainland.

a) Assuming that all the snakes are descended from an ancestral blue snake, where did the other colors come from?

At the present time, the snakes are still the same variety of colors, but most of the snakes are green.

b) Explain this change in color frequency (micro-evolution) as though it were based solely on each of the following processes:

i) Bottleneck effect.

ii) Founder effect.

iii) Migration.

iv) Natural selection.

Bio 112 Solving Population Genetics Problems

Reminder:

Genotype frequencies are the frequencies of the three possible genotypes (AA, Aa, aa).

Allele frequencies are the frequencies of the two alleles (A with frequency p; a with frequency q)

In general:

Solving population genetics problems usually follows this pattern:

- (1) Find the allele frequencies; there are 2 methods to use depending on what you know:
 - (1a) if you know all the genotype frequencies
 - (1b) if you know at least one of the genotype frequencies **and** can assume that the population is at HWE. You can then find the other genotype

frequencies.

- (2) Predict the genotype frequencies in the next generation.

- (3) See if the population is at HWE.

The particular steps:

(1a) Find the allele frequencies given all three genotype frequencies. This is the most general way to get allele frequencies; it works under **all** conditions (at HWE and not at HWE). You do it by calculating the number of alleles contributed by each genotype to the gene pool.

- since each individual has two alleles to contribute, the size of the gene pool is the number of individuals times 2.
- each AA individual contributes 2 A's to the pool
- each Aa individual contributes one A and one a to the pool
- each aa individual contributes 2 a's to the pool

For example: given this population

genotype	number
AA	30
Aa	20
aa	50

you calculate the total # of individuals = $30 + 20 + 50 = 100$; this lets you calculate the genotype frequencies:

genotype	number	genotype frequency (number divided by total)
AA	30	$30/100 = 0.3$
Aa	20	$20/100 = 0.2$
aa	50	$50/100 = 0.5$

Now, you can get the allele frequencies in two ways:

⇒ either calculate the contributions using the numbers of each genotype (easy):

genotype	number	contributions to gene pool		
		total alleles	A alleles	a alleles
AA	30	60	60	0
Aa	20	40	20	20
aa	50	100	0	100
total # of alleles = $100 \times 2 = 200$		(or $60 + 40 + 100 = 200$)		
total # of A's = $60 + 20 = 80$		frequency of A = $p = 80/200 = 0.4$		
total # of a's = $20 + 100 = 120$		frequency of a = $q = 120/200 = 0.6$		

⇒ or calculate using the frequencies of each genotype (more advanced):

$$\text{frequency of } A = p = (\text{frequency of } AA) + (\text{frequency of } Aa) / 2 \\ = 0.3 + (0.2) / 2 = 0.3 + 0.1 = 0.4$$

$$\text{frequency of } a = q = (\text{frequency of } aa) + (\text{frequency of } Aa) / 2 \\ = 0.5 + (0.2) / 2 = 0.5 + 0.1 = 0.6$$

(1b) Find the allele frequencies given at least one genotype frequency **and** assuming the population is at HWE. This **only** works if you can assume that the population is at HWE; this will be given in the problem. To do this, you need to find one of the genotype frequencies and then use the following relationships which only hold at HWE:

$$\text{frequency of } AA = p^2$$

$$\text{frequency of } Aa = 2pq$$

$$\text{frequency of } aa = q^2$$

Once you've found either p or q , you know that $p + q = 1$ always, so you can get the other.

For example: "Sickle-cell anemia is an autosomal recessive genetic disease:

allele contribution to phenotype

A normal (dominant)

a sickle-cell anemia (recessive)

In a particular population, 99% (frequency = 0.99) are normal (AA and Aa) and 1% (frequency = 0.01) are sickle-cell (aa). Assuming that this population is at HWE, find the frequencies of each allele."

If we call the frequency of the normal allele (A) p , and the disease allele (a) q :

From above, we know that $0.99 = p^2 + 2pq$ (a difficult equation to solve)

but, we also know that $0.01 = q^2$ (this is much easier to solve)

take the square root of both sides: $\sqrt{0.01} = q$ so $q = 0.1$

since we know that $p + q = 1$, $p = 1 - q$ so $p = 1 - 0.1$ so $p = 0.9$

Now we have both allele frequencies. We can then go on to find the frequencies of the other genotypes using the relationships above:

$$\text{frequency of homozygous normal (AA)} = p^2 = (0.9)^2 = 0.81 \quad 81\% \text{ AA}$$

$$\text{frequency of carriers (Aa)} = 2pq = 2(0.1)(0.9) = 0.18 \quad 18\% \text{ Aa}$$

(note that $81\% + 18\% = 99\%$, the number of phenotypically normal individuals).

Note that the sum of the allele frequencies ($p + q$) is **always** = 1 whether at HWE or not.

