Environmental Change and Human Security: Research Directions

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Executive Summary

Accelerating rates of anthropogenic environmental change are stressing human institutions and can present novel security threats to our nation. These changes manifest in many ways, such as in the extreme weather events that impact food and water systems, contributing to conflict, or in the human encroachment on critical ecosystems that drive disease transmission, as seen with COVID-19. Environmental stresses are an increasingly clear influence on security. Within the national security community, some view environmental stresses as 'threat multipliers' that can exacerbate existing social, economic, and political tensions, while parts of the defense sector may not take environmental stresses into account. Within the U.S. environmental science community, research efforts on the linkages between environmental stress and human security remain piecemeal and have generated only a limited understanding. There are few examples of the comprehensive basic research programs needed to understand how such stresses shape threats to the many dimensions of U.S. security. Scientists and practitioners do not yet have a fundamental understanding of the factors that determine a society's resilience to environmental stress. These are challenging problems to study because they are complex and require integration of perspectives from a range of academic disciplines that rarely come together in the current funding landscape.

The U.S. scientific community could substantially ameliorate the limited understanding of important research questions at the intersection of environmental science and national security. Examples of these critical research questions include: (1) Which if any correlations observed between extreme weather events such as droughts or heat waves and social unrest or conflict are causal? (2) What potential do global environmental changes have to exacerbate existing tensions, disrupt geopolitical relationships, and create new threats to national and international security, as well as to the local security, health and welfare in places experiencing these changes? (3) What is the role of environmental peacebuilding and diplomacy in national security? There are, moreover, important ancillary process questions about the most appropriate scales at which to study these problems and the kinds of tools that will be most useful to support security broadly.

The goal of this report is to lay out opportunities to promote research at the intersection of environmental science and security. The report is prepared by the NSF Advisory Committee for Environmental Research and Education (AC-ERE). The report identifies near-term opportunities to promote critical research through existing disciplinary approaches; more diverse and robust interdisciplinary/convergent research inclusive of social and behavioral sciences; and to design novel mechanisms to overcome barriers between academic groups and the national security community. Opportunities also exist to create partnerships with other US Federal agencies, and international counterparts seeking to predict and prevent security threats driven by environmental change. A more robust research community focused on these issues will both produce new understanding and a new workforce ready to tackle the rapidly growing number of security threats tied to environmental change ensuring improved national security for generations to come.

Introduction

Environmental change and variability have always been part of the fabric to which human societies must adapt and from which they have learned to prosper. But today's world has entered a new phase of rapid environmental change, driven in large part by our own economic activity, growth, and demand for goods and services. These changes include rapid land-use change, encroachment on natural habitats, overexploitation of wild natural resources and subsequent depletion of biodiversity, and increases in the damages from changes in climate and associated extreme weather events and disasters. Fossil fuel extraction, emissions, and burning have contributed to increases in extreme weather events through climate change, and also to sea level rise and ocean acidification. In short, human activities have both exacerbated existing environmental pressures on society, and created entirely new ones for which history does not provide a guide.

To what degree are social, economic and political interactions with and responses to environmental stresses constructive, or do they exacerbate fault-lines in social cohesion, economic activity, opportunity and stability?

These heightened and unforeseen environmental pressures constitute new stresses for many societies around the world. At the same time, there is new willingness and ability to better understand how these stresses shape threats and opportunities for human security. The dynamics of social, behavioral, economic, and political responses to environmental stresses and the degree to which they are constructive or exacerbate underlying fault-lines in social cohesion, economic activity and opportunity, and stability[(Q1)] are of great interest to scholars and practitioners alike.

Despite some research activities, and a growing collection of interesting case studies, we do not have a well developed understanding of the factors that determine a society's resilience to environmental stress—the factors that determine whether societies are resilient to newly observed and rapid environmental change, or are fragile and unable to adapt.[(Q2)] We lack a fundamental understanding of why some combinations of societal resources and environmental stress contribute to harm or lead to conflict, while others lead to enhanced cooperation and resilient coupled systems.[(Q3)] The environmental research requirements to develop fundamental understandings for security are wide ranging, from disciplinary to interdisciplinary and convergent. Are some types of environmental change more difficult for societies to adapt to than others, for example when water, agriculture, climate change, and ecosystems are interconnected both ecologically and socially?[(Q4)] Research has drawn attention to inequality in negative climate change impacts on different groups of people including the exacerbation of existing vulnerabilities of under-resourced populations, marginalized due to their gender (Heckenberg and Johnston 2012; Sultana 2014), race, class, or ethnicity (Thomas et al. 2019). One example that tends to be overlooked is how climate change impacts will amplify inequities in child health in places where children already have poor survival and life expectancy rates (Bennet and Friel 2014).

Why do some combinations of societal resources and environmental stress lead to conflict, while others lead to enhanced cooperation and resilient coupled systems?

These are fundamental questions about the *relationships* between environmental change and societal security; in a world that is changing as rapidly as we now observe, they raise issues that only a deep understanding of those relationships can resolve. For this reason, we view the environment-security nexus as being of foundational importance for the kind of fundamental research that is the purview of the National Science Foundation (NSF). Moreover, it is equally clear that questions about these relationships cannot be answered by one discipline alone—the contributions of physical and natural scientists; information and data scientists; geographers; social, behavioral, and political scientists; demographers; and economists – at a minimum – will need to be part of the research efforts. Questions that are jointly agreed on, and jointly pursued, will be necessary, and this is a foundational characteristic of what the NSF and others have labeled "convergent research."

We explore these issues in this report, beginning with the historical context, and an assessment of the state of scientific knowledge about relationships between rapid environmental change and security. We then lay out our view of the major research opportunities and suggest strategies for addressing them. A wide range of scientific questions about environmental change has direct and increasing relevance to security considerations. The report lays out how these opportunities to advance environmental sciences and security fit squarely within the realm of fundamental research that is both deeply interdisciplinary and leads to improved decision making and practical applications.

