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Commentary

Climate Extremes, Rewilding, and the Role of Microhabitats

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Climate extremes are expected to become more commonplace and more severe, putting species and ecosystems at unprecedented risks. We recommend that rewilding programs can create conditions for ecosystems to endure and recover rapidly from climate extremes by incorporating ecosystem engineers of various body sizes and life forms.

Climate extremes (extreme weather or extreme climate events) that are linked with anthropogenic climate change are increasing in frequency and intensity across much of the biosphere.[1] Among these are heatwaves and extreme droughts, which threaten species through exposure to extremes of temperature and low moisture. One of the major challenges posed by climate extremes is in devising strategies that optimize the conservation and restoration of biodiversity. For instance, heat waves create highly stressful conditions for several species. Over time, species can go locally extinct as a result of severe thermal stress, which eventually leads to the fraying of food webs and the breakdown of ecosystem functions.[2]

Given that heatwaves and droughts are expected to only become more frequent and extreme, it is crucial that conservation and restoration programs prioritize approaches that minimize their severe negative effects on biodiversity. One strategy could lie in rewilding, an approach that sees species (re)introduced into our landscapes and is generating increasing attention across much of the world. In this Commentary, we outline how rewilding could reduce the negative effects of climate extremes on biodiversity mainly by protecting and creating microhabitats.

What Is Rewilding?

The term "rewilding" was first used to refer to the (re)introduction of large carnivores for the restoration of usually a large and connected wilderness area. The concept originated in North America with the reintroduction of species such as wolves.[3,4] This concept has since extended to other areas of the world and with other species, including the (re)introductions of large vertebrates, such as herbivores (e.g., red deer or Eurasian elks) in Europe. Given its successes in restoring lost species (or similar, proxy species), rewilding has been gaining popularity in conservation programs. Moreover, it can also benefit the overall well-being of ecosystems and their biodiversity. For instance, river floodplains in the Netherlands were restored by the reintroduction of primitive cattle, horse breeds, and beavers, creating a landscape of grasslands and shrubs that provide habitats for migratory birds.[5]

More recently, the key ingredient of many recent rewilding programs has been allowing ecosystems to restore with as few human interventions as possible so that natural processes can regain their dominance and reduce the need for ongoing management.[3,6] In line with this, a broader concept of rewilding has recently been proposed as a strategy for conserving and/or restoring complex ecosystem dynamics in natural areas.[4] This approach of rewilding goes beyond the focus on large, often charismatic vertebrate animals and includes plants and animals (of any size) that contribute to the functioning of ecosystems.

Within this recent concept of rewilding, there is much potential to conserve or restore natural habitats and their species. One opportunity is to take advantage of ecosystem engineering species for their ability to create microhabitats. These microhabitats can rescue other species during climate extremes and therefore help protect ecosystems.

Importance of Microhabitats during Climate Extremes

Microhabitats are local habitats that are constructed by the activity of ecosystem engineering species and are habitable for other additional species.[7] Although every species to some extent modifies its environment, here we focus on ecosystem engineers that physically create and maintain habitats for other species through their biological activities. Ecosystem engineers can be of any life form (plant or animal) and of any body size. Some well-known ecosystem engineers are trees, aquatic plants, coral reefs, benthic worms, ants, termites, earthworms, beavers, prairie dogs, bison, and elephants. Their activities can alter habitats at smaller scales, such as by changing soil structure and creating cavities in trees, to much larger scales, such as generating openings in forest canopies, digging extensive burrows, and creating understories beneath vegetation. Through these activities, ecosystem engineers not only provide a variety of potential microhabitats for species to reside in

