The Center for Growth and Opportunity at Utah State University

Can Gene Editing Increase Ecosystem and Species Resilience?

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Research in Focus

Introduction

In the early 20th century, the American chestnut tree was an icon of United States forests. It grew up to 100 feet tall and had a population of over 3.5 billion in 1904.[1] The chestnuts from this tree provided food and shelter for many species, and its lumber sustained economic activity. It was even featured in song lyrics. Then an unexpected fungal disease known as the chestnut blight wiped out nearly the entire population.[2] Now there are only a few trees left in controlled environments, and while most Americans know the lyric "chestnuts roasting on an open fire," they have never seen an American chestnut.

In an attempt to counter the disease, in the 1950's, scientists began cross-breeding American chestnuts with other blight-resistant varieties. The resulting chestnut trees were resistant to the blight but lost their American chestnut features like larger growth potential and better wood quality. Modern methods have allowed for better selectiveness in gene editing. In 2014, researchers using genetic engineering added a wheat gene to the chestnut tree that made it resistant to blight while retaining its characteristics. Now this variety, called Darling-58, is ready for release into the wild.

Before this happens, however, it must clear several regulatory hurdles. The US Department of Agriculture (USDA), Food and Drug Administration (FDA), and Environmental Protection Agency (EPA) must all review the altered tree before it can be approved for release.[3] A key barrier to the introduction of Darling-58 is public opinion. As part of the deregulation process, the FDA held a public comment phase that ended in January of 2023. Over 38,000 comments were submitted, and while some commenters expressed strong opposition, many others expressed support.[4]

This primer leaves it to future research to discuss broader industrial policy concerns and needed policy changes. The aim here, however, is not to propose solutions, but to foster a deeper comprehension of the politics and economics that gave rise to the CHIPS and Science Act.

Climate change threatens the survival of many species when changing conditions weaken or kill populations of a species in a given area. Advancements in gene-editing technology have the potential to help through the selection of more resilient traits. In this paper, we explore what species resilience is and how gene editing can strengthen that resilience. Then we explain how specific technologies like CRISPR, a tool that allows for targeted gene editing, could help. We conclude with recommendations for how to overcome barriers to scaling the use of gene editing to enhance species and ecosystem resilience.

1. What is Species Resilience?

Traditional approaches to conservation focus on the mitigation of individual threats to species. Some species, such as peregrine falcons and other birds, have benefited through this approach.[5] For example, peregrine falcons, once threatened by the widespread use of DDT in pesticides and herbicides, recovered once conservationists discovered the specific threat and reduced its use and impact.[6]

Another approach to conservation is focused on population resilience, which seeks to improve species' resistance and ability to adapt to external and internal threats.[7] This approach is currently being used on the American chestnut by helping the tree develop resistance to chestnut blight. While traditional approaches seek to remove threats and human impact on ecosystems, resilience works to develop stronger systems resistant to those external factors. A combination of the two approaches can improve conservation efforts as the climate continues to shift.

Genetic diversity is a key characteristic determining species survival over time.[8] Species with greater genetic diversity are more likely to have individuals with traits resistant to a particular shock. Those individuals are then more likely to reproduce and pass the resistant traits on. These might be resistance to disease, extreme temperatures, or other shocks.[9] In one study, researchers tested resilience outcomes for forests with different genetic structures.[10]

Some groups were given higher genetic diversity while others received a specific pest resistance trait. The groups with diversity and those with pest resistance developed greater resilience to threats from pests. Both genetic diversity and introduction of specific traits can help species adapt to various threats that emerge as their environment changes.

2. Gene Editing Can Help Foster Resilience

One way for scientists and conservationists to assist the natural selection process is by adding genes and traits artificially, or gene editing. For example, using CRISPR technology, scientists select and manipulate traits. They then add favorable traits to a population via gene drives, which spread traits to a population quicker than natural selection.[11] Gene drives work by making the new trait dominant and more likely to pass on to offspring. The dominant trait then works its way into the general population as the species reproduces. Self-limiting gene drives control the impact of the desired effect on a species by separating the elements of a trait in the genetic sequence, which limits the inheritance period.[12] By selecting more resilient traits and adding them to a species, gene editing helps increase that species' resistance to threats as well as its genetic diversity.

An example of the benefits of increasing diversity of a population can be found in coral reefs, which are essential to global biodiversity but face the threat of rising ocean temperatures. Higher temperatures create challenges in coral reproduction and cause bleaching, which reduces growth rates and increases susceptibility to disease.[13] Scientists are currently working to increase coral resilience to warming ocean temperatures in order to help the coral itself and to benefit a wide array of species.[14]

The researchers concluded that coral reef longevity would be better improved by introducing a variety of traits through gene editing rather than selecting for heat tolerance.[15]

Other studies discuss the ways that gene editing can help enhance genetic variance within species. This helps increase long-term species resilience. Researchers suggest that it is not enough to restore the original genetic structures but that new, resilient genes added by gene editing best improves species outcomes. With greater variance, species are more resistant to new diseases and threats.[16] For example, gene editing of the American chestnut could restore the tree to its original levels of genetic diversity, but it would still be vulnerable to the chestnut blight. A better option, which combines the two approaches of improving species and reducing threats, is to use gene editing to develop a blight-resistant chestnut tree. This is what is currently happening with the development of Darling-58.