Historical context

National security typically refers to a nation's ability to protect its stability and prosperity from external threats, and in its most narrow form, territorial integrity. This traditional definition usually focuses on the use of force to respond to threats and, in the United States, is largely the responsibility of military and intelligence organizations. Increasingly, however, it is clear that this narrow definition of security as a military function does not adequately capture what makes a society secure. A broader concept of human and community wellbeing, used more in the context of humanitarian and development activity is "human security". (UNDP 1994)

Although the relationship between the natural environment and human security has always been ingrained in human societies, more contemporary appreciation of the links between natural resources, industrialization, and security tracks to the energy crises in the 1970s. These energy-related revelations helped spur a broader understanding about environmental security, beginning with the Brundtland Report in 1987 (World Commission on Environment and Development, 1987), the U.S. National Security Strategies starting in the early 1990s (e.g., The White House, 1991, p22) and the United Nations Development Programme (UNDP) report on human security in 1994 (UNDP, 1994). Center for Naval Analyses reports (CNA 2007, 2014) and National Intelligence Council (NIC) Assessments (e.g., NIC 2012, 2014) have highlighted how climate change poses a threat to national security. These reports, which are more informational than analytical, laid out in detail how certain security concerns are influenced, multiplied, and even catalyzed by environmental changes, and the need for a broader definition of security that includes but is not limited to traditional definitions.

Pandemic-related events of 2020-21 have highlighted the need to think more broadly about the connections between environmental change and security. In its first half year, the COVID-19 pandemic—which has its roots in human encroachment in certain ecosystems leading to spillover of the virus from animals to humans (Plowright et al. 2017)—had done more damage to the American economy and killed more people than almost any previous war, and provoked widespread civil unrest (Committee for the Coordination of Statistical Activities, 2020). Moreover, organized violence does not occur in a vacuum; a complicated network of root causes, from power relationships within and across societies to poverty, can provoke civil unrest, political friction, and cross-border violence. Access to food, water, energy, non-fuel minerals, and other natural resources, as well as the consequences of industrial age economic productivity, such as climate change and biodiversity loss, are part of this root network of drivers of instability. More to the point, reliable and affordable access to natural resources is necessary for building stability and well-being.

While this interlinkage of the natural environment, human societies, and violence is nothing new, the sheer amount of systemic environmental change is shifting the balance and arguably the definition of national security. The findings of both the Intergovernmental Panel on Climate Change (IPCC; Adger et al., 2014) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2019) suggest that the magnitude of environmental change over the 21st century will be unprecedented in human history.[(Q5)] A related concern is that inherent planetary boundaries are being reached whereby the environmental capacity to meet certain basic societal functions becomes increasingly stressed (Rockström et al., 2009). Significant new scientific understanding and technological innovation are needed if societies are to mitigate the damage and adapt to new circumstances without widespread suffering, instability, injustice and conflict. To date, only a small fraction of the environmental research community has been focused on understanding these processes.

Definitions.
This paper defines key terms as follows:

Environmental Security: usually refers to the way environmental trends, stressors, and quality affect individuals, communities, or nations. But this term can also refer to general health and stability of ecosystems.

Human Security: the health, safety, and wellbeing of individuals and communities, usually revolving around human development indicators such as poverty, disease, equity, and reliable access to natural resources.

Societal Security: the ability of a community or group of communities to maintain a cohesive identity and functioning collective governance and civil society. Threats can be internal or external.

National Security: usually refers to the security of nations, generally meaning the protection of territorial integrity from external threats. Usually revolves around violence and use of force.

State of the science

Scientific understanding of climate change and biodiversity loss has improved dramatically in the last two decades, but the understanding of how environmental change interacts with human and societal security has lagged behind. There is a small canon of interdisciplinary research on environmental change and human security. This includes work aimed at a more general audience suggesting a causal link between climate change and conflict. One approach has been to assess whether a statistical relationship exists between the occurrence of particular weather patterns and the occurrence of conflict, including that incidences of civil conflict doubles in the tropics during El Niño conditions relative to La Niña conditions (Hsiang et al. 2011), unusually warm temperature being associated with civil war in Africa (Burke et al. 2009), and that natural disasters increase civil conflict (Nel and Righarts 2008). A review of this literature, making the case for a distinct causal relationship, is provided by Burke et al. (2015). However, the validity of such causal relationships has come under question,[(Q6)] including questions regarding what constitutes a proper measure of conflict and whether it is adequately observed (Scheffran et al. 2012; Buhaug 2015).[(Q7)] An additional concern is that these studies look at just a few dimensions of environmental change, such as heat or precipitation.

Other dominant narratives point to climate change-induced drought as a contributing factor to the conflict in Syria, and to the Arab spring uprisings brought on by high food prices and food insecurity. These kinds of narratives support the argument that climate change will lead to resource scarcity and violent conflict (Parenti, 2011; Klare, 2013). Framing environmental issues as security concerns can result in a narrow problem-solving approach (Deudney, 1991; Marzec, 2015) rather than a more comprehensive assessment of a situation that instead asks, "What is being secured and for whom?" (Dalby, 2009). Closer inspection of some case studies reveals that sometimes those narratives are misleading. For instance, water stress has not been conclusively shown to be a cause of war. A recent expert elicitation (Mach et al., 2019) summarized that, whereas there is agreement that climate has influenced organized armed conflict, this influence is substantially smaller than other drivers, such as low socioeconomic development and low state capabilities. Continued climate trends are, however, anticipated to contribute to more substantial increase risks of future conflict.

An open question is the necessary spatial and temporal scales of analysis. Understanding of conflict or harm can be further constrained by spatial focus. For instance, state-level water sharing agreements may appear to be politically stabilizing, but they can overlook mundane violence experienced at local scales in the form of disrupted water supplies, soil erosion, and insufficient fish stocks (Thomas, 2017; see also Petersen-Perlman et al., 2018). Statistical analyses can be conducted with modern instrumental data from repeated observations, but a lingering issue is whether short-term variations used in a given analysis will prove analogous to the long-run consequence of climate change with respect to instigating conflict.[(Q8)]

Will short-term variations in environmental pressures, such as disrupted water supplies, prove analogous to the long-run consequence of climate change with respect to instigating conflict?

As noted above, a prominent issue is the possible link between climate change-related water scarcity and conflict in Syria. Kelley et al. (2014), for example, link migration within Syria to the occurrence of a sustained drought and present evidence that climate change made this drought more likely. While there is a correlation, further study suggests that the relationships between these factors are more complicated than early analysis suggested. The wheat crop in Syria, for instance, is irrigated, and the climate change models used as evidence of drought are not necessarily skillful predictors of drought in the Middle East, nor in the specific regions of interest within Syria (Selby et al., 2017). It is notable that the debate regarding causality and credibility of predictions continues (e.g. Kelley et al., 2017), suggesting that further careful work is important, and that entraining a broader research community could be useful.[(Q9)] Furthermore, there exist counter-examples whereby environmental pressure has been associated with greater cooperation, such as shared river systems leading to more international water agreements (De Stefano et al., 2012) or that countries subject to climate-related natural disasters tend to have lower incidences of conflict (Slettebak, 2012). Other analyses find that there is little to no evidence that countries engage in interstate war over water (e.g., Wolf et al., 2003). Detailed historical analysis at the nexus of environmental, political and social events has the potential to inform better policy outcomes and conflict prevention.

