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Appendix S1: Characteristics of single-event studies

What proportion of the literature on ecological responses to extreme climatic events (ECE) is based on a single event and what are the characteristics of these studies? We examined 242 studies originally identified as relating to extreme events by Bailey and van de Pol [1]. We regard this sample as representative - albeit not exhaustive - of all studies that examined ecological responses to ECEs (Table S1). Among these, 72% (174) were observational studies; 24.3% (59) reported experiments, i.e. organisms were experimentally exposed to extreme climate; another 2.1% (5) were modelling studies; and the remaining 1.6% (4) included both experimental manipulations and an observational component.

Of the 174 observational studies, 56.3% (98) investigated one ECE, 12.1% (21) investigated two events, 5.2% (9) investigated three events, and 26.4% (46) investigated four or more events. Of the 98 single-event studies, 45% (44) were initiated in response to the event (opportunistic) and the rest observed an extreme event during a long-term study. Seventy-eight (80%) of these 98 single-event observational studies used a climatological definition of an extreme event, another 13 studies (13%) used a hybrid definition and only 7 studies (7%) used a biological definition.

Observing cascading responses over time and the return of the system to normal conditions is important for understanding the impact of the extreme event [2,3]. In the 129 long-term observational studies the median study duration was 10 years for studies that observed one (n=54), two (n=20) or three (n=9) extreme events, but was much longer (51 years) for studies that observed four or more extreme events (n=46). Of the 129 long-term observational studies 73% (94) were able to examine delayed responses. The 44 opportunistic single-event studies were shorter (median 1.5 years) and 48% (21) of these considered delayed responses.

Bailey and van de Pol [1] listed 75% (44) of the 59 experimental studies as single-event studies, i.e. these experiments included one treatment exposing organisms to an ECE. The

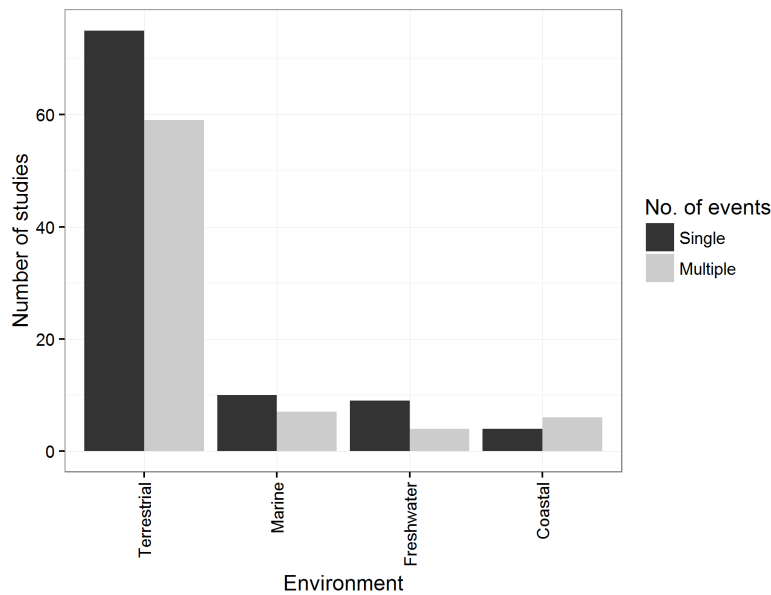


Figure S1: The environment in which extreme events were observed (Data from [1]). Most extreme events were observed in terrestrial environments ($n = 134$; 77%), with far fewer studies conducted in aquatic ($n = 30$; 17%) or coastal environments ($n = 10$; 6%). There was little difference between studies with respect to the number of extreme events that were observed in each environment (single-event studies in black and multiple-event studies in grey).

other 25% (15) of experimental studies either included multiple extreme treatments or examined the reaction of the organisms to multiple sequential extreme conditions. Delayed responses were only examined in 37% (22) of experimental studies and the median duration of experimental studies was 0.7 years. Most (83%; $n=49$) experimental studies focused on relatively sedentary organisms, like plants, microbes or small invertebrates.

