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Short Communication

A new mission: Mainstreaming climate adaptation in the US Department of Defense

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A R T I C L E I N F O

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A B S T R A C T

The United States Department of Defense (DoD) recognizes growing climate risks across its responsibilities as land manager, operator of hundreds of installations, and in its core mission to protect national security. However, DoD climate risk reduction is complicated by frequent leadership turnover among base commanders, which encourages focus on near-term challenges, and changing US government priorities that downplay climate risk. We used risk-based deliberation, through workshops, with climate scenario-based fire and flood impact modeling to evaluate risk and adaptation opportunities at bases in the southwestern United States. We found that success in working with Defense installations hinges on linking risks of increasing climate-related impacts to DoD's ability to achieve its mission objectives at installations. Workshop participants offered insights into barriers to adaptation, including access to decision-makers in a hierarchical organization, leadership focus on near-term challenges, insufficient training or capacity to integrate climate information into short and long-term decisions, and rapid turnover in leadership. We also found opportunities for mainstreaming climate risk management into DoD activities, including emphasizing risks to DoD's mission, opportunities to form symbiotic partnerships with external partners, and the potential for standardized procedures for considering physical climate risks that could be integrated across the DoD to achieve longer-term solutions to climate change challenges.

1. Introduction

The large number of high-profile climate-related events that have occurred on US soil and internationally in recent years, (e.g., 17 more than $1 billion events in the US in 2017; NOAA, 2020) is raising awareness of the rapid escalation of physical climate risk. Recent wildfires in California were the largest in recorded history, and the highest rainfall total in a single storm in the continental United States occurred in association with hurricane Harvey in Texas in 2018 (Di Liberto, 2017). The Fourth National Climate Assessment noted the direct and indirect impacts of climate events outside of the United States on the US economy, national security, and international development programs (Jay et al., 2018).

Some military installations have been dealing with the consequences in real time, such as a "near miss" in 2012 when the Waldo Canyon fire and subsequent severe flooding threatened the town of Colorado Springs and much of its military infrastructure (Chin et al., 2016). Similarly, ongoing nuisance flooding, affecting operational efficiencies in four Navy installations near Norfolk, Virginia, where more than 100,000 people are employed by the armed services, is anticipated to be

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exacerbated by sea-level rise, (HRPDC, 2019).

The United States Department of Defense (DoD) is the largest employer in the world, with 2.15 million service members and over 770,000 civilian personnel (US DoD, 2020). DoD is the largest single energy consumer in the US (Lyle, 2012). Thus, it was headline news when DoD publicly released its adaptation "Roadmap," in a longer-term effort to adapt to physical climate change impacts, reduce greenhouse gas (GHG) emissions, and recognize potential geopolitical consequences of climate change (US DoD, 2014). For example, an October 2014 *New York Times* article announcing the Roadmap release was titled "Pentagon Signals Security Risks of Climate Change" (Davenport, 2014). In 2016, DoD Directive 4715.21 further articulated climate adaption as a Department-wide priority and established responsibilities for implementation (US DoD, 2016).

The DoD, 2014 Roadmap, which explicitly acknowledged the potential impacts of climate change on achieving the agency's mission, noted that "climate-related effects are already being observed at installations throughout the US and overseas and affect many of the Department's activities and decisions related to future operating environments, military readiness, stationing, environmental compliance and stewardship, and infrastructure planning and maintenance" (US DoD, 2014). The three main goals of the Roadmap were to: (1) identify and assess the effects of climate change on the DoD; (2) integrate climate change considerations across the DoD and manage associated risks; and (3) collaborate with internal and external stakeholders on climate change challenges (US DoD, 2014). Nonetheless, implementation of the Roadmap has been an enormous challenge. A Government Accountability Office (GAO) assessment of DoD's actions to adapt its US infrastructure to climate change challenges concluded that although the DoD had made progress in adapting its domestic infrastructure to potential climate change impacts, the Department had not provided "planners with projections for the full set of expected impacts of weather effects associated with climate change" (GAO, 2017). Moreover, a recent study noted that despite DoD efforts thus far, "a herculean collaboration" between civil society, researchers and others will be needed to address climate change challenges (La Shier and Stanish, 2019).

Leadership on climate issues within DoD came primarily from top-down institutional policy, including Congressional and Executive Branch actions, beginning with the fiscal year 2008 National Defense Authorization Act, signed by President Bush. Federal efforts during both the G.W. Bush and Obama administrations pushed federal agencies to include climate considerations in their protocols for sustainability and security. The 2010 Quadrennial Defense Review recommended that climate change adaptation be considered in strategies and operations across the Armed Services (US DoD, 2010). This was reiterated in the Roadmap and in a 2016 Directive aimed at mobilizing climate preparedness within DoD (US DoD, 2016), in Executive Orders and in the President's Climate Action Plan (Obama, 2013), which directed all federal agencies to develop and implement strategies to evaluate and address the most significant physical climate change-related risks.