(2) Predict the genotype frequencies in the next generation. To do this, you must assume that the 5 conditions for HWE hold for the population. In the case where they do not hold (like in lab where there was selection), you can assume that they hold for the breeding population (the part of the population that can reproduce). As long as you are using the allele frequencies (p & q) for the breeding population, you can use the relationships below:

$$\text{frequency of } AA = p^2$$

$$\text{frequency of } Aa = 2pq$$

$$\text{frequency of } aa = q^2$$

(3) See if the population is at HWE. If the conditions of HWE hold, the next generation calculated using (2) will be at HWE. You can use this as a test to see if a population is at HWE.

- calculate the allele frequencies using (1a). You cannot use (1b) because (1b) **assumes** that you are at HWE already!
- predict what the genotype frequencies will be at HWE using (2)
- compare the predicted genotype frequencies with the actual ones. If they're equal, then the population is at HWE.

For example: the population in 1a has $p = 0.4$ and $q = 0.6$. If it were at HWE, the frequency of AA would be $p^2 = 0.16$; the frequency of Aa would be $2pq = 0.48$; and the frequency of aa would be $q^2 = 0.36$ – since the actual frequencies are 0.3, 0.2 and 0.5, respectively, the population is **not** at HWE.

Note that $p^2 + 2pq + q^2$ **always** = 1, whether at HWE or not; so testing to see if $p^2 + 2pq + q^2 = 1$ does **not** test to see if the population is at HWE.

Hints for solving the practice problems: (numbers in [brackets] are appropriate steps as above)

#1a = [1a] #1b = [2] #1c = [not above] #1d = [2]
#2a = [1b] #2b = [1a] #2c = [not above]
#3ai = [1a] #3aii = [3] #3bi = [1a] #3bii = [3]

You should try the problems before using these hints.

Solutions to: Population Genetics Practice Problems

1) a)

	C^R	C^W	
108 red cows $C^R C^R$	216		frequency of C^R allele = p
144 roan cows $C^R C^W$	144	144	p = 360/600 = 0.6
48 white cows $C^W C^W$		96	frequency of C^W allele = q
	<u>360</u>	<u>240</u>	q = 240/600 = 0.4
	600	600	

b) Assuming that the population satisfies the 5 requirements for HWE, we can predict that:
 frequency of $C^R C^R = p^2 = (0.6)^2 = 0.36 = 36\%$ red cows
 frequency of $C^R C^W = 2pq = 2(0.6)(0.4) = 0.48 = 48\%$ roan cows
 frequency of $C^W C^W = q^2 = (0.4)^2 = 0.16 = 16\%$ white cows

If the assumptions required for Hardy-Weinberg equilibrium are met, then any population will reach equilibrium in one generation. Therefore, we know that the frequencies above are equilibrium frequencies. To find if the population in part (a) is in equilibrium, take these frequencies, multiply by the population size, and compare the numbers to those given in part a.

$$\begin{aligned} \text{number of red cows} &= 0.36(300) = 108 \\ \text{number of roan cows} &= 0.48(300) = 144 \\ \text{number of white cows} &= 0.16(300) = 48 \end{aligned}$$

Since these are the same as those in part (a), then the population in part (a) was already in equilibrium.

c) To answer this, one recalculates p and q in the same way as in part a, but does not include the 48 sterile (unable to reproduce, infertile) white cows. It is important to realize that the breeding population is reduced to 252 cows, or a total of 504 alleles.

	C^R	C^W	
108 red cows $C^R C^R$	216		frequency of C^R allele = p
144 roan cows $C^R C^W$	144	144	p = 360/504 = 0.71
			frequency of C^W allele = q
	<u>360</u>	<u>144</u>	q = 144/504 = 0.29
	504	504	

d) Assuming that the conditions for HWE hold for the breeding population, we can calculate:
 frequency of $C^R C^R = p^2 = (0.71)^2 = 0.504 = 50.4\%$ red cows
 frequency of $C^R C^W = 2pq = 2(0.71)(0.29) = 412 = 41.2\%$ roan cows
 frequency of $C^W C^W = q^2 = (0.29)^2 = 0.084 = 8.4\%$ white cows

This population is not in equilibrium due to the reproductive selection against the C^W allele resulting from the sterility of white ($C^W C^W$) cows. Realize that $p^2 + 2pq + q^2 = 1$ **at all times**, even when not in equilibrium. That is, the frequencies will always add to 100% of the population. (50.4% + 41.2% + 8.4% = 1 but is not in equilibrium.)

2) a) You need to use the Hardy-Weinberg equilibrium formula for 2 alleles to solve this problem. If we define q as the frequency of the populophobia allele (d) and p as the frequency of the normal allele (D):

$$1 = p^2 + 2pq + q^2$$

where, q^2 represents the fraction of individuals who are homozygous recessive (dd - populophobic). Thus,

$$q = \sqrt{\frac{32}{200}} = \sqrt{0.16} = 0.4$$

since $p + q = 1$, $p = 1 - q$ or: $p = 1 - 0.4 = 0.6$

The frequency of heterozygotes (Dd) is:

$$2pq = 2(0.6)(0.4) = 0.48$$

$(0.48)(200) = 96$ individuals are heterozygous.