Given that more than half of the observational studies were based on a single ECE, are they biased towards specific types of events or ecological responses compared to those studies that observed more than one ECE? The most frequently studied ECEs were temperature and precipitation extremes (figure 1a in main text). Single- and multiple-event studies investigated the different climate variables in comparable proportions (figure 1a in main text). However, single-event studies investigated abundance or survival responses relatively more often than multiple-event studies (figure 1b in main text). Multiple-event studies, on the other hand, investigated growth relatively more often than single-event studies (figure 1b in main text), partly due to many dendrochronological studies that usually include multiple ECEs but are limited to radial growth. Both single-event and multiple-event studies were biased towards animals and plants in terrestrial systems, as opposed to other taxonomic groups and habitats (figures S1 and S2).

There were major geographic biases in our sample with most studies being conducted in the

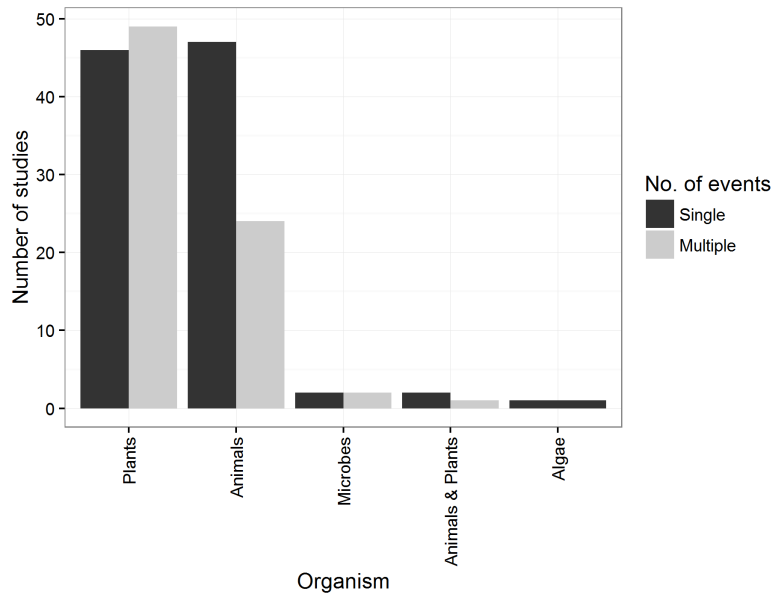


Figure S2: The organisms that were investigated during an extreme event or across multiple extreme events for both observational and experimental studies (Data from [1]). Most studies observed plants ($n = 135$; 58%) or animals ($n = 84$; 36%); few studies observed microbes ($n = 8$; 3%), algae ($n = 1$; <1%) or both animals and plants (in the same study; $n = 5$; 2%) during extreme events. There was little difference between studies with respect to the number of extreme events that were observed for each type of organism (single-event studies in black and multiple-event studies in grey).

northern hemisphere, particularly in Europe, and also with regards to the types of climate variables investigated (figure S3). Overall, more studies were conducted in Europe (40; 42% of all studies), North America (22; 23%) and Asia (12; 13%) compared to Australasia (10; 11%), Antarctica (4 each; 4%), South America (4 each; 4%) and Africa (3; 3%) (figure S3). Multiple-event studies were more frequent in Europe (32; 47% of all multiple-event studies), North America (16; 24%) and South America (12; 18%), compared to Africa (2; 3%), Antarctica (0; 0%) and Australasia (2; 3%) (figure S3). A similar pattern was observed for single-event studies, with more of these studies in Europe (40; 42% of all single-event studies), North America (22; 23%), compared to Africa (3; 3%) and Antarctica (4; 4%). Notably, there were relatively more single-event relative to multiple-event studies in Asia (12; 13% of all single-event studies vs. 4; 6 % of all multiple-event studies) and Australasia (10; 11% vs. 2; 3%). The opposite was true for South America, with relatively fewer single-event studies compared to multiple-event studies (4: 4% vs. 12; 18%). Precipitation-related studies were relatively numerous in South America and Australia, but few temperature-related extreme events were investigated in these regions (figure S3). The relatively greater number of studies in the northern hemisphere probably reflects the predominance of climate studies in developed countries [4], and to a lesser degree, inherent climatic change and differences between continents.