A risk of tailored gene editing to increase species survival is that adding resistant traits can reduce the ability to survive in opposite conditions. For example, adding heat resistance in coral reefs can reduce tolerance to colder temperatures. Adding resistance to one disease may increase vulnerability to another. While this is not always the case, it does illustrate a tradeoff in gene editing.[17]

3. Gene Editing is Already Helping Species Resilience

Gene editing has already been used to help achieve conservation goals. In 2021, scientists managed to use frozen cells of the long-dead black-footed ferret to successfully create a clone and increase genetic diversity.[18] From the early 1900's to around 1970, the black-footed ferret was nearly wiped out due to disease. On more than one occasion, scientists thought it was extinct. The current estimated population of 300 remaining ferrets can all trace their lineage to just seven surviving members of the population.[19] As a result, the current ferret population lacks the genetic variance necessary to make it resilient to changes in climate and habitat. The cloned ferret scientists created, named Elizabeth Ann, offers a solution to that problem.[20] Since it was cloned from the cells of a long-dead ferret, it can help reintroduce diversity into the population.[21]

Elizabeth Ann is confined to labs for now, and it would require regulatory approval to introduce her into the current genetically homogenous population. A key concern is with reproduction, and it is not known if there are risks posed by releasing Elizabeth Ann into the environment. If risks are minimal, this breakthrough could help recover black-footed ferret resilience.

4. Barriers to Gene Editing in Conservation

Before gene editing can reach its full potential in species conservation, many issues with its scaled use must be addressed. One barrier is the negative public perception of gene editing. Another is the regulatory structure surrounding gene-edited organisms. The American chestnut and the potential deregulation of Darling 58 provide context for both of these challenges.

In the US, bioengineered organisms go through a regulatory process primarily run by the USDA. It derives its regulatory authority from the Plant Protection Act and the Animal Health Protection Act. Any biotechnology product like Darling 58 that poses risks to agricultural plants and animals is automatically restricted by the USDA. The agency must consciously choose to deregulate that product before it can be introduced into the wild. For Darling 58, part of this process was the public comment phase which is closed while the agency deliberates on the decision.[22]

The FDA regulates bioengineered animals that produce food under current regulations. Any ingestible bioengineered product must go through a review by the FDA. Because the American chestnut produces edible nuts, this means the FDA could stop the deregulation process if it deems the nuts unsafe for human consumption.[23] In a 2022 article, John Tibbetts discusses arguments for and against gene editing in species conservation. Some of the expressed concern comes from the tradeoffs between unknown impacts and being able to have a timely and positive impact on the species. Others express support for Darling 58 because of its potential to restore a once-great forest tree.[24] But groups like Biofuel Watch feel that the risks still outweigh the benefits.[25]A poll published in Conservation Biology found 70% of US adults felt that gene editing could be misused in the context of conservation. Respondents were also more favorable to using it for survival and resilience rather than decreasing populations of disease-carrying insects, for instance.[26]

A key cultural concern is the viewpoint of indigenous cultures. A study from 2019 indicates mixed views on gene editing among the Haudenosaunee people and their sovereign leaders, who reside in forests that once housed the American chestnut. While some see gene editing as a tool to restore lost wildlife, others are concerned about the nontraditional nature of gene editing.[27] Other indigenous cultures, like the Eastern Band of Cherokee Indians in North Carolina, have requested Darling-58 chestnut seedlings to plant on their land.[28] When gene-edited species could impact native tribes, it is important that they are made aware of opportunities to provide meaningful public comment in the process.

Conclusion

In his 2022 article, John Tibbets emphasizes that "not taking innovative genetic action also has risks that should be considered."[29] Failing to act due to uncertainty can lead to species not getting the timely intervention needed for resilience. Current evidence suggests that gene editing has the potential to greatly enhance conservation if it is allowed to do so. While the gene edited chestnut tree promises an innovative conservation strategy, a segment of Americans disagree with using gene editing for any purpose.

The chestnut represents the first gene-edited forest tree that would exist in the wild. If reintroduced, the American chestnut could serve as an experiment, allowing researchers to understand more about how gene-edited plants interact with the environment and their own parent species. Better understanding of these processes can lead to more effective conservation.

Because of its ability to add diversity quickly and target specific traits, gene editing could change the future of species protection.[30] It is a powerful and innovative technology that has the potential to enhance species resilience in the face of a changing climate. In order to take advantage of its benefits, we must ensure our regulatory structure allows for responsible use of technologies like CRISPR that show amazing promise to help bring back beloved species like the American chestnut and protect others from future threats of extinction.

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Endnotes

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