Are predictions of droughts and other extreme events based on climate change credible?

It is generally the case that environmental influences need to be placed in a broad context. Analysis of food security has sometimes overlooked processes of land acquisition for purposes of commodity agriculture, biofuel energy production (e.g., jatropha), or for green agendas (e.g., conservation, biocarbon sequestration).[(Q10)] International land acquisitions involve networks of governments, transnational corporations (who sanitize the activity through "grainwashing", Scanlan 2013), and international organizations and result in the dispossession of people, often Indigenous, from their repurposed land (Sassen, 2013; Nally, 2015). Food shortage and price are only part of the overall picture. Familiar narratives that draw direct linkages between environmental features and conflict or human suffering have often underplayed the significant role of poor governance, which is hard to capture quantitatively.[(Q11)] They also have tended to overlook forms of slow violence and harm that are not immediately visible and that are difficult to measure (e.g., Nixon, 2011; O'Lear, 2016, 2021; Davies, 2018).

Do narratives that directly link environmental features with conflict or human suffering underplay the significance of poor governance?

ARCTIC ENVIRONMENT AND SECURITY RESEARCH OPPORTUNITIES

Long known as a hotspot for hydrocarbon and natural gas resources (Bird et al., 2008; Gulas et al., 2017), for the first time in human history, the Arctic Ocean has become navigable and is consequently now a place of growing geopolitical friction. With Arctic sea ice melting at unprecedented rates, new shipping routes and valuable natural resources are increasingly more accessible (Allen et al., 2017). Arctic and non-Arctic countries are lining up to take advantage of these new opportunities that include, in the case of Russia, an increased military presence. Since the 1982 UN Convention on the Law of the Sea (UNCLOS) treaty was established (but not ratified by the U.S.), all Arctic nations have experienced expensive cycles of mineral exploration with little success. Many factors are at play here: global commodity prices, the costs of exploration and production and their related technologies, geographic access and infrastructure, environmental consequences, and legal and political climates (Council on Foreign Relations, 2014). A balance between new opportunities and missing infrastructure affects both marine and terrestrial environments in the Arctic (i.e., ice-breaking capacity, maritime navigation, deep-water port facilities, roads, pipelines, railways, airfields, communications) while the changing terrestrial environment (e.g., thawing permafrost) already affects existing communities (residents, businesses, governments, newcomers) and assets (Council on Foreign Relations, 2014).

Many Arctic nations, although eager, are not prepared to take on the responsibilities of the consequences of a drilling-related disaster (Knol and Arbo, 2014; Gulas et al., 2017; WWF, 2018). Meanwhile, Arctic communities are living and/or bracing for the effects of climate change as rising seas, coastal erosion and thawing permafrost threaten their security. Such rising sea levels due to thermal expansion and glacier melt already affect the security of island communities around the world. Internationally, the Arctic Council working group provides scientific advice on Arctic human and ecosystem environmental assessments and recommendations (Arctic Council, 2018) to be balanced with national interests, security and claims (Council on Foreign Relations, 2014). In other words, focusing on Arctic oil and/or gas activities and likely spills overlooks the impacts of the measured trends in sea ice decline on ecosystems diversity and food webs, coastal erosion and local towns' stability, maritime and terrestrial transportation and shipping, naval security, and national security.

Environmental changes in the Arctic are linked to social, economic, and political aspects of Indigenous societies and pertain to issues of resource use, management, and monitoring at multiple spatial scales (Nuttall 2020). Underlying these current implications of change is the historical imposition of Euro-American property regimes in Arctic regions that have opened possibilities for Indigenous groups to negotiate with governing bodies over land claims and self-governance. However, this imposition of the language of property and practices of territoriality devalues and overlooks non-territorial forms of Indigenous socio-political organization and interaction with environmental features (Nadasdy 2017). For example, in the Arctic it is critical to reconsider how material substances such as ice are geopolitical matters. Although ice has been brought into settler colonial perspectives of empty, ungoverned space, ice is experienced and represented differently in Indigenous oral cultures and working interactions with the physical environment (Dodds 2019). To "fully understand how to identify, promote, incentivize, and reward sustainable behaviors and the barriers to them" in the Arctic "requires contributions from communications, cultural studies, ethics, history, law, literature, linguistics and philosophy" (Petrov et al 2016, p 172).

The rapid decline of Arctic sea ice and glaciers over the last century and their far-reaching ramifications exemplify how global environmental changes have the potential to disrupt geopolitical relationships within and between nations as well as create new threats to national and international security (Dalby 2020; NRC 2011). The consequences of this rapid change are affecting local security, health and welfare in places with already vulnerable racial, ethnic, or low socioeconomic status populations. This also raises the more general question of which global environmental changes have the potential for such wide-reaching consequences. A variety of research strategies are highlighted here that afford opportunities to address these and related questions:

ARCTIC ENVIRONMENT AND SECURITY RESEARCH OPPORTUNITIES (continued)

