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Letter

The Tarnished Silver Lining of Extreme Climatic Events

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Extreme climate events (ECEs) such as heatwaves, droughts, intense downpours, and attendant events like fires and floods are increasing in frequency, intensity, and duration, threatening biodiversity and ecosystem functioning across the biosphere at all levels of organization [1]. Despite this, a recent forum article [2] attempted to reframe climate extremes positively by suggesting that rapid evolution, driven by ECEs, can facilitate adaptation and climate resilience. We argue that the available evidence suggests that climate extreme impacts posit a more multidimensional ecological and evolutionary problem than directional selection acting on a single species.

The authors acknowledged that ECEs are having devastating impacts on species and ecosystems, but then suggested that directional selection will drive increased tolerance, and that this will subsequently make ecosystems more climate resilient. The few empirical studies used to underpin this statement indeed show that ECEs impose strong selection pressures on different traits. These studies offer evidence for rapid evolution when populations experience increased mortality and are reduced in size after being exposed to an extreme event. However, there are the negative genetic and ecological consequences of population bottlenecks and selective sweeps. We believe that such legacy effects may severely weaken the general viability of evolved populations, despite adaptations in specific traits, thus lowering, rather than enhancing, climate resilience. Three factors underpin this argument, two at the population level, and one at the community level.

First of all, adaptation to certain types of ECE may come at the loss of other traits, such as competitive ability or tolerance to other abiotic factors [3,4]. Although the evolved traits may provide some benefit during a similar ECE, those selected traits may reduce fitness under other climatic conditions. An important fact is that ECEs often occur concomitantly or sequentially, such as heat waves associated with droughts or fire, or followed by increasingly severe storms and floods. Adaptation to one extreme climatic event is unlikely to provide consistent fitness benefits during concomitant or subsequent extreme events of a very different nature, which could undermine the notion of creating climate-proof genotypes.

Second, exposure to ECEs will invariably lead to a reduction in density and genetic variability in populations. The genomic signature of such a selective sweep involves not only fixation of adaptive alleles for increased stress tolerance, but also unwanted deleterious alleles at other loci through genetic hitchhiking [5]. Surviving genotypes are therefore typically burdened with a harmful genetic load. Using those genotypes as targets for restoration – as suggested by Coleman and Wernberg [2] – would propagate and amplify these

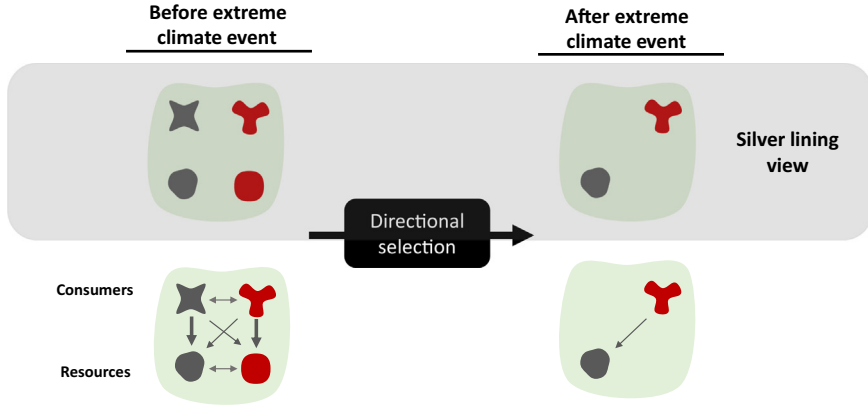

Figure 1. Responses of Consumers and their Resources to Extreme Climate Events under Directional Selection. The silver lining perspective of extreme climate events aims to exploit the benefits of directional selection in ecological communities to help build up climate-resilient ecosystems. By adding interactions among species (lower panel), we show that directional selection of few species will lead to loss of many ecological interactions which are crucial building blocks of resilient systems. Strong interactions are indicated by thick arrows within the green shading and weak interactions indicated by thin arrows; double-sided arrows indicate interactions in the same trophic level, and single-sided arrows indicate interactions between different trophic levels (predation).

negative fitness effects, and potentially be a poor choice.

Third, ECEs can cause not only deleterious selection at the population level, but they may also instigate the removal of species from communities through extirpation or extinction. Furthermore, as Janzen [6] said, 'what escapes the eye, however, is a much more insidious kind of extinction: the extinction of ecological interactions'. The impact of ECEs thus needs to be studied primarily in the context of multitrophic interactions and food webs, rather than exclusively focusing on individual physiological responses in organisms (Figure 1; [7]). Differential responses among intimately interacting species may disrupt trophic cascades and, for instance, deprive surviving predator species of the prey on which they depend [8]. Asymmetric responses between consumer and resource organisms (Figure 1) will seriously hamper the diversity of interactions present in ecological communities, which are crucial for the functioning and resilience of ecosystems [9,10].

Given the array of human-mediated assaults that threaten biodiversity in addition to anthropogenic climate change [11], we thus believe that there are caveats to the idea that there are silver linings to ECEs. Although the authors acknowledge multiple knowledge gaps in our understanding of ECE impacts, their final sentence – 'shifting focus towards the positive and beneficial impacts [of extreme events]' – is perhaps overly optimistic. Such a conclusion may also be abused by climate change contrarians and others downplaying the need for the mitigation of greenhouse gas emissions. Instead, we emphasize that, in order to minimize the negative impacts of increasingly frequent and severe climate extremes, an integrative approach is required combining ecology, evolution, and conservation science. This can be achieved through in-depth studies of behavioral, physiological, and ecological responses of interacting species in trophic chains or food webs to actual or simulated climate extremes. The resulting data can be used for management and policy in developing a climate-resilient world.

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Letter

A Glass Half Full: Solutions-Oriented Management under Climate Change

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A 'silver lining' is choosing to see a positive aspect of an otherwise negative impact or event. It is akin to choosing to see the glass as half full, rather than half empty. In Coleman and Wernberg [1], we identify what might be considered a silver lining of extreme climate events – the likely occurrence of directional selection and increased tolerance for specific climate stressors that characterise those otherwise destructive events. We acknowledge that this silver lining occurs under specific circumstances, and there remains knowledge gaps that must be addressed before this silver lining can be realised, however, the choice to acknowledge that there is indeed a silver lining is a powerful and potentially transformative approach to enable novel climate interventions. This choice to focus on positive, rather than overwhelmingly negative aspects of climate and environmental change is advocated widely in marine conservation [2,3], science policy [4], and through powerful social media initiatives (e.g., www.oceanoptimism.org) and provides great promise to transform the way we conserve our natural systems into the future.

We do not disagree with the points raised in Harvey *et al.* [9]. Indeed, in our Forum article we acknowledge that there is a clear need to understand trade-offs that come with directional selection, the potential for maladaptation to additional stressors, as well as the implications for ecological interactions in changing climates. It is also true that extreme events and directional selection can lead to reduced genetic diversity [5,6], which may compromise the ability of populations to respond in the multistressor land- and seascapes that characterise the Anthropocene. These are pressing scientific questions and knowledge gaps that need to be tackled. However, choosing to focus only on these negative consequences and questions, rather than acknowledge that there can be silver linings, is an opportunity lost to start the conversation around proactive and novel climate interventions [7]. Regardless of what we do at this point in time, we are locked into