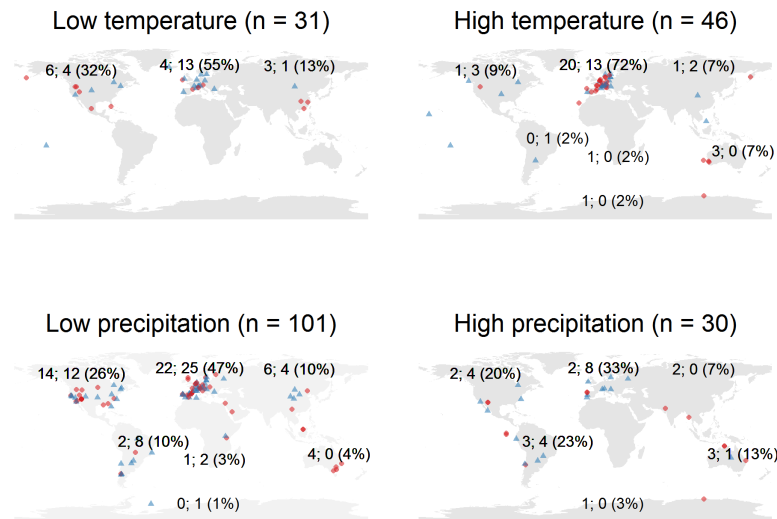


Figure S3: Geographical spread of observational extreme climatic event studies. Each map shows the locations of studies categorised by the four most common types of extreme climatic event observed (See figure 1a in main text: low or high temperature, and low or high precipitation). Single-event studies are indicated by red circles, multiple-event studies by blue triangles. Above each continent is also shown the number of single-event studies (1st number), the number of multi-event studies (2nd number) and the percentage of studies conducted on that continent (% in parentheses).

References

1. Bailey, L. D. & van de Pol, M. 2016 Tackling extremes: Challenges for ecological and evolutionary research on extreme climatic events. *J. Anim. Ecol.* **85**, 85–96. (doi:10.1111/1365-2656.12451)
2. Smith, M. D. 2011 An ecological perspective on extreme climatic events: a synthetic definition and framework to guide future research. *J. Ecol.* **99**, 656–663. (doi:10.1111/j.1365-2745.2011.01798.x)
3. Gutschick, V. P. & BassiriRad, H. 2003 Extreme events as shaping physiology, ecology, and evolution of plants: toward a unified definition and evaluation of their consequences. *New Phytol.* **160**, 21–42. (doi:10.1046/j.1469-8137.2003.00866.x)
4. Vasileiadou, E., Heimeriks, G. & Petersen, A. C. 2011 Exploring the impact of the IPCC Assessment Reports on science. *Environ. Sci. Policy* **14**, 1052–1061. (doi:10.1016/j.envsci.2011.07.002)

Table S1: (provided as separate file): Extreme event studies identified by a search of the literature.

The information provided in this list of studies is based on a literature search conducted by Bailey and van de Pol [1]. This list was obtained by searching the Web of Science for studies published between 1990 and 2014 using the terms extreme* climatic* event*, retaining only those studies that measured biological or ecological responses of non-human systems. Our sample excluded purely climatological studies, human health studies and any studies on crops or agriculture. We only included studies that reported original data but made no distinction about how the authors defined an ECE. We regard this sample as representative - albeit not exhaustive - of all studies that examined ecological responses to extreme climatic events.

Also provided in the table is information on the number of extreme events observed during the study (No. extreme events; 4 = four or more events), the type of definition for extremeness used (climatological, biological or hybrid, see section 1) whether the study was opportunistic (study initiated in response to the event) or long-term (Opportunistic / long-term), whether the study continued to monitor the system long enough to observe delayed responses to the extreme event (Delayed responses), the duration of the study in years (Study duration), the type of organism investigated (Organism), the type of extreme event, i.e. which climate variables were observed (Climate variables), the type of response variables investigated (Type of response variable), whether the study provided any sort of statistical measure of extremeness for the climatic event (Evidence of extremeness), the type of environment in which the study was conducted (Environment).