- Invest in improved predictive capability for Arctic forecasts for weather, high resolution ice pack extent and concentration (fast/shore ice breakup, sea ice breaking and navigation).
- Combine geophysical observations with local knowledge for fast/shore-ice for transportation, breakup, navigation.
- Increase in situ meteorological and oceanographic observations year-round to advance basic research.
- Improve and maintain the Alaska transportable array (NSF-sponsored; this array is used to detect earthquakes with below ground sensors, can include meteorological sensors). In general there is a need for more environmental sensors.
- Improve and maintain Arctic Observing Network (NSF-sponsored) for land, ocean, air continuous measurements that are essential for regional model improvement for forecasts.
- Invest in and improve on high resolution (space and time) coupled land-ocean-atmosphere regional Arctic models, in which each reservoir (air, water, soil) includes physical, chemical and biological processes and can then be linked to management human and environmental goals.
- Increase understanding of vessel waste discharge (oil, sewage, grey water, harmful algal blooms and associated pathogens, microplastics) and its influence in the Arctic ecosystems and people.
- Investigate invasive species in the Arctic (land and ocean).
- Examine the habitat connectivity of land-based animals and associated human communities (subsistence hunting).
- Advance convergent research on novel changes in the physical environment: (a) Coastal erosion, controls and remediation (land loss, ocean turbidity increase + change in food web/subsistence fisheries, coastal communities, infrastructure, storm events, loss of landfast ice), (b) permafrost thaw and degradation (transport, building/infrastructure stability, changing plant/bacterial/fungal ecology, release of climate-active CH_4, Hg release and volatile organic compounds), (c) land-fast ice melting (transport, subsistence hunting and fishing, coastal stability).
- Monitor and model Hg processes in delta environments (e.g., mining anew in 9 rivers).
- Characterize the deposition of atmospheric black and brown carbon and its influence on Arctic systems (atmospheric chemical monitoring, chemical transport model improvement for the Arctic, human health, ecosystem health, wildfires).
- Assess approaches to sustainable Arctic community development (renewable energy vs. oil-dependency in the high north; high energy costs; many engineering and materials challenges with respect to solar panels in this harsh environment; cold-improved re-chargeable batteries and even plain batteries – the latter would go for science instrumentation and industry as well).
- Make Arctic-relevant data accessible in formats that are easy for the user, rather than easy or less expensive for the data facility to store; enhance display and translational tools; overcoming that gap – consider how, where, and in what format the data will be most accessible; also invest in people to play the translational role, getting a better understanding of users' information needs and playing the informed "matchmaker" role for all stakeholders, to help translate between science and security communities.
- Expand the National Snow and Ice Data Center (NSIDC); data collection, analysis, management and access technologies and tools are available for some parameters but need to be systemic, long-term.
- Identify how environmental change contributes to migration to or from the Arctic, and to migratory patterns of Indigenous peoples in the Arctic, and how environmental changes in the Arctic and elsewhere contribute to migration in other parts of the world, such as in the Americas.

Opportunities for the research community

At what temporal and spatial scales should research be focused?

Three categories of research have the potential to fill identified needs for the broader human security community: direct effects of environmental change; the relationships between environmental change and social stress; and environmental and ecological surprise.

1. The first category is an overarching research area that includes research on the direct effects of climate change and environmentally associated natural disasters, patterns of infectious disease, direct effects of environmentally-triggered agricultural pests or invasive species with direct economic impacts (e.g., emerging research on pathways to zoonotic spillovers, Plowright et al., 2017). The societal dimensions of biodiversity and habitat change, including redistributions of species—especially fisheries—are critical to security.(Q12)

How do the direct effects of climate change and environmentally associated natural disasters, and of environmentally-triggered agricultural pests or invasive species with direct economic impacts, such as zoonotic spillovers, affect security? What roles do the societal dimensions of biodiversity and habitat change, such as the redistributions of species in fisheries, play in security?

2. In the second category, there is a growing recognition that the systems upon which society and human security rely reflect complex, intertwined, and compounded effects of human activity, such as the food-energy-water (FEW) nexus (Andrews-Speed et al. 2015). Several funded projects under the "Innovations at the Nexus of Food, Energy, and Water Systems (INFEWS)" joint initiative between the NSF and USDA NIFA have focused on the climate security issues that are exacerbated by not using an integrated nexus approach to make decisions in at-risk areas. For example, in order to make informed nexus-based decisions, an understanding of multiscale resilience options is required, including an understanding of what types of agriculture systems are more at risk from climate change and other extreme events.(Q13) The inclusion of international partners, such as China, in this joint initiative has facilitated scientific access to at-risk areas in partnering countries.

Environmental conditions are changing extremely rapidly, and generally for the worse in much of the developing world. INFEWS is beginning to provide insights into some of the vulnerabilities to these changes in the developing world. The Johns Hopkins research groups of Benjamin Zaitchik and Sauleh Siddiqui were awarded an INFEWS Track 1 project in 2016 (Award ID 1639214) to study the FEW nexus reactions to climate change in emerging economies and identify the effect of climate change on energy and food security development. A recent publication from this group examined agricultural production of smallholder farmers in Ethiopia using the Livelihood Vulnerability Index IPCC method. The study concluded that major differences in vulnerability to climate change were linked to varying household statistics (i.e., years of farming experience, education, isolation from community support, etc.), lack of access to infrastructure (e.g., nearby health centers and consistent water supplies), low levels of livelihood diversification (e.g., reliance on only agriculture for livelihood), and low access to available technologies (e.g., availability of solar panels for power supply). Understanding such vulnerabilities in small-holder agricultural communities can lead to integrated approaches to impart resilience in the face of climate change (Dendir et al 2019). More generally, there is a need for a better understanding of how the increasing stress of climate change will affect integrated food-energy-water systems and threaten food, energy, and water security for communities around the world.(Q14) This would include global supply chains that directly affect the United States.

3. Within the third category are largely unanswered questions about large-scale tipping elements, regime shifts, and sequential or clustered extreme events and the compound nature of multiple events. This includes smaller scale surprises that don't necessarily appear to be catastrophic at first but can have regionally significant effects and impacts on people, e.g., toxic or harmful algal blooms in Florida and the Midwest or the seaweed *Sargassum* explosion in the Caribbean Sea. Environmental surprises are anticipated from an ice-free Arctic, as illustrated by the research opportunities highlighted above.(Q15)

What are the local, regional, and global causes and security consequences of environmental surprises at different scales, for example as can be anticipated from an ice-free Arctic, or from harmful algal blooms?

How will the increasing stress of climate change affect integrated food-energy-water systems and threaten food, energy and water security for communities around the world?

