The Evolution of Meiotic Drive in the House Mouse – a Very Simple Model

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The t-allele in the house mouse distorts the frequencies of the gametes that tw ("w" means wild type) heterozygotes form. Instead of exhibiting the "fair" Mendelian ratios of 50/50, the gametes formed by heterozygotes are 85% t and 15% w. Another detail affecting the evolution of the two genes is that ww and wt individuals are fertile, whereas tt males are sterile. For simplicity, I'll assume that all tt individuals, not just the males, are sterile. I'm also going to ignore the possible relevance of group selection to the evolution of the t-allele (Lewontin 1970).

To make this problem concrete, let's suppose that ww and tw organisms produce 1000 viable gametes apiece, and that tt organisms produce zero. The choice of 1000 is arbitrary; it could be 10^{10}, and the analysis would be the same. I'll describe this process by talking about the number of gametes a chromosome in a diploid organism produces. That depends on whether the chromosome has t or w, and on whether its partner chromosome has t or w, as shown in the accompanying table.

Number of viable gametes produced by chromosome C			
		State of chromosome C's partner	
		t	w
State of chromosome C	t	0	850
	w	150	500

If chromosome C in an individual has t, what's the probability that its partner chromosome has t? That depends on whether the parents of that individual mated at random. I'll assume that they did. If the frequency of t in the parental generation is f, then the chance that C will sit next to a partner that has t is also f. The same point about random mating applies if chromosome C has w. The probability that its partner has w is 1-f. All this leads to the following:

fitness of a t-bearing chromosome = the number of gametes produced by a chromosome in a diploid organism that has t = (0)f + 850(1-f)

fitness of a w-bearing chromosome = the number of gametes produced by a chromosome in a diploid organism that has w = (150)f + 500(1-f)

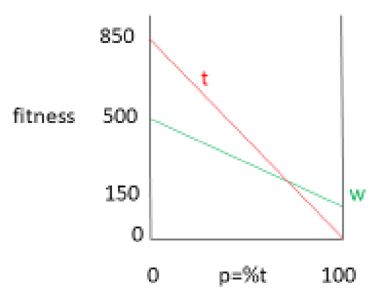
This entails that

fitness of a t-bearing chromosome > fitness of a w-bearing chromosome precisely when 350(1-f) > (150)f, which is true if and only if f < 70%

The evolutionary upshot is depicted in the accompanying figure. When t is rare, a chromosome with t will produce 850 gametes, because that chromosome is almost always in a heterozygote. When t is at 100%, a chromosome with t will produce 0 gametes, since tt homozygote are sterile.

When t's frequency is in between its fitness is in between these two extremes. Similarly for a chromosome with w. When w is rare (i.e., when t is common), that chromosome will produce 150 gametes. When w is common (i.e., t is rare), the chromosome produce 500 gametes. And when w's frequency is intermediate, its fitness is in between these two extreme values.

The evolution of a driving gene t and a wild type gene w in the house mouse. Chromosomes in diploid organisms produce different numbers of gametes, depending on whether they have t or w genes on them, and also on whether their partner chromosome has t or w.



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Rare traits have a selective advantage, so the population evolves to a stable equilibrium where the two traits are equal in fitness; this happens when t attains a frequency of 70%. It is no accident in this model that the degree of segregation distortion (the difference between the fraction of gametes produced by the t chromosome and that produced by the w chromosome in heteroyzgotes, 850/1000 – 150/1000) is one and the same number as the equilibrium frequency of t, namely 70%.

This model is all about gamete production, and that ignores the next step, where gametes are brought together in pairs to form the next generation of mice. You can model this next step as random sampling of pairs of gametes from the population's gamete pool. The number N of gametes in that pool depends on the number of mice in the population and on the number of gametes that each individual produces. N is gigantic. If you're going to draw n pairs of gametes to make n babies, you can calculate the probabilities of the different proportions of t and w that will make their way to the next generation. Each gamete in the gamete pool has the same chance of being chosen, but the success of the t and w types depends on their frequencies in the pool. This is why the number of gametes produced by t and w chromosomes matters.

Reference

Lewontin, R. (1970). "The Units of Selection." *Annual Review of Ecology and Systematics* 1: 1-18.