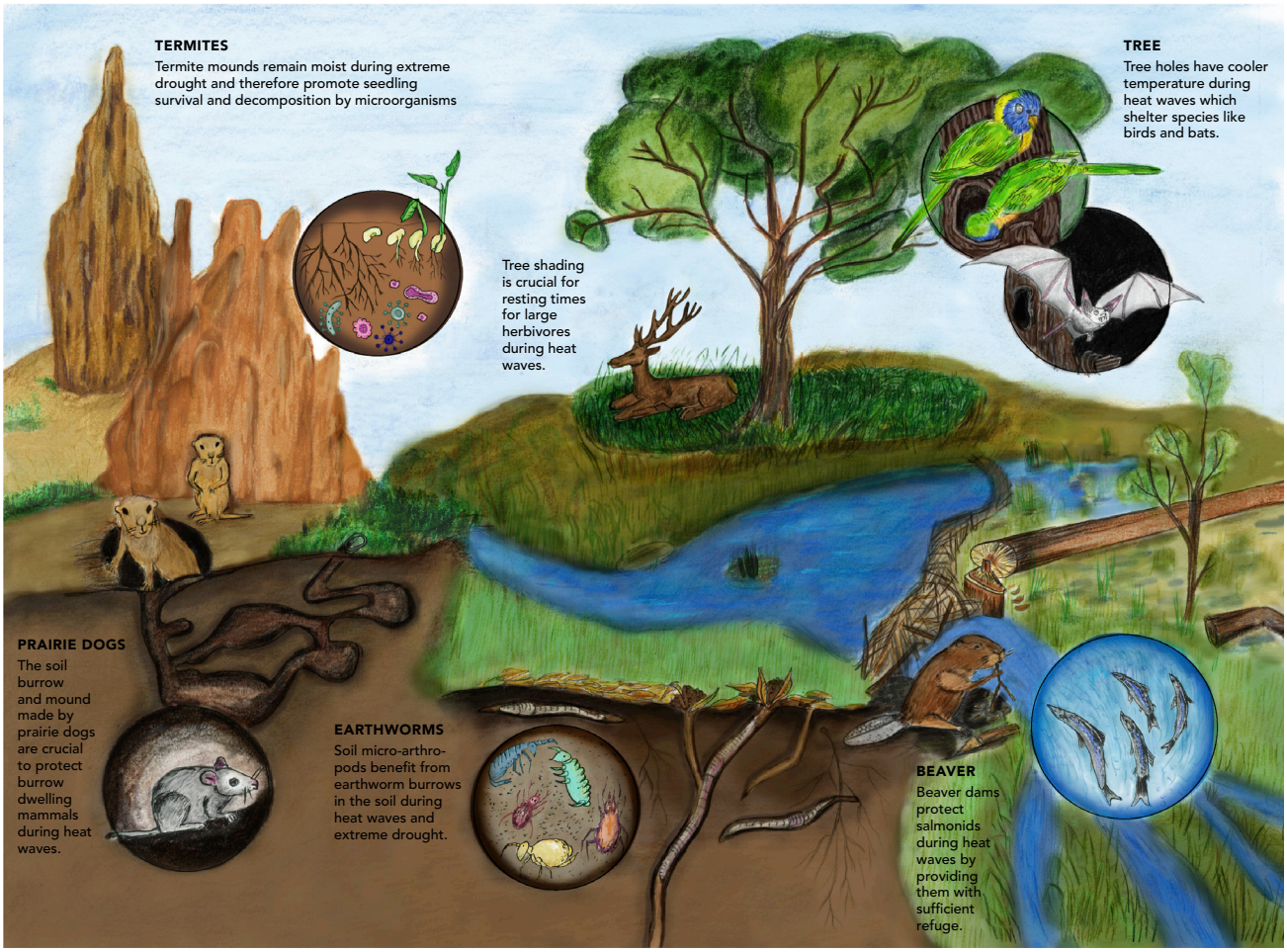

Figure 1. Examples of Microhabitats Created by Ecosystem Engineers in Rescuing other Species during Climate Extremes
These examples are only a limited set of ecosystem engineers that have the potential to rescue other species during climate extremes. In this Commentary, we suggest that rewilding programs help foster ecosystem engineers, and their engineering activities are crucial for protecting several groups of species during climate extremes.

but also provide them with favorable temperature and moisture, which are often more stable than the surrounding environment. These microhabitats will therefore be important refuges for species during extremes of temperature and drought (Figure 1).

The key feature of microhabitats is that the abiotic conditions therein are generally less harsh than the ambient climate at larger spatial scales. Microhabitats such as tree holes in some tropical habitats are about 4°C cooler than the surrounding air temperatures.[8] Moreover, microhabitats provide more stable temperature conditions for species. Hollows in old trees are a good example of this. They could provide more stable microclimates for animals such as bats and birds (with a maximum buffering of 15.1°C below the surrounding air temperature), particularly during the hottest periods.[9] Compared with their vulnerability in surrounding temperatures, the vulnerability of ectothermic animals (whose body temperature depends on external sources) such as frogs and lizards decreases in microhabitats by several folds.[10] The engineering activities of ecosystem engineers can also directly benefit other species during climate extremes. For instance, during an experimentally induced extreme drought, dung beetles created microhabitats by modifying soil structures, which were then able to enhance soil water retention by 10%. This in turn promoted plant growth by nearly 300% in drought treatments.[11] It is therefore likely that the introduction and conservation of ecosystem engineers can help protect and restore natural habitats and make them better equipped to withstand climate extremes.