In addition to these three categories, opportunities also exist to better understand, particularly from social and policy sciences perspectives, the role of the environment in peacebuilding, not just as an accelerant of instability. Key questions include what motivates different actors to engage in environmental peacebuilding, the effectiveness and criteria for success for such environmental peacebuilding, and the extent to which environmental peacebuilding has mitigated or enhanced tensions in other topical areas of negotiation.(Q16) This sort of environmental diplomacy often revolves around two arenas of engagement: negotiations around the use of natural resources (e.g., water, land, or fisheries) and negotiations around environmental pollution (e.g., water, air, or greenhouse gases) (Dorsey, 2017). Diplomatic efforts can be comprised of formal bi-lateral or multi-lateral negotiations as well as more informal, multi-track engagements that include a broader range of government and non-government actors. Because the environment has traditionally been viewed as a secondary issue by governments, environmental diplomacy has generally operated with more freedom than traditional bi-lateral diplomacy (Orsini, 2020). The environment may be seen as a "safe" topic where it may be easier to find common interest and opportunities for cooperation relative to other issues. For example, the NSF routinely provides funding to U.S. researchers through the Belmont Forum, which supports international collaborative research. Such research cooperation may be seen as a safe arena of engagement relative to other issues, and various research cooperative agreements often exist among nations that are otherwise seen as adversaries. That said, with climate change now viewed by many nations as being a major issue of concern, the environment is increasingly becoming a primary arena of diplomatic efforts (Tourney and Cross, 2018). Climate change, in particular, has moved environmental diplomacy into the mainstream, as evidenced by the negotiations among parties to the United Nations Framework Convention on Climate Change and the Paris Accord (Tourney and Cross, 2018). Even with such a high-profile environmental security concern, however, there is potential for scientific cooperation where scientific integrity norms are shared. This will be especially important with nations the United States is at odds with, such as China, that are critical to achieving global greenhouse gas reductions.

In what form will the research have greatest impact?

What are the relative roles of synthesis and assessment, data mining and "big data" approaches, more comparative case studies, model development and simulation?

Adequate observational systems and indicators for environmental security have yet to be developed.(Q17) Although frameworks for indicators of climate change impacts have been developed (Kenney et al. 2016, 2018), there is no widely accepted analogous system of indicators for environmental security that allows researchers to make appropriate observations or affords reliable insights into when rapid environmental stresses lead to strife, or to cooperation. There have been significant efforts to develop indicators for environment, conflict, fragility, and state failure. These go back to the first Bush and Clinton Administrations when there were huge data quality and quantity problems and mismatches in scale and resolution (e.g., SFTF, 1999; Baker and Zall, 2020). More recently, with better data, efforts have been made on both unclassified and classified databases at the Department of Defense (DoD), Intel, USAID, and State Department staff, and by outside academics to narrow down the priority environmental variables that need to be tracked with greatest utility for predicting conflict. However, what at times could be described as a "pick one or two variables and we'll add it to our model" approach has not been fruitful for those focused on predicting the next conflict (Buhaug, 2015; Mach et al., 2019), and has been of widely varying quality. Like other previous approaches, it again privileges the environmental contribution to the onset of conflict question. A more productive approach may be to have systems and indicators collecting a wide range of data to allow analysis on wider impacts on economic activity and food systems in order to provide insights into human responses, both good adaptations and bad, with sometimes divergent consequences for individuals and societies collectively (Busby et al., 2018). Having environmental data may not be the primary problem – rather, it is understanding both environmental impacts and human (mal)adaptations to these, and how these influence both human security and traditional security endeavors that matters most. Identifying indicators and tracing nonlinearities through environmental and social interactions is challenging, but will also create new opportunities for modeling and simulations to support security-enhancing decisions.(Q18)

What indicators and data collection systems will allow the most productive analysis of the wider impacts of environmental change on economic activity and food systems, in order to provide insights into human responses and adaptations, and their consequences for the security of individuals and societies collectively?

What is the role of the environment in peacebuilding, or as an accelerant of instability? What motivates different actors to engage in environmental conflict resolution? What makes environmental peacebuilding effective or successful? To what extent has environmental peacebuilding mitigated or enhanced tensions in other topical areas of negotiation?

A contributing factor to limited views of human-environment interactions is a narrow understanding of science. There is a tendency to look for assurances from science with a focus on large, quantitative studies because they appear to present a comprehensive view (see Gleditsch et al. 2006). Yet smaller scale, qualitative studies can contribute rich nuance to our understanding (Wolf, 1998; Wolf et al., 2003) and offer deeper insights into multiple, simultaneous meanings of both "environment" and "security" as well as fragility. Advanced forms of data collection and synthesis, such as satellite remote sensing, drone proximal sensing, and geographical information systems (GIS), open up new possibilities for expanding our knowledge of human-environment interactions, especially when combined with social science insights.[(Q19)] Rule-based or risk-based decisions are inherently political in their processes and effects on the world (Amoore 2014), just as algorithms based on big data and deployed for security purposes have ethical and political implications (Amoore and Rayley 2016). Visual technologies like remote sensing have helped to construct an understanding of environmental risk and security as visible and governable in line with established structures or agendas (Roth 2017). Although combinations of remotely sensed imagery and big data are currently deployed in projects involving natural resource exploitation and infrastructure development, grounded, ethnographic work is invaluable for understanding geopolitical realities of these projects (Bennett 2020) and security implications at multiple spatial scales. Although access to some forms of big data and remotely sensed visual imagery has expanded well beyond military or even corporate actors, care should be taken to understand how activism by non-governmental organizations and on-the-ground environmental activism efforts using these data streams and technologies may serve to reinforce existing power structures or challenge them (Rothe and Shim, 2018; Schneider and Olman, 2020). It can be valuable to acknowledge not just territorial areas of uneven distribution of environmental features, access, and justice, but also to understand the vertical geographies and the uneven vertical distribution of features and processes (Elden, 2013), such as who has access to remotely sensed data and other aerial perspectives. Critical approaches to the uses of visual and other technologies, and to the geographies of knowledge they help to construct, can usefully engage collaborative efforts of both physical and social scientists (Garrett and Anderson, 2017) and with local communities.

What are the geopolitical realities of natural resource exploitation and infrastructure development? How can ethnographic research complement or be integrated with remote sensing and big data approaches to understand these?

Just as security may be defined at different spatial scales and in different dimensions (e.g., food security, human security, etc.), environmental and social data are collected at any number of spatial and temporal scales for particular foci and variables which may or may not be useful for addressing the most urgent or more forward-looking research questions. The available data may not fit emerging questions. If they are to be useful to local communities in the Arctic region, data cannot all be annual and panarctic.[(Q20)] It will be important to bring researchers who understand the nuance of their own discipline together with researchers from other disciplines and Arctic communities, especially Indigenous people, in order to foster conversations and research designs that address and also integrate disciplinary specializations in innovative ways.