Subsequent elections led to dramatic swings in the US administration perspective on the urgency of climate issues. It is notable that the US military continued to demonstrate significant interest in climate adaptation even after President Trump rescinded all climate-related federal agency actions directed by President Obama. From 2016 to 2020, the internal DoD emphasis shifted to managing risks, rather than on preparing for climate change *per se* (Copp, 2017). However, senior DoD officials have continued to draw attention to climate adaptation. In the period between January 2017 and October 2019, 35 senior DoD officials warned publicly of the security implications of climate change for the US (Center for Climate and Security, 2019). In his 2017 US Senate confirmation testimony for the position of Secretary of Defense, nominee James Mattis asserted that "Climate change is impacting stability in areas of the world where our troops are operating today…It is appropriate for the Combatant Commands to incorporate drivers of instability that impact the security environment in their areas into their planning." In that same testimony, he argued for a "whole-of-government response" to climate change. In September 2019, the Climate and Security Advisory Group called on the U.S. President to recognize climate change as a vital national security threat and issue a National Strategy to fulfill a "responsibility to prepare for and prevent" that threat (Center for Climate and Security, 2019).

In January 2018, the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (ATL) released the *Climate-Related Risk to DoD Infrastructure Initial Vulnerability Assessment Survey (SLVAS) Report* (US DoD, 2018), in response to a Senate request. The Report evaluated risk exposure, at over 3,500 DoD installations and associated sites, to storm-surge flooding, non-storm surge events (e.g., rain, snow, river overflow), extreme temperatures, wind, drought, and wildfire. The Report noted that extreme temperatures, storm surges, and wildfire have affected 6–10% of DoD sites surveyed. Importantly, this survey and report may have been motivated by "checking the box," as required by the National Defense Authorization Act; follow-up activities have not been reported.

2. A new mission: origins, goals and objectives

In support of managing climate risks, DoD funds research through the Strategic Environmental Research and Development Program (SERDP), with the goal of improving "our ability to assess the potential impacts to Department of Defense (DoD) permanent installations due to climate change and to facilitate appropriate adaptive responses" (SERDP, 2010). As one group conducting SERDP-funded research, we investigated opportunities and challenges faced by the DoD as it attempts to incorporate climate change adaptation planning in its domestic southwestern US installations. Our goal was to study DoD's adaptation efforts in the context of best practices currently being adopted by a growing global community of climate adaptation scientists working with a wide range of stakeholders and organizations (Willows and Connell, 2003; Bierbaum et al., 2013). Our primary objectives were to assess current and future climate challenges faced by DoD installations in the region, identify perceived physical climate risks, test approaches to producing and sharing adaptation information, assess the degree to which "mainstreaming" climate adaptation into DoD activities could accelerate progress in managing climate related risks, and determine climate service needs. Examples of climate service needs relevant to DoD installations include improved water supply forecasts, fact sheets on recent sea-level rise trends and changes to baselines, climate risk assessments, and interpretation of climate model projections and associated uncertainties. Other objectives included (a) comparing DoD climate adaptation barriers and opportunities (e.g., Moser and Ekstrom, 2010) to those in multiple economic sectors and geographic regions, and (b) assessing engagement and science collaboration strategies that can be effective at individual installations, where implementation of national policy can be most problematic, but the needs are most acute.

2.1. Project approach and philosophy

Our approach was guided by research suggesting that current experience of climate impacts or imminent risks enhances people's willingness to prepare for longer-term impacts (Wilby and Dessai, 2010; Briley et al., 2015). To avoid mismatches between the information produced by scientists and the type and format needed by decision-makers and managers (Dilling and Lemos, 2011), we engaged directly with installation managers and others to assess their concerns and needs, gain understanding of their decision context (including common procedures and constraints), exchange knowledge about the ability of the scientific community to provide timely and useful information, and share information about decision criteria and local knowledge (e.g., Meadow et al., 2015; Parris et al., 2016).

In working with military installations, we emphasized "deliberation with analysis," recommended by the National Research Council to support climate-related decisions (Kirchhoff et al., 2013; NRC, 2009). By co-developing communication ground rules and protocols, and encouraging two-way communication through iterative dialogue, we aimed to communicate clearly and build mutual understanding (NRC, 2010). These approaches formed a foundation for identifying and discussing risks and uncertainties, evaluating the appropriateness of information to be used in the process (Moser and Eckstrom, 2010), and facilitating the uptake of scientific information to inform decisions (Kirchhoff et al., 2013).

