Extreme event ecology needs proactive funding

Christopher J Patrick[1*], **Enie Hensel**[1], **John S Kominoski**[2], **Beth A Stauffer**[3], **and William H McDowell**[4]
[1]*Department of Biological Sciences, Virginia Institute of Marine Science, Gloucester Point, VA* *(*cpatrick@vims.edu*);
[2]*Department of Biological Sciences, Florida International University, Miami, FL;* [3]*Department of Biology, University of Louisiana at Lafayette, Lafayette, LA;* [4]*Department of Natural Resources and the Environment, University of New Hampshire, Durham, NH*

Front Ecol Environ 2022; 20(9): 496–497, doi:10.1002/fee.2569

Extreme events such as wildfires, hurricanes, and floods have increased in frequency and intensity. It is no longer a question of if, but rather when and where these events will occur (Stott 2016), with adverse impacts on essential ecosystem services including clean water, harvestable materials, and carbon sequestration. In some cases, extreme events such as wildfires may have positive impacts on populations and ecosystems. Managing these impacts requires understanding how environmental context as well as ecosystem and disturbance characteristics drive system responses (Hogan *et al.* 2020). However, funding for ecological extreme events research, such as through the US National Science Foundation's (NSF's) RAPID program, is typically reactive. Pre-event data, a RAPID prerequisite, are typically lacking or only sporadically available, and case studies of extreme events often arise from chance disturbances at existing long-term research sites. This reactive stochastic approach has seeded the literature with unplanned case studies describing individual events. While useful for meta-analyses (eg Patrick *et al.* 2022), such studies provide limited spatiotemporal inference and predictive capacity. Prioritizing the study of extreme events and empirically testing fundamental concepts in disturbance ecology is paramount (Aoki *et al.* 2022). Although NSF is the logical US funding agency for supporting this type of work, we – the authors – are unaware of any funding model at NSF (or other US federal agencies) for proactive, coordinated, hypothesis-driven research at the spatiotemporal scales needed to effectively study future natural events. Therefore, new funding mechanisms are necessary, ones that combine elements of existing programs in novel ways to provide researchers the flexibility to fill critical knowledge gaps.

Advancing our understanding of the drivers and effects of extreme events on Earth's diverse ecosystems requires carefully planned tests of conceptual frameworks in the field. Such mechanistic, empirical studies will necessitate: (1) collection of pre-event data at locations ideal for testing a priori hypotheses; (2) data collection from and maintenance of experimental arrays over timescales sufficient to resolve seasonal and interannual dynamics, pre-event periods, stochastic disturbance events, and post-event recovery periods; and (3) replication across geographically distinct locations to ensure that studies include comparison of impacted and unimpacted sites. Networked experiments and monitoring over sufficient time periods are both critically important to this approach.

Networked studies can provide powerful inference and are an efficient way to design investigations of future extreme events. Planning a disturbance study around a future event is inherently risky, as there is no guarantee that a study site will be disturbed during the study period. However, this risk can be greatly reduced. First, working at multiple, geographically distinct study sites increases the probability that one or more sites will be affected during a study period. Second, using historical disturbance frequency data to select locations with the highest chance of a disturbance occurring further increases the probability that a study site will be impacted. For example, there are three hurricane hotspots along the continental US coastline that could serve as sites for a sustained hurricane research network (Landsea and Franklin 2013): Cape Fear in North Carolina, southern Florida, and the central Louisiana coast (Figure 1). During any given five-year interval in the past 20 years there was a 100% chance that one or more sites within these three hotspots would be impacted by hurricanes (Figure 1). Thus, an eight-year networked study of these three high-risk areas with paired control sites in lower-risk areas would almost certainly capture at least one, and likely more, events within the first 5 years, followed by at least 3 years of recovery time. The approach described above can be applied to many types of extreme events, not just hurricanes. However, there is currently no funding solicitation that allows the combination of acceptable risk, funding amount, multi-site approach, and necessary time horizon required to support such a design.

Within NSF's Division of Environmental Biology (DEB) and Biological Oceanography–Division of Ocean Sciences (BIO-OCE), there are many funding models. While aspects of the design described above can be found in individual solicitations, no single funding mechanism includes all the components necessary for proactive ecological investigations of extreme events. For instance, standard NSF grants allow for starting new experiments across a network of locations but have a maximum of 5 years of allowable funding, an insufficient time horizon for planning studies around future natural disturbance events. Furthermore, the riskiness of planning for an uncertain future event may prevent favorable review in this funding category. EAGER, a special solicitation type, allows for higher-risk projects but is limited to 2 years and has a modest budget (up to $300K) that precludes a networked or distributed approach. DEB's Long Term Research in Environmental Biology (LTREB) proposals cover 10-year