Security analysts may lack the time, expertise and resources to access academic journals and the large volume of environmental data currently available. Data available on unclassified systems (e.g., Landsat imagery) can be difficult to obtain and use in the classified operating systems within which security analysts work. These conditions create a critical need for syntheses and regular summaries and interpretations of priority research on environment and security, including large scale visual analytics and imagery assessing connections between environment and security.[(Q21)]

There is a critical need for syntheses, regular summaries, and interpretations of priority research on environment and security.

Who should conduct the research?

What should be the relative roles of individual investigators, small teams, large teams, research networks, partnerships and other social and organizational arrangements?

The NSF is well situated to stimulate advances and fundamental innovations in environmental security, through all of the forms of research that it supports, as well as by developing and expanding partnerships with the Department of Energy (DOE), DoD and other agencies to this end. Environmental security is a critical and by many accounts relatively neglected potential broader impact of investments made in research through standing programs in each of the NSF Directorates, as well as for convergent research across spatial and temporal scales. This includes opportunities for individual investigators, teams and larger research networks and partnerships, as well as investments in Centers and research infrastructure.

Boundary organizations and translators/boundary-spanners between environmental science and security communities currently exist, but with very limited funding. Investments in these have the potential to transform environment and human security sciences and their broader impacts. Three initiatives—MEDEA, the Minerva Research Initiative, and the Strategic Environmental Research & Development Program (SERDP)—illustrate some of the opportunities and possibilities for the NSF:

- Through the auspices of the MEDEA program (1993 to 2001, 2001 to 2008), an unprecedented amount of previously classified environmental data from early spy satellites was declassified, enabling advances in environmental sciences, including but not limited to understanding of oceanography, ice movement and glacial flow, sea level rise, and coastal vegetation change (Baker and Zall, 2020). MEDEA also facilitated the Gore-Chernomyrdin Commission's US-Russia Environmental Working Group, which cooperatively created a unique set of digital atlases combining the two countries' complementary ocean data from the Arctic. Comparisons employing the US-Russia Oceanographic Atlases led to the interagency SEARCH program (SEARCH, 2005), and to the NSF Arctic Observing Network. Further, MEDEA created the Global Fiducials Program, through which the Intelligence Community has provided and continues to provide satellite data to support and enhance the environmental sciences, including analyses of extreme weather events, oil spills, and wildfires (Baker and Zall, 2020).
- Evaluated recently by the National Academies as having made important contributions to national security and the social sciences, the DoD Minerva Research Initiative has funded about $20M per year of unclassified research in the social, behavioral and interdisciplinary sciences since 2008 (NASEM, 2020). The goal of the Minerva Research Initiative is "to improve DoD's basic understanding of the social, cultural, behavioral, and political forces that shape regions of the world of strategic importance to the U.S." (Minerva Research Initiative, undated), including addressing the national security consequences of environmental change, identified at Minerva's start as one of the most pressing post-Cold War security issues (Desch, 2019 p 233ff; NASEM, 2020). At the outset, the NSF collaborated with DoD on the review and funding of grants, but this collaboration ended after the first round of grants (NASEM, 2020 p 9). The Minerva Research Initiative has contributed to bridging the gap between sciences and the national security community.
- The Strategic Environmental Research & Development Program (SERDP) at DoD funds basic and applied research as well as advanced technology development. Current calls for proposals ("statements of need") for SERDP focus on threatened and endangered species (e.g., marine mammals multi-stressor environments); mesoscale phenomena associated with wildland fire; and innovative approaches to understanding risk and resiliency. The research conducted focuses on stewardship of the environment and tends to be installation-centric; DoD is the second largest federal landowner, with a high concentration of endangered species on its lands. Specific installations also fund local studies; currently, there is no national coordination of these local studies. Although pertinent federal agencies are invited to send representatives to participate in reviews of applications to SERDP (Environmental Protection Agency and DOE are statutorily required to do so; other agencies participating have included the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers), NSF staff have not participated in recent years.

EMERGING RESEARCH AREA. CLIMATE ENGINEERING - UNDERSTANDING EARTH SYSTEMS INTERVENTION AND ITS IMPLICATIONS FOR NATIONAL SECURITY

Large-scale manipulation of the earth system designed to counteract the drivers of climate change is under increasing discussion in both scientific and policy circles. Even though economy-wide decarbonization is the most important step in stabilizing the earth system, some form of climate engineering may still be adopted by some countries. These interventions are generally proposed to alter either the carbon balance or the energy balance of the planet. Climate engineering raises a range of environmental and security questions that require transdisciplinary and convergent research approaches NSF is uniquely positioned to support, such as:

What are socio-environmental-systems dimensions of climate engineering? The tradeoffs inherent in all climate engineering technologies are difficult to understand a priori for a number of reasons. For one, they generally involve large-scale infrastructure-intensive coordinated activities that would need to be sustained for decades (Shepherd et al., 2009). Further, many of the proposed approaches could exhibit emergent systems-behaviors that are difficult to foresee (e.g., Robock 2008). For these reasons among others, the risk tradeoffs in climate engineering are challenging to navigate or even fully understand. For example, solar radiation management has been denounced by the International Panel on Climate Change (IPCC), even though (a) many of the models the IPCC uses assume that we will in future be able to deploy carbon dioxide removal at enormous scales, and (b) solar radiation management is a theoretically achievable way to manage the impacts of rising global temperatures. The requisite technologies for carbon removal at scale have yet to be proven (e.g., Shepherd et al., 2009). There are also steep disparities in power dynamics associated with these technologies. Current climate engineering project proposals, funded and promoted by powerful groups of people in richer countries (Stephens & Surprise 2020; Szerszynski et al. 2013), are not only un-democratic in procedure but also quite likely to have vastly uneven patterns of benefit and detriment around the planet (Castree, 2020; Yusoff, 2013). As a result, climate engineering raises ethical, national security, and environmental dilemmas (Dalby 2015, Surprise 2020) that have slowed or stalled some research. While some climate engineering methods, such as bioenergy with carbon capture and storage, may with sufficient funding be locally adopted, and in some policy scenarios be assessed as acceptable for stabilizing climate (Bellamy et al., 2018; Cox et al., 2020), other proposals, such as unilateral solar radiation management, concern policymakers (e.g., Mathur & Roy 2019) and fail to meet ethical demands for transparency and public deliberation (NASEM 2020; Gupta et al. 2020; Preston 2012).