3. Setting and methods

To address the project goals and objectives, our team conducted an array of activities at installations in the southwestern US and interacted with defense personnel in the US and abroad. The southwestern U.S. is a critical zone for DoD readiness. In February 1993, General Colin Powell noted the importance of the southwest region to military readiness, stating, “in the southwestern US all four services have training, test and evaluation ranges that provide a land, airspace, sea area, and offshore supersonic operating domain that could accommodate a major portion of our joint test and evaluation needs” (US House, 1993). The region is the locus of a combination of rapid temperature increases, reduced late-season snowpack and substantial surface water supply declines, and increases in the frequency of large wildfires (Overpeck and Udall, 2010). Thus, the region provided an important setting for understanding the challenges faced by military installations in adapting to a changing operational environment. We worked with four southwestern US DoD bases (Fig. 1) representing a range of DoD branches, missions, environments, and potential climate impacts (Table 1). The activities included: (a) preliminary meetings, to understand decision-making contexts and operations affected by climate and weather, (b) climate adaptation assessment workshops at multiple installations, to identify perceived climate-related risks, observed and potential climate impacts to operations and missions, and strategies to address those risks, (c) detailed case study research and analysis of selected climate-related risks, as a proof of concept, to illustrate how defense installations can incorporate local climate adaptation into ongoing decision-processes, (d) a multi-project workshop and interviews with DoD personnel, to garner insights on barriers and opportunities to implementing climate adaptation planning within the DoD and to identify climate service needs (*sensu* Jacobs and Street, 2020), and (e) a review of literature, combined with interviews with international military practitioners to assess best practices for decision-making in the face of climate uncertainty. The mix of approaches and activities ensured that we would elicit information about climate risks and potential adaptation strategies from those with responsibilities for managing installation assets (a, b), corroborate the aforementioned information from others with similar responsibilities (d, e), evaluate promising approaches to climate services, that mesh with military culture, leadership, and practice (c, e), and evaluate current obstacles to adopting climate adaptation measures and possible solutions to overcome these obstacles (c, d, e). We refer to

Table 1
DoD installations included in the study.

Installation	Branch of Service	Location and ecological setting	Area in hectares (acres) (Source: US DoD, 2017)
Naval Base Coronado	Navy	Coronado, CA (coastal, inland chaparral)	23,067 (57,000)
Fort Huachuca	Army	Sierra Vista, AZ (San Pedro Watershed, Sonoran Desert, Huachuca Mountains)	29,704 (73,400)
Barry Goldwater Range West	Marine Corps	Yuma, AZ (lower Colorado River, Sonoran Desert)	279,945 (691,759)
Barry Goldwater Range East	Air Force	Gila Bend, AZ (Sonoran Desert)	470,783 (1,163,330)

Fig. 1. Locations of DoD installations in the southwestern US where climate change risks and adaptation options were assessed in this project. Installation boundaries from the National Transportation Atlas Database, US Department of Transportation (https://www.bts.gov/geospatial/national-transportation-atlas-database) (accessed 20 May 2020). Aerial imagery from ESRI.

activities (a), (b), and (c) as “pilot projects,” because the scope of the SERDP funding precluded the development of plans or operational practices for military installations. Methods associated with each set of activities are described briefly, below, and in greater detail in Garfin et al. (2017).

3.1. Engagement methodology

We initiated engagement with each installation through a designated DoD service branch liaison. The liaisons facilitated meetings with base personnel responsible for a range of installation activities. During initial meetings, we exchanged information with installation personnel about the range of physical climate-related issues of potential interest to the base, and recorded our knowledge exchange dialogues through extensive notes. We subsequently sponsored workshops that included a wider range of installation personnel and, where appropriate, representatives from NGOs, tribes, state and federal agencies with jurisdiction over adjoining lands. Our participatory risk-based assessment method (Willows and Connell, 2003; UK Ministry of Defence, 2015) was designed to connect immediate risks with future threats; similar approaches have been endorsed by climate assessment processes (e.g., IPCC, 2014; Melillo et al., 2014). These workshops provided base staff with an overview of regional assessments of climate impacts and projections and specific information relevant to the installation. Through structured workshop breakout groups, we identified installation personnel’s primary roles, responsibilities, key objectives and success criteria, and reviewed potential risks for different mission areas. The rationale for this approach was to introduce the concept of *mainstreaming*, i.e., integrating climate-related risks into the language and framework already used by DoD for non-climate-related risks to operational activities (e.g., Klein et al., 2007).

