Learning Mitigates Genetic Drift

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Abstract

Genetic drift is a basic evolutionary principle describing random changes in allelic frequencies with far-reaching consequences in various topics ranging from species conservation efforts to speciation. The conventional approach is to assume that genetic drift has the same effect on all populations undergoing the same change in size, regardless of the different behavior and history of the populations. However, here we show that a simple act of learning from experience can significantly mitigate the effects of genetic drift.

Main text

Genetic drift is commonly thought to depend on allele frequencies, population size, number of reproducing individuals, and not much else[1,2]. Just as in other areas in biology[3] such a simplistic approach proved to be very useful, but as we show further in this article, it is likely not entirely correct. Just as the phenotype of an individual animal changes and develops during its life so

can change its response to various potentially deadly situations. And if such change is systematic, it can, in principle, create some structure on the population level even when the triggering event of such behavioral change occurs at random. Furthermore, if such a change in response to deadly situations is caused by personal experience and if it improves the chances of a given animal to survive such experience in the future, it can also affect the loss of genetic variability caused by drift in a given population. But, why should a simple act of learning from experience decrease random fluctuations in allele frequencies? To answer this question, let us imagine a hypothetical scenario. Let us suppose that there is a species subject to predation and that every young individual of this prey species has approximately the same chance to escape a predator if it is attacked, let us say 50%. However, if a given individual survives the attack of a predator, it learns from this experience and is more cautious in the future, increasing its chances to survive future encounters of a similar kind (e.g., to 75%). Furthermore, every future encounter that the prey individual survives allows it to learn from it and slightly increases its chance to survive the next one. In other words, individuals who survive and learn from such encounters gain an advantage in comparison to those who have not yet encountered predators and thus increase their fitness, even though this advantage has random origins and is not heritable. As a consequence, alleles carried by a given lucky individual get a temporary boost to their average fitness in the population regardless of their function. However, because such an effect is random, all alleles benefit at some point, which, in the long run, protects them against the effects of genetic drift.

Agent-based simulations can easily test the above-described hypothesis that learning from experience mitigates genetic drift. For this purpose, we developed a simple agent-based model that monitors allele frequencies in a population of prey, either able or not able to learn how to avoid/escape predators more effectively from the experience of unsuccessful past predator attacks (the link to the code in R is provided below article). Our results demonstrate that ability

to learn from experience significantly reduces the loss of genetic variability caused by drift (Fig 1). However, the size of this effect depends highly on specific circumstances. Our simulations consistently showed that the effect of learning on genetic drift increases with the fraction of population killed by predators, e.g., in panels a-c of figure 1 predators killed 500 out of 1000 prey individuals while in panels d-f predators killed 800 out of 1000 prey individuals each time step. Furthermore, the ability of learning to conserve genetic variability highly depends on how effective learning is. In our simulations, the maximal limit on how effectively prey could learn to avoid or escape predators was an even more important factor than the intensity of predation itself. When the prey could learn at best to escape with 90% probability the effect of learning was noticeable (fig 1 a and d) but much smaller than when they could eventually reach 95% chance to escape (fig 1 b and e) or even 99% chance (fig 1 c and f).