What are impacts of climate engineering across scales? While carbon dioxide removal strategies are gaining traction because of their perceived importance in achieving net zero carbon goals, a number of questions remain about the impacts of these approaches at the regional scale, where many land and water use decisions are made (e.g., Holifield & Williams 2020; Vörösmarty et al., 2015). Impacts that climate engineering might have on the hydrologic cycle, agriculture, and other critical earth system processes may contribute to uneven impacts and increased vulnerability for some groups of people (Boyd 2009). Effective and equitable management of climate engineering technologies requires better understanding of how impacts can vary across scales and locations. Emerging research suggests public interest, support and resistance to climate engineering are likely to be sensitive to the same characteristics that drive acceptability of risks from other technologies, including perceptions of the costs of such technologies, how well the technologies are understood, and how similar the approaches are to natural processes (Burns et al 2016; Mahajan et al., 2018). There is also a need for better understanding the social dynamics of such perceptions and how they influence or are influenced by decisions across scales.

How can we monitor and plan for a future where climate engineering may be deployed? A number of U.S. federal agencies and other groups, including other governments and non-governmental actors, are grappling with understanding the ways in which climate engineering might impact national security. These subject matter experts need frameworks and tools to identify the key issues in different situations and scenarios. Given the extreme complexity of such studies, and the time and computational power currently required to conduct requisite sensitivity analyses, there is a need to develop tools and frameworks for understanding these technologies. In light of the widespread misgivings that these proposals could do more harm than good, there is a need to create science that can help de-risk viable technologies. Like the anti-nuclear proliferation movement decades earlier, the risks of climate engineering are too great to leave the consequences of its deployment unstudied.

Sustained funding is needed for innovative interdisciplinary work—work akin to what Minerva has funded—with even broader applicability across environmental, human, and societal security. It would also be helpful to adopt a systematic strategy to diversify review panelists, move into new areas, and fund organizations and activities that explicitly bring together environmental and security practitioners and scientists for scenario or tabletop exercises, new science briefings, and to familiarize scientists and practitioners with the respective norms, incentives, and operations of each community.

The type of research partnerships described above allow for early and long-going dialogues between practitioners and scholars of questions and puzzles across domains. This makes them essential for progress. As a result of emphasizing convergence, the NSF has developed new capacity to support research partnerships in the environment and security domain, where they will create new opportunities. In the absence of such partnerships, current integrative research on security can be slow to reach those who might be able to act on the findings (NASEM 2020).

Because the topic of environment and security overlaps with the missions of other federal agencies, the pursuit of joint solicitations between the NSF and other federal agencies can enhance the impact and relevance of sponsored research. In addition to the DoD, the USDA, the Department of Homeland Security, the DoE, the State Department, and the Agency for International Development all have human and/or national security as an aspect of their missions. Various models exist for collaborative research programs that span multiple agencies. For example, the NSF's Innovations at the Nexus of Food, Energy and Water Systems (INFEWS) program has been active since 2015 in funding research in collaboration with the USDA on the safety, security, productivity, and resilience of integrated food, energy, water systems.[1]

In addition, there are precedents for collaborations between the NSF and science agencies in other nations. USAID supports the Partnerships for Enhanced Engagement in Research (PEER) program in partnership with the NSF, National Aeronautics and Space Administration, National Institutes of Health, Smithsonian Institution, USDA, and USGS.[2] The PEER program provides support for researchers in eligible developing countries to engage in collaborative research projects with U.S. Government-supported researchers. The NSF participates in the Belmont Forum, an international partnership that mobilizes funding of environmental change research.[3] The NSF has also engaged in bi-lateral international research partnerships. For example, since 2019, the NSF and the National Natural Science Foundation of China (NSFC) have partnered to encourage joint research by U.S. - China teams collaborating on fundamental research that addresses critical environmental sustainability challenges.[4] Building on these models of international cooperation may suggest useful pathways for the NSF to consider supporting research on environment and security in vulnerable regions.

To succeed, research partnerships must be designed to address and be robust against the numerous practical barriers that exist between the environmental science and security communities. These include: stereotypes and caricatures of what questions each community is interested in and what tools are used; mismatched timelines for asking questions and getting research done; community and cultural diversity, for example the security community is sometimes viewed as monolithic when it is heterogeneous with diverse questions, tools, and focal areas; costs of engagement between the two communities, including the absence of incentives and resources, and the presence of opportunity costs for engagement (e.g., coordination costs); transparency and other issues related to scientific integrity; (mis)alignment of research priorities; conflicts between striving for peer-review quality science vs. "good enough" science; and different understandings (and comfort with) uncertainty (e.g., Desch, 2019).

[1] See NSF 15-040 Dear Colleague Letter: SEES: Interactions of Food Systems with Water and Energy Systems https://www.nsf.gov/pubs/2015/nsf15040/nsf15040.jsp
[2] See Partnerships for Enhanced Engagement in Research Program Summary at https://www.usaid.gov/what-we-do/GlobalDevLab/international-research-science-programs/peer
[3] See https://www.belmontforum.org/
[4] See NSF 20-019 Dear Colleague Letter: NSF/NSFC Joint Research on Environmental Sustainability Challenges at https://www.nsf.gov/pubs/2020/nsf20019/nsf20019.jsp

Summary of opportunities

Research produced in the U.S. and funded by the NSF is used internationally and is an important part of U.S. soft power. In contrast to a decade ago, now those with access can look every day at a new peer-reviewed article that concerns some national security issue, especially for climate change and food and water security, although this is less true for other environmental issues. The NSF has the opportunity to translate this momentum into robust advances in the environmental sciences that contribute to human security.

Although it has been obvious for several decades that environmental change affects national and human security in the U.S. and globally, the COVID-19 pandemic has illustrated the urgency of understanding security in this broader sense. However, the scientific knowledge and technological innovation to support a more robust understanding of security that includes environmental change is nascent. In the wake of the current coronavirus pandemic, reassessments of research investments are likely. Improving modeling and projections of the confluence of human behaviors and environmental stressors that increase public health and security risks from novel zoonotic diseases have the potential to pay off many times over.[(Q22)] This is an opportune time for the NSF to contribute to American security and prosperity by promoting scientific advances at the nexus of environment and security.

NSF has the opportunity to translate recent momentum in research on topics such as climate change and food and water security into robust advances in the environmental sciences that contribute to human security. For example, improving modeling and projections of the confluence of human behaviors and environmental stressors that increase public health and security risks from novel zoonotic disease have the potential to pay off many times over.