3.2. Risk and adaptation assessment process

We used a risk-based climate change adaptation assessment framework developed by the UK Climate Impacts Programme and the UK Environment Agency (Willows and Connell, 2003). The framework has been used by the World Bank and has been adopted by the IPCC (2014), and the UK Ministry of Defence. Background research and preliminary dialogues with stakeholders led to identification of key climate-related concerns and details of operational procedures. In workshop breakout sessions, participants examined recent weather- and climate-related impacts, and articulated decision-making criteria currently used by installations to mitigate or respond to disaster risks. These steps grounded conversations about projected climate changes and the ways that future climate may augment the risk. Other workshop exercises examined sensitivities and critical thresholds that may be breached (e.g., flood and erosion thresholds, wildfire risks, changes to endangered species’ tolerance). Participants examined strengths and potential weaknesses in existing risk management guidance and procedures, and identified information needs, barriers and opportunities for promoting adaptive responses to future climate exposure. These activities account for steps 1–3 in Fig. 2. In collaboration with installation personnel, we conducted a semi-quantitative expert assessment of specific risks, including cause-and-effect pathways between physical climate drivers and impact consequences, asset vulnerability ratings, and response capabilities (i.e., deeper examination of step 3 in Fig. 2). Workshop participant responses were transcribed into notes and reports to SERDP. (See Garfin et al. [2017], for workshop agendas and reports).

3.3. Case studies

In collaboration with personnel at Fort Huachuca and Naval Base Coronado, following the workshop-based initial climate risk screening, we quantitatively assessed wildfire and post-fire flood risks, using process models to examine plausible vegetation, fire and flood risk changes, given combinations of climate change projections and treatment options specified by installation natural resources staff (see Section 4.4; Steps 3–5 in Fig. 2). In these quantitative assessments we engaged iteratively with installation staff and senior decision makers, to ensure that the

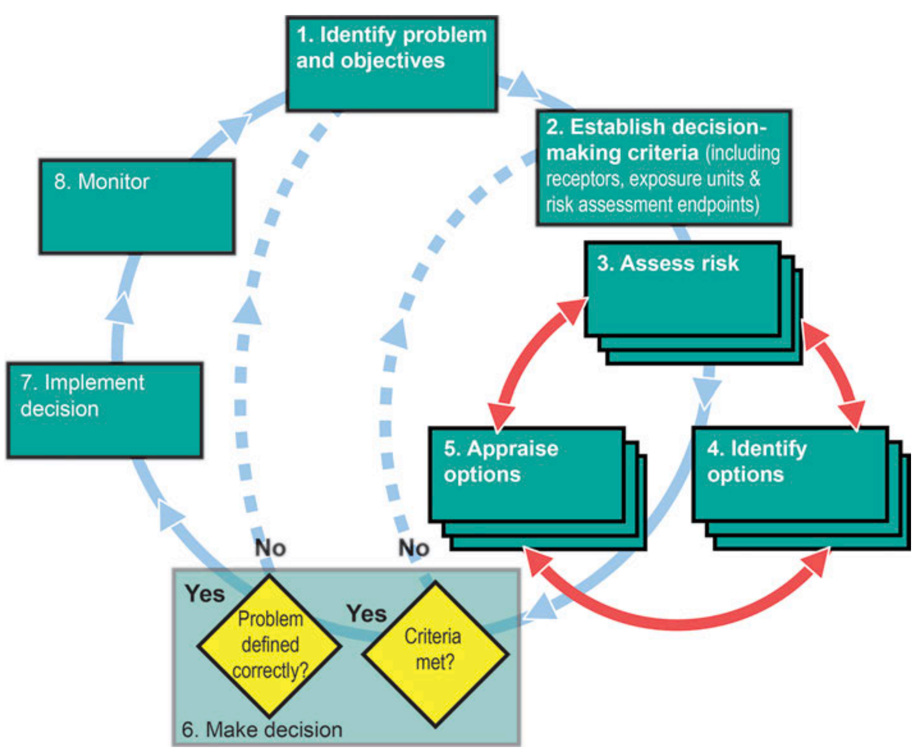

Fig. 2. Risk and adaptation assessment process used in this study (adapted from Willows and Connell, 2003). Bold titles, in boxes 1–5, indicate steps conducted in this study.

concerns and plausible management pathways of DoD personnel were addressed sufficiently to help inform risk management. Insights from interactions with personnel were recorded in meeting notes, which were cross-referenced with interview and workshop data. Vegetation analyses, wildfire and post-fire flood risk studies and associated methods were documented in a series of reports to SERDP and individual installations (Garfin et al., 2017, Appendices D, E, F) and a peer-reviewed paper (O'Connor et al., 2020).