Microhabitat Protection via Rewilding

Although the benefits that ecosystem engineers bring to conserving and restoring natural ecosystems are undeniable, many habitats have lost some of these vital species as a result of anthropogenic disturbances. In other ecosystems, these engineers are often threatened. Moreover, they can be vulnerable to the same climate extremes from which they protect other species. If these ecosystems lose their engineers, several other species could be pushed to local

extinction. Rewilding programs can foster the conservation of microhabitats during climate extremes by focusing on the conservation of ecosystem engineering plants, invertebrates, and vertebrates of various size groups. To improve our opportunities for success, we must be mindful of a number of factors.

We must build an inventory of key ecosystem engineering organisms in habitats targeted for rewilding. Although this might not be a simple undertaking, a better understanding of which organisms in a targeted habitat are key species for microhabitat construction and maintenance will do much to build upon the successes of rewilding projects.

We must also be mindful that ecosystem engineers differ in their body sizes and their ability to disperse, and so they operate at different spatial scales. Ecosystem engineers ranging from those as small as insects (dung beetles or termites) to those as large as vertebrate herbivores (e.g., deer or elks) construct microhabitats of different sizes, and they do so in different ways. Reintroducing a greater diversity of such species can therefore help create a greater variety of microhabitats. The greater the variety of microhabitats during climate extremes, the higher the chances of biodiversity rescue. However, we also caution that the introduction of non-native ecosystem engineers can be detrimental to native species.

There is a chance that some ecosystem engineers will decline dramatically after an extreme climatic event. Rather than taking these as failures, rewilding programs can help repopulate the engineering species of interest, including the native engineering species. This could even involve relocating the native ecosystem-engineering species of interest to disturbed habitats to accelerate the recovery of other species that rely on specific microhabitats.

We must also be mindful of how a reintroduced species could affect the ecosystem engineers that are already present in the system. For instance, rewilding with larger herbivores could negatively affect or, alternatively, enhance the biological activities of smaller ecosystem engineers already present in the targeted habitat. One good example is how the dung of howler monkeys promotes the abundance of dung beetles and how the activity of dung beetles promotes nutrient availability for tree growth, on which howler monkeys depend.[4] Preserving such ecological interactions is vital for protecting biodiversity during climate extremes.

Finally, rewilding should also promote extensive land-use management strategies that can foster both engineering and other species. For instance, less intensive livestock grazing promotes the growth of vegetation, such as tall grasses, beneath which microhabitats for several soil-dwelling organisms exist.

Outlook

Rewilding is generating a lot of interest among conservation practitioners and policymakers and is more than an opportunity to see charismatic animals in our countryside and wild areas. However, it still receives less attention for its potential to conserve biodiversity during climate extremes. We believe that it can bring a broad swathe of benefits to restore ecosystem functions and create microhabitats to help other species endure climate extremes. Restoring habitats after climate extremes with a focus on promoting ecosystem engineers can enhance the recovery rate of many other species that depend on microhabitats.[12] This can significantly help in the rapid recovery of our ecosystems.

Thus far, however, several rewilding programs have explicitly prioritized the introduction of large and charismatic vertebrate animals (e.g., wolves, beavers, red deer, ibexes, Eurasian elks, tapirs, and howler monkeys) and large-scale wild-area restoration with less consideration to small-sized organisms.[3,13] This can be problematic because many large animals depend on smaller organisms through a vast number of ecological interactions.[14] In the absence of their microhabitats, some of these smaller organisms are also likely to be vulnerable during climate extremes. If we are to protect natural ecosystems from climate extremes, we must take a "whole ecosystem" perspective when planning for rewilding. We must remember the importance of ecosystem engineers—not only the size or popularity of the species—and be aware of how they interact with other species.

As the world faces and will continue to face more frequent and severe climate extremes, it is crucial that we prepare, protect, and restore ecosystems. We advocate that identifying native ecosystem engineers of various body sizes in target habitats and prioritizing their presence in rewilding programs will be crucial for protecting native biodiversity via their microhabitat protection and maintenance in a world exposed to increasing climatic extremes. We believe that modern rewilding programs have great potential to achieve this.

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