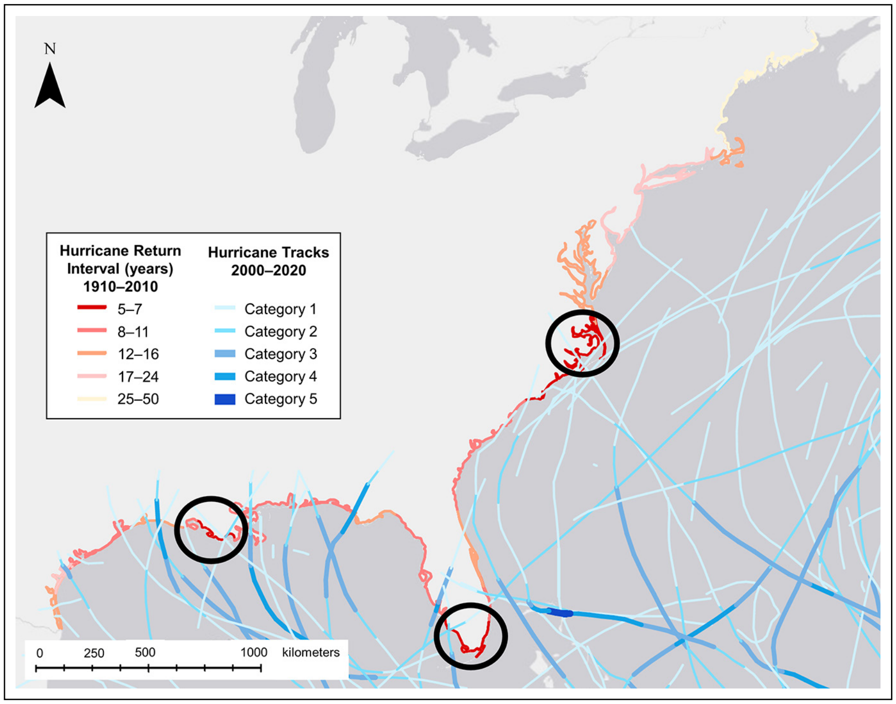

Figure 1. Hurricane tracks from 2000 to 2020 in relation to hurricane hotspots on the US coastline. Coastline color indicates mean hurricane return interval from 1910 to 2010 with smaller return intervals (higher storm frequency) corresponding to darker reds. Hurricane hotspots are circled in black. Blue lines are storm tracks from 2000 to 2020; line darkness and thickness increase with Saffir-Simpson cyclone wind scale. For any 5-year interval between 2000 and 2020, there was a 100% chance that at least one hotspot experienced a category 1 or greater hurricane. Among 5-year intervals there were 4.76 ± 2.71 (mean ± standard deviation) hurricanes directly impacting 2.47 ± 0.62 of these three hotspots.

periods (subject to a renewal after the initial 5 years) but are limited to $100,000 per year and require 6 years of pre-existing data, thereby excluding projects selecting new sites that are explicitly designed around disturbance questions. Existing long-term research and monitoring networks funded by NSF (eg National Ecological Observatory Network [NEON], Long Term Ecological Research [LTER]), as well as other federally funded programs like the National Oceanic and Atmospheric Administration's National Estuarine Research Reserve network, provide excellent data on spatiotemporal patterns in ecology, but these sites were not explicitly selected for this type of initiative (Aoki *et al.* 2022). Likewise, ad hoc experimental networks borne out of LTER (eg NutNet, DroughtNet) are not coordinated to capture complex cross-site responses within regions experiencing dynamic and repeated exposure to extreme events. Lastly, RAPID is designed to provide up to $200K in post-event evaluation in localized areas for 1 year after the event. While pre-event data are typically required, the reactive model effectively precludes the ability to provide funding to design and implement experiments in advance of disturbances. In addition, while multiple RAPID awards can be combined to increase the budget for comparison among multiple sites (Patrick *et al.* 2020), each proposal is evaluated independently, making networked projects difficult to fund. These limitations illustrate that while the reactive funding model has advanced our understanding of disturbance ecology and remains an essential funding tool, it is insufficient in several important ways. Importantly, existing programs fail to provide the combination of features required to address the need to advance our mechanistic understanding of extreme event ecology.

In conclusion, a new funding program for extreme event research is needed. A program that supports the collection of new pre- and post-event data over 10-year periods from networks of frequently impacted sites would advance our understanding of how disturbances are (1) changing the structure and function of ecosystems worldwide and (2) interacting with other long-term environmental changes. Both are greatly needed in this era of unprecedented global change (Aoki *et al.* 2022), in which we need to rapidly adapt, and develop flexible and proactive funding programs. A shift to funding projects that embrace the uncertainty of the future will lead to important intellectual advancements and convergence in the arena of global change science.

The work was supported by NSF Award 20003292. This manuscript is contribution number 4120 from the Virginia Institute of Marine Science and contribution number 1487 from the Institute of Environment at Florida International University. We thank D Wilcox and M Smith for assistance with figure creation and E Blood for reviewing the factual accuracy of our statements regarding features of NSF funding categories.

Aoki LR, Brisbin MM, Hounshell AG, *et al.* 2022. Preparing aquatic research for an extreme future: call for improved definitions and responsive, multidisciplinary approaches. *BioScience* **72**: 508–20.

Hogan JA, Feagin RA, Starr G, *et al.* 2020. A framework to integrate cross-ecosystem response to tropical cyclones. *BioScience* **70**: 477–89.

Landsea CW and Franklin JL. 2013. Atlantic hurricane database uncertainty and presentation of a new database format. *Mon Weather Rev* **141**: 3576–92.

Patrick CJ, Kominoski JS, McDowell WH, *et al.* 2022. A general pattern of trade-offs between ecosystem resistance and resilience to tropical cyclones. *Science Adv* **8**: eabl9155.

Patrick CJ, Yeager L, Armitage AR, *et al.* 2020. A system level analysis of coastal ecosystem responses to hurricane impacts. *Estuar Coast* **43**: 943–59.

Stott P. 2016. How climate change affects extreme weather events. *Science* **352**: 1517–18.