3.4. Cross-project workshop and interviews

To inform and corroborate findings garnered from interactions with installation personnel, we organized a "cross-project workshop" with investigators and practitioners involved in work on climate services to inform DoD adaptation, and we conducted interviews with DoD personnel. The 21-participant workshop included other SERDP-funded investigators, private sector contractors, and current and past DoD personnel focused on other geographies and adaptation-related topics. We facilitated discussions focused on best practices for climate risk assessment, approaches to engagement with installations, similarities and differences between DoD and other communities working to manage climate risk, climate services, research needs, and the roles of leadership and institutions. We conducted 16 ethnographic semi-structured interviews with US military personnel. We derived questions from debriefings, following adaptation workshops and the cross-project workshop (Appendix A). We used an ethnographic approach, because it examines behavioral norms, perceptions, and personal experiences (Neuman, 2000). We used convenience and snowball sampling to recruit respondents (Delamont, 2004; Spradley, 2016); some cross-project workshop participants were invited to participate. The population interviewed offered viewpoints from various command levels within the US armed services. Responses reflect the experiences, insights and perceptions of individuals who were familiar with the project team to some degree, or individuals suggested by others aware of the project. Interview data were coded, de-identified and analyzed in compliance with human research protocols, to protect the identity of participants.

3.5. Best practices assessment and international interviews

We conducted an assessment of climate adaptation best practices in foreign defense forces, focusing in particular on the United Kingdom and Australia and on organizations that share similar characteristics to DoD, namely a reliance on large, long-lived assets with large workforces and the need to manage natural resources carefully to maintain operational continuity. Although processes such as the UK Climate Impacts Risk Assessment Methodology (UK Ministry of Defence, 2015) are well established, there is little peer-reviewed literature comparing defense-related adaptation with adaptation in other sectors. The assessment included case studies of ports on the US east and west coasts, and facilities of the mining, oil and gas sector. The literature review was supplemented by semi-structured interviews with current and retired UK and Australian defense personnel (Appendix B), to inform our understanding of barriers and opportunities to mainstreaming climate change adaptation. Detailed analyses from this assessment are available in Garfin et al. (2017).

3.6. Analysis and synthesis

The project team distilled notes from the workshops, meetings, interviews, and best practices assessment into reports to SERDP. Through group discussions, the team culled themes and insights that were repeated among multiple sources of information. These themes and insights are presented in Section 4.

4. Results and discussion

4.1. Climate challenges for Southwest DoD installations

We documented a range of climate-related risks at pilot study DoD facilities in the Southwest (Table 2), derived from workshop participants' assessment of the effect of these risks on the mission of each installation. These included imminent risks, such as sea level rise (SLR) worsening erosion due to waves and high tides at Naval Base Coronado (NBC), fire at Ft. Huachuca and inland NBC sites, and flooding and erosion at Barry Goldwater Range West. We also assessed increasing risks, such as expansion of fire-prone invasive plant species and loss of endangered species habitat at Barry Goldwater Range East.

In several cases, base personnel were already examining weather-related risks or were able to identify potential climate impacts. For example, personnel at NBC noted that the combination of waves, high tides, and SLR is expected to erode the beach where Special Forces are trained (Chadwick et al., 2014); these same factors would also erode area for stewardship of endangered bird nesting grounds (Fig. 3). Findings from our case studies and interviews, corroborated by other SERDP researchers at the cross-project workshop, were consistent with the conclusions of a GAO assessment, which concluded that planning and implementation of climate adaptation actions are insufficient to protect DoD installations (GAO, 2014). Our study found, for example, that land managers at NBC had not previously fully assessed fire risk to their on-the-ground training mission, nor had they planned a response. A 2016 SERDP report noted that DoD decision makers may lack familiarity with sources of information and tools to implement climate change decisions (SERDP, 2016). As in this prior work, we found that many DoD decision-makers were unaware of local resources, such as federally-funded applied climate and ecosystem science teams at local universities.

4.2. Lessons learned for engagement with DoD on climate issues

All stakeholder engagement efforts face predictable challenges, such as getting the attention of busy decision-makers. However, there are also challenges specific to the culture, mission and organization of DoD that require extra effort in facilitating communication between researchers and practitioners. From our adaptation workshops at DoD installations in the Southwest, we identified crucial benefits from in-person discussions, which included:

- improving awareness of the range of possible interrelated impacts, across scales of time and space (e.g., Friggens et al., 2013) among practitioners who seldom use climate information; our workshop risk-assessment process explicitly elicited discussion on potential cascading risks (Garfin et al., 2017);
- building confidence in the research team as a credible source of information, through explicit adaptation workshop discussions of complex questions—regarding uncertainty and the limits of predictability—that aren't often addressed well in existing assessments; and
- expanding our own understanding of the operational challenges at a given installation, which we achieved through iterative meetings with personnel and in workshop-based discussions.