That leaves: $200 - (96 + 32) = 72$ who are homozygous normal

b) If 75% of the individuals with populophobia spontaneously combust, then:

$$(0.75)(32) = 24 \text{ } dd \text{ individuals lost from the population}$$

$$32 - 24 = 8 \text{ individuals remaining who are homozygous recessive (} dd \text{)}$$

Thus, the surviving population is:

72 DD

96 Dd

8 dd

total: 176

To calculate the new allele frequencies, you must determine the total number of p and q alleles remaining in the population. This is equal to the number of heterozygotes plus *twice* the number of homozygotes.

$$\text{total } D \text{ alleles} = 2(72) + 96 = 240$$

$$\text{total } d \text{ alleles} = 96 + 2(8) = 112$$

$$\text{total alleles in population} = 240 + 112 = 352$$

The frequency of each allele in the new population is:

$$\text{frequency of } D = p = 240/352 = 0.68$$

$$\text{frequency of } d = q = 112/352 = 0.32$$

The frequencies of each *genotype* are:

$$\text{frequency of homozygous normal} = 72/176 = 0.41$$

$$\text{frequency of heterozygotes} = 96/176 = 0.545$$

$$\text{frequency of homozygous populophobia} = 8/176 = 0.045$$

The frequencies of each *phenotype* are:

$$\text{frequency of normal} = 0.41 + 0.545 = 0.955$$

$$\text{frequency with populophobia} = 0.045$$

c) Most recessive alleles are masked in heterozygotes and are unaffected by selection pressures. Even if there was complete selection against populophobia (100% spontaneously combust), it would take almost 100 generations to reduce the populophobia allele from 40% to 1%.

3) a) i)

<u>height</u>	<u>Number</u>	<u>Genotype</u>	<u>#H's contributed</u>	<u>#h's contributed</u>
tall	16	HH	32	0
medium	48	Hh	48	48
short	36	hh	0	72
total H's = 80		total h's = 120		total alleles = 200

frequency of H = $p = 80/200 = 0.4$
frequency of h = $q = 120/200 = 0.6$

ii) If it were at HWE, then:

frequency of HH = $p^2 = (0.4)^2 = 0.16$	so in 100 plants $0.16 \times 100 = 16$ plants
frequency of Hh = $2pq = 2(0.4)(0.6) = 0.48$	so in 100 plants $0.48 \times 100 = 48$ plants
frequency of hh = $q^2 = (0.6)^2 = 0.36$	so in 100 plants $0.36 \times 100 = 36$ plants

These are the same numbers as observed, so the population is at HWE.

b) i)

<u>height</u>	<u>Number</u>	<u>Genotype</u>	<u>#H's contributed</u>	<u>#h's contributed</u>
tall	2	HH	4	0
medium	57	Hh	57	57
short	41	hh	0	82
total H's = 61		total h's = 139		total alleles = 200

frequency of H = $p = 61/200 = 0.305$
frequency of h = $q = 139/200 = 0.695$

ii) If it were at HWE, then:

frequency of HH = $p^2 = (0.305)^2 = 0.093$	so in 100 plants $0.093 \times 100 = 9$ plants
frequency of Hh = $2pq = 2(0.305)(0.695) = 0.424$	so in 100 plants $0.424 \times 100 = 42$ plants
frequency of hh = $q^2 = (0.695)^2 = 0.483$	so in 100 plants $0.483 \times 100 = 48$ plants

These are not the same numbers as observed, so the population is not at HWE. One of the 5 assumptions must be violated. Note that there are much fewer tall plants than expected.

c) The number of tall plants must have dropped because the tall plants were at a disadvantage because of their height. Perhaps they poked out of the snow more than the other plants and were frozen by the cold winds and died. The shorter plants were protected by the snow.

d) There are several possibilities, here are some:

- genetic drift: all the tall plants happened to be near a tree that fell down and crushed most of them.
- migration: your neighbor has mostly short and medium plants and seeds from them blew onto your yard.

4) No. Survivors are randomly selected (not on the basis of genotype) so frequencies are not related to fitness. Because of this, the results would likely have been different if the experiment were run again.

5) a) Mutation. Mutations in the pigment-producing genes of the snake could have resulted in progeny of different colors.

b) i) It happened that most of the snakes on the island were killed by a flood that did not discriminate on the basis of color. Although there was no selective advantage to green, it just so happened (chance events) that most of the surviving snakes happened to be green (the survivors were not a representative sample of the original population); resulting in a mostly green population.

ii) Although there was no selective advantage to green, it just so happened that a catastrophe killed all the snakes on the island. It then happened that the island was colonized by a group of snakes from the mainland of different colors, most of which were green, resulting in a large population of green snakes on the island.

iii) A large number of green snakes migrated to the island from the mainland; the mainland population happens to be mostly green. This increased the frequency of the green allele in the island population, resulting in mostly green snakes.

iv) Some selective force acts against the non-green snakes, reducing their number or reproductive output, resulting in a relative increase in green snakes. For example, a predator could come to the island which is unable to see the green snakes against the green foliage and therefore eats only the other snakes.