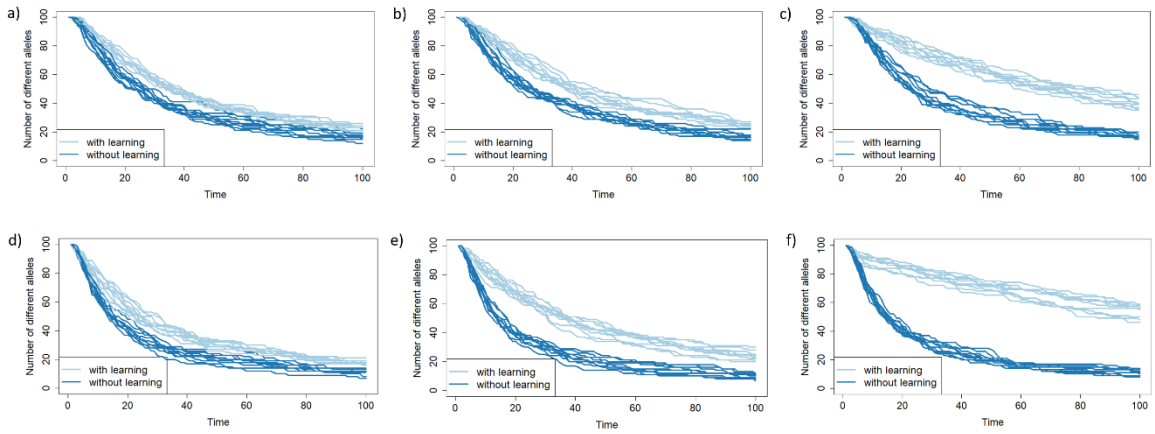

Figure 1: Learning slowdowns a loss of genetic variability caused by genetic drift. Temporal dynamics of the number of alleles present in populations of prey subject to predation. All prey populations consist of 1000 individuals at the beginning of each step. Individuals killed by predators are replaced at the end of each step by reproduction of surviving individuals (see Methods). In panels a-c, predators consume 500 prey individuals per time-step while in panels d-f, predators consume 800 prey individuals per time-step. Predators kill the same number of individuals in both learning and non-learning conditions to allow for a fair comparison. The upper bound on the probability to avoid/escape predator attack is set to 90% for panels a and d, 95% for panels b and e, and 99% for panels c and f. Each panel shows ten simulation runs for both learning and non-learning conditions.

The above-presented arguments and simulations consider the effect of learning in the context of predation. However, for the same reasons, learning exerts the same influence on any genetic drift caused by any source of mortality (or sterility), which individuals of a given species may learn to avoid. For example, if individuals of a given species were able to learn to avoid traffic from their experience, the effect on the genetic drift would be identical with the learned ability to avoid or escape predators more efficiently. To go even further, any learned improvement in the ability to find a partner for mating, to find food and thus decrease the risk of starvation, to care for offspring and thus, increase their chance of reaching adulthood, etc., will, to some extent, help to preserve genetic variability despite the raw effects of drift.

Furthermore, the here-described relationship between learning and genetic drift also leads to some testable predictions. First, species that can learn more effectively should, on average, better conserve genetic variability than species of less capable learners living in populations of similar size. Second but the connected prediction is that species that are "better learners" should have a lesser risk of extinction. This prediction is in good agreement with a recent study showing that bird species with greater behavioral plasticity have a smaller risk of extinction.[4] The third prediction is that causes of excess mortality, which individuals of a given species may learn to avoid, reduce genetic variability to a smaller degree than those which members of that species cannot learn to avoid or escape.

Overall, our results show that view considering genetic drift as independent on an underlying behavior of a given species is incorrect and that a simple act of learning may significantly mitigate the effects of genetic drift. Furthermore, we have shown that the level of protection against genetic drift varies in different situations, suggesting that loss of genetic variability by genetic drift is a more complex issue than it is generally believed. We hope that these findings will make existing models of evolution more precise and could prove useful in a variety of

topics, including the development of effective species protection strategies, studies of evolutionary past as well as evolutionary future.

Methods

We start with a given number of prey individuals (1000) and an initial number of unique alleles (100). The individuals are assumed haploid and each obtains a randomly chosen allele. Moreover, each individual has a probability of avoiding or escaping the predator's attack (initially 0.5). Each simulation runs for a given number of time steps (100). Predation is implicit: each time step, a given number of prey individuals are removed from the population – an individual is randomly selected, and its probability to avoid/escape predation is used to decide whether the predator's attack is successful. If yes, the individual is removed from the population. This random selection of prey is repeated until a given number of prey are removed from the population. If the attack is not successful, the probability of avoiding/escaping predation of the surviving prey is increased by a given proportion (non-zero proportion means learning, whereas zero proportion means no learning, we use 0.75); we set an upper bound on the probability to avoid/escape predation. Finally, the removed prey individuals are replaced by new ones: at the end of the time step, a surviving individual is repeatedly randomly chosen (with repetition) and gives birth to one offspring, until the population is restored. Each offspring inherits the allele from its parent, and its probability of avoiding or escaping the predator's attack is set to the initial value (0.5).

The above-described model was run using statistical software R, v. 4.0.1.

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Authors' Contribution

P.L. formulated the research problem, interpreted the results, designed the simulation scenarios, and co-wrote the manuscript. J.B.V. supervised the project and obtained funding. L.B. developed and coded the mathematical model, interpreted the results, designed the simulation scenarios and co-wrote the manuscript. All authors reviewed the manuscript.

Code availability

The computer code used to generate results reported in this article can be accessed at https://github.com/PeterLenart/Learning_Mitigates_Genetic_Drift.

Conflict of interest

The authors declare no conflict of interest.