We summarize these lessons learned under two broad categories, barriers and opportunities.

4.2.1. Barriers to implementing climate change risk management

Through evidence gleaned from our cross-project workshop and interviews with current and past DoD officials, we identified barriers to engagement that are especially challenging due to the culture, mission and organization of DoD. For example:

Access to the "right people" (those with decision-making authority

Table 2
Significant climate change risks at DoD installations identified by pilot project workshop participants.

Installation	Cause (physical climate drivers)	Processes affected	Operational and mission consequences
Fort Huachuca	Warmer and drier conditions Climate-driven vegetation change, altered landscape fuels	Water scarcity Increased risk of wildfires	Competition for resources increases with neighboring communities and private sector water users; long-term water management challenges increase; Endangered Species Act-related impacts Training grounds and buildings damaged or destroyed; training readiness affected; potential short and long-term impacts on mission and budget
Barry Goldwater Ranges	More frequent extreme high temperatures	Equipment operating near or above critical temperature thresholds	IT and communications equipment failures affecting operations, training and mission-readiness
Fort Huachuca and Barry Goldwater Ranges	Warmer conditions and more variable precipitation	Increased ecosystem stress, including for threatened and endangered species Potentially increased invasion of non-native species, altering ecosystem function and fire regimes	Land management requirements and constraints are more complex Potential reductions in biodiversity, increased cost, and damages associated with wildfire
Fort Huachuca and Barry Goldwater Ranges	More intense precipitation	Inundation and erosion of transportation routes; severe post-fire flooding	Emergency preparedness and evacuation procedures compromised; property damage
Naval Base Coronado	Rising sea level; increased erosion by waves and high tides	Damage or loss of coastal training facilities and infrastructure; potential impacts on transportation, biodiversity, water quality, etc.	Reduced training days, increased costs of facility maintenance; in extreme events, significant impact on mission-readiness
All Installations	More frequent extreme high temperatures and extended heat waves	Heat stress for personnel engaged in outdoor activities	Increased rotation of personnel required; lost training time

or even informal leaders within units) may be more problematic than in other adaptation efforts. In DoD, this challenge is exacerbated by the complex hierarchy and frequent rotation of personnel, including top leadership such as base commanders.

Base-level DoD leadership is generally focused on managing the complexity of near-term challenges of their highly demanding jobs and may not have the training or capacity to integrate climate information into short and long-term decisions. Signals from the chain of command are the number one consideration in prioritizing activities in the military; thus, lower level staff had little incentive and few resources for engagement on climate issues. Participants in pilot project meetings and workshops emphasized the frequent rotation of personnel undermines the accumulation of institutional knowledge; institutional knowledge is necessary to build adaptive capacity for challenges that span multi-year to multi-decade climate time scales. In addition, installation officials we interviewed said they rarely propose climate change adaptation projects, because the processes for approving and funding military construction projects do not include climate change adaptation in the criteria used to rank proposals. This result is consistent with the GAO (2014) report finding that installation officials believed adaptation projects would not compete well with other funding priorities.

Access to relevant information may be more challenging than in civilian decision processes. Our best practices assessment noted that limited ability to share data, particularly where information is sensitive or classified, was a greater problem than in urban and industry contexts. For example, one workshop participant raised a concern over whether outlining the physical climate risks to an installation, in a non-classified manner, might expose vulnerabilities of the facility to enemies; this was corroborated by our examination of best practices, which also noted multiple risks, including possible cyber-sabotage of climate observation and reanalysis data, that could lead to underestimation of risk and concerns about the security of information held by non-classified organizations (Garfin et al., 2017).

Inadequate time to build trusted relationships between researchers and operational staff. Cross-project workshop participants noted that if external researchers lack sufficient time to build interpersonal connections with internal "climate champions," then risks identified by researchers may be ignored. This finding is corroborated by literature on climate services and use-inspired science efficacy (Owen et al., 2019).

Convincing managers to act despite uncertainty. Many military decisions are pursued in the face of uncertainty, and climate futures are inherently uncertain to some degree. Nonetheless, DoD leadership participating in our study displayed reluctance to commit to action, based on information from climate projections (e.g., Briley et al., 2015); we have observed this reluctance in other sectors. Based on discussions with DoD participants in our case studies, we noted that some base managers were reluctant to commit resources to protect against medium- and long-term impacts perceived as not representing imminent danger. Moreover, one DoD interviewee mentioned that "Ten years is 5 commanders away…meaning it's the 5th or 6th commander down the line that will have to tackle the problems." International best-practices assessment interviewees emphasized the importance of communicating in terms impacts, costs and tangible information, in contrast to the terms of sustainability or environmental programs.