The NSF can advance environmental science and security with existing disciplinary work, by increasing investment in more diverse and robust interdisciplinary/convergent research inclusive of social and behavioral sciences, and by advancing platforms and mechanisms to overcome barriers to greater collaboration and exchange. Some of this can be achieved with changes to currently funded efforts, both within the NSF and in collaboration with other agencies, and some will need to be new activity.

PRIMARY RESEARCH QUESTIONS

1. What are the social, economic, and political interactions with and responses to environmental stress, and how dynamic are they? To what degree are these interactions constructive or do they exacerbate underlying fault-lines in social cohesion, economic activity, and stability? **(Q1-Q4)**
2. Are statistical relationships that exist between the occurrence of particular weather patterns (e.g., droughts) and the occurrence of conflict valid as causal relationships? This includes questions regarding what constitutes a proper measure of conflict, whether it is adequately observed, and the extent to which responses to short-run environmental changes inform about long-run changes **(Q6-Q7)**
3. What environmental and ecological surprises—large-scale tipping events or shifts in the natural environment-
-will the accelerating rate and scope of environmental change deliver by the end of the century? What unprecedented (in human history) shifts can be expected? What smaller scale surprises will have regionally significant effects and impacts on people (e.g., toxic / harmful algal blooms in Florida and the Midwest; seaweed Sargassum explosion in the Caribbean Sea; environmental surprises anticipated from an ice-free Arctic). (Arctic text box, **Q15**)
4. What will be the direct effects of climate change and environmentally-associated natural disasters, for example on patterns of infectious disease, direct effects of environmentally-triggered agricultural pests or invasive species with direct economic impacts (as examined in emerging research on pathways to zoonotic spillovers), and societal dimensions of biodiversity and habitat change, including redistributions of species (e.g., fisheries)? **(Q12)** How can we best improve modeling and projections of the confluence of human behaviors and environmental stressors that increase public health and security risks from novel zoonotic diseases? **(Q22)**
5. What potential do global environmental changes have to disrupt geopolitical relationships and create new threats to national and international security, as well as to the local security, health and welfare in places experiencing these changes (e.g., in the Arctic)? (Arctic and Climate Engineering text boxes)
6. What is the role of environmental peacebuilding and diplomacy in national security? **(Q16)** What systems and indicators can provide data that will allow analysis of the wider impacts of environmental changes on economic activity and food systems in order to provide insights into human responses—both good adaptations and bad? **(Q18)**
7. What spatial and temporal scales of research will permit addressing the environment and human security concerns of local and regional communities? **(Q20)**
8. What types of visualizations and analytics have the greatest potential for assessing connections between environment and security that can inform security endeavors? **(Q21)**

Research Areas denoted by Q1-Q22 throughout the report

Q1 To what degree are social, economic and political interactions with and responses to environmental stresses constructive, or do they exacerbate fault-lines in social cohesion, economic activity, opportunity and stability?

Q2 What factors determine a society's resilience to stress?

Q3 Why do some combinations of societal resources and environmental stress lead to conflict, while others lead to enhanced cooperation and resilient coupled systems?

Q4 Are some types of environmental change more difficult for societies to adapt to than others, for example when water, agriculture, climate change, and ecosystems are interconnected both ecologically and socially?

Q5 Will the rate and scope of current environmental change deliver unprecedented shifts in the natural environment by the end of the century?

Q6 Is there a statistical relationship between the occurrence of particular weather patterns and the occurrence of conflict?

Q7 Is the statistical relationship between the occurrence of particular weather patterns and the occurrence of conflict causal? What constitutes an adequate measure of conflict? What constitutes a valid and reliable observation of conflict?

Q8 Will short-term variations in environmental pressures, such as disrupted water supplies, prove analogous to the long-run consequence of climate change with respect to instigating conflict?

Q9 Are predictions of droughts and other extreme events based on climate change credible?

Q10 Does research on food security consider adequately the processes and diverse purposes of land acquisition?

Q11 Do narratives that directly link environmental features with conflict or human suffering underplay the significance of poor governance?

Q12 How do the direct effects of climate change and environmentally associated natural disasters, and of environmentally-triggered agricultural pests or invasive species with direct economic impacts, such as zoonotic spillovers, affect security? What roles do the societal dimensions of biodiversity and habitat change, such as the redistributions of species in fisheries, play in security?

Q13 What types of agricultural systems are more at risk from climate change and other extreme risks? What are the consequences of implementing multiscale resilience options, and how should these inform decisions at the nexus of systems such as the food-energy-water nexus?

Q14 How will the increasing stress of climate change affect integrated food-energy-water systems and threaten food, energy and water security for communities around the world?

Q15 What are the local, regional, and global causes and security consequences of environmental surprises at different scales, for example as can be anticipated from an ice-free Arctic, or from harmful algal blooms, or seaweed explosions? How do large-scale tipping elements, sequential or clustered extreme events, or the compounding of multiple events contribute to environmental surprises?

Q16 What is the role of the environment in peacebuilding, or as an accelerant of instability? What motivates different actors to engage in environmental conflict resolution? What makes environmental peacebuilding effective or successful? To what extent has environmental peacebuilding mitigated or enhanced tensions in other topical areas of negotiation?

Q17 What observational systems and indicators for environmental security will allow researchers to make appropriate observations and afford reliable insights into the how environmental stresses lead to strife, or to cooperation?

Q18 What indicators and data collection systems will allow the most productive analysis of the wider impacts of environmental change on economic activity and food systems, in order to provide insights into human responses and adaptations, and their consequences for the security of individuals and societies?

Q19 What are the geopolitical realities of natural resource exploitation and infrastructure development? How can ethnographic research complement or be integrated with remote sensing and big data approaches to understand these?

Q20 At which spatial and temporal scales should environmental and social data be collected to be useful for addressing the most urgent and forward-looking research questions about environmental change and human security?

Q21 There is a critical need for syntheses, regular summaries, and interpretations of priority research on environment and security. What types of visualizations and analytics have the greatest potential for assessing connections between environmental change and security that can inform security endeavors?

Q22 NSF has the opportunity to translate recent momentum in research on topics such as climate change and food security into robust advances in the environmental sciences that contribute to human security. For example, improving modeling and projections of the confluence of human behaviors and environmental stressors that increase public health and security risks from novel zoonotic disease has the potential to pay off many times over.

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