4.2.2. Opportunities to implement climate risk management

Our team noted opportunities for mainstreaming physical climate considerations into day-to-day operations:

Symbiotic partnerships, which can often be fostered at little additional cost, can alleviate problems of access to expertise and resources. Effective partnerships often develop directly from a crisis, as illustrated by Sagarin (2012) and Sagarin et al. (2010). In pilot studies, Barry Goldwater Range (BGR) personnel described coordination with the Bureau of Land Management (BLM), during extensive fires in 2005, in which the BLM provided firefighting assets. This has evolved into a partnership whereby BGR personnel consult with BLM colleagues on fire assessments, particularly during windy red-flag warning days. BGR personnel also described close coordination with BLM personnel, from the adjacent Cabeza Prieta National Wildlife Refuge, on endangered species inventory and monitoring, in which personnel exchange information and best practices. (Also, see Fort Huachuca example, below).

Standardized procedures for considering physical climate risks can be integrated across DoD to achieve longer-term solutions to climate change challenges. An insight from our cross-project workshop is that many lessons learned through installation-level engagements are difficult to disseminate across the portfolio of DoD installations, because each facility has some unique climate-related risks, and each operates under different leadership and within compartmentalized organizational structures. Nonetheless, opportunities for cross-DoD efforts that support mainstreaming of climate information may create economies of scale, and the "deliberation with analysis" process of facilitating climate change engagement is transferrable and generalizable, even if installation-specific analyses, like our case studies, are also needed.

Ongoing funding for research partners from a flexible pool can

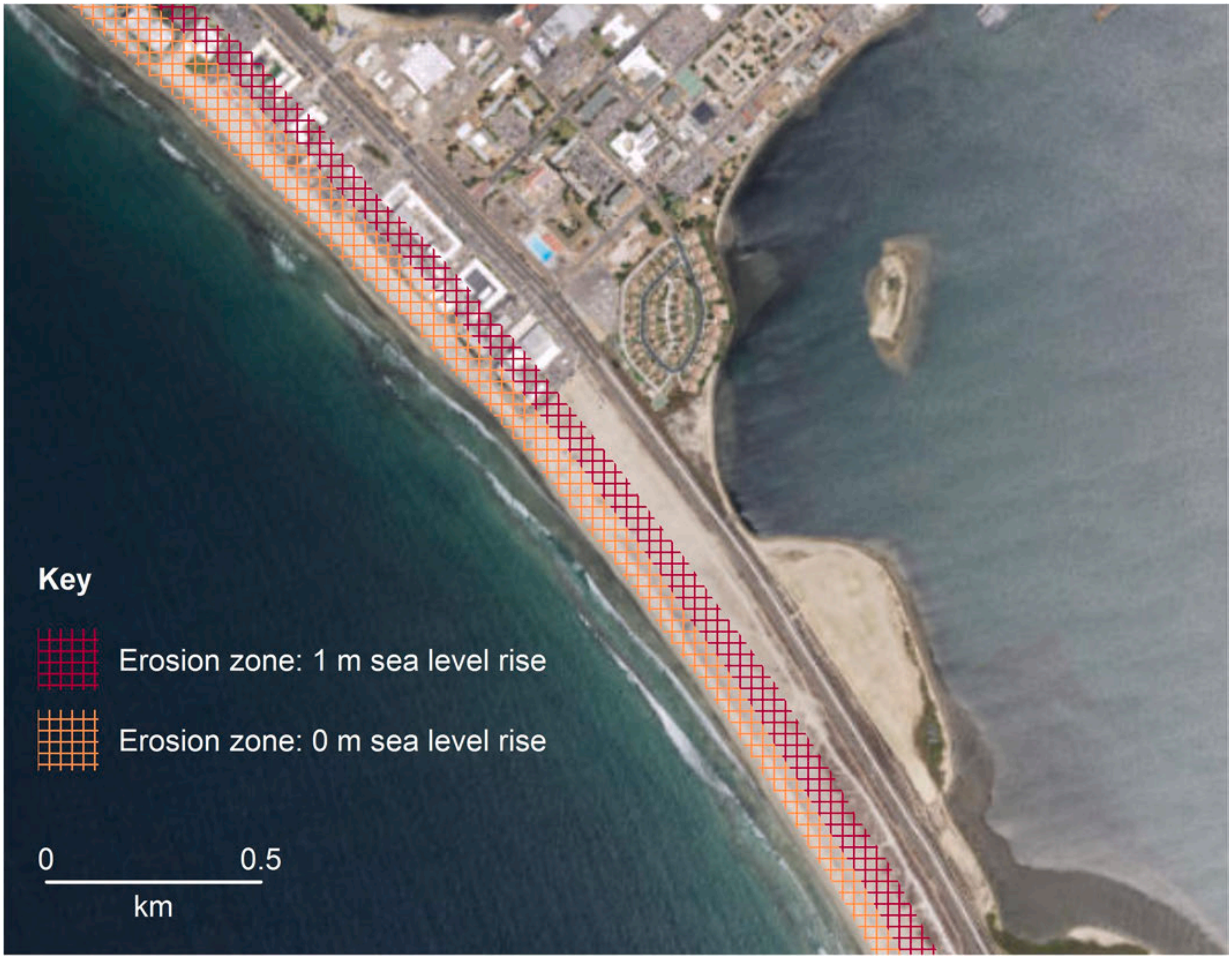

Fig. 3. Erosion zones at Naval Base Coronado expand when local mean sea level increases by one meter (1 m sea level rise) relative to that in year 2000 (0 m sea level rise; Chadwick et al., 2014). In addition to different local mean sea level heights, modeled erosion zones are based on sand budget deficits and wave conditions of a 100-year return period. Aerial imagery from ESRI.

reduce expenses, save time, and promote adaptation action. We speculate that region-based core groups of researchers, supported by boundary organizations and/or existing science translation expertise within universities, could serve as partners for DoD installations.

Tap into climate change knowledge networks. Several federal agencies have developed programs and fostered regional networks aimed at bringing scientists and stakeholders together to understand climate change risks and adaptation strategies. These networks include the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessments program (Parris et al., 2016), the Department of Interior Climate Adaptation Science Centers (O'Malley, 2012) and Landscape Conservation Cooperatives (Petersen et al., 2014), and the US Department of Agriculture Climate Hubs (Johnson et al., 2014). These networks are designed to engage land management agencies and scientists to address complex, regional-scale management issues; the experiences of these networks could greatly reduce the cost and ramp-up time (e.g., Lemos et al., 2014) for a DoD-wide climate program, and streamline incorporation of climate science into its operations. Funding for such programs is vulnerable to politics, but demand for these services is on the rise and DoD's interest in their services could influence their chances for longevity.

Focus on DoD's "mission-orientation". While it is now widely understood that climate change is a threat multiplier, the specifics of how it might affect the ability to carry out operational and mission objectives at individual installations are rarely understood. Reframing climate-related challenges as critical to achieving DoD's mission and, in particular, the specific operational success criteria of individual installations, is an effective way to move beyond skepticism about climate science and related political dimensions of the issue. For the installations with which we interacted, typical success criteria included protection of mission essential infrastructure, assets and services; force protection and safety; environment and regulatory requirements; local communities and public relations; training and operational readiness; and emergency preparedness. DoD personnel referred to these as aspects necessary to carry out their *mission* and showed a strong "can-do" or "action-oriented" attitude with respect to ensuring successful execution of necessary tasks. One international defense interviewee mentioned that climate change must be communicated in military and operational language. Similarly, we found that articulating the bottom line of achieving "mission success" in terms of the aforementioned categories of activities allowed us to insert climate change into our conversations. Interviews with representatives from the extractives industries showed similar action-oriented attitudes and attitudes of responsibility for attending to the costs of doing business, i.e., climate change preparedness actions (Garfin et al., 2017).

To illustrate the benefits of leveraging DoD's mission-orientation, we describe a case study involving a working dialogue with Ft. Huachuca (FTH; U.S. Army) personnel in southeastern Arizona, around shared concerns about wildfire and post-fire flooding risk. These concerns relate to mission success criteria, including protection and maintenance of mission essential assets (i.e., roads, buildings, lands), and demonstration to the public of no adverse effects to natural resources and wildlife stewarded by the installation. FTH is flanked by the city of Sierra Vista (pop. 44,000) along its eastern boundary, a National Forest to the west, and a nature preserve to the south, (Fig. 4). Controlled burning and other active fuel reduction measures are conducted regularly in lower elevation grasslands, but in the ~1/3 of FTH that is located within the Huachuca Mountains, decades of fire suppression have resulted in high fuel loading in much of the Madrean juniper, oak, pine, and dry mixed-conifer forest along the 1350 m ascent from the lower basin to the central ridge of the mountain range.

From our FTH adaptation workshop, we learned that fires and post-fire flooding are significant concerns for resource managers at Fort Huachuca and surrounding land ownerships (Chin et al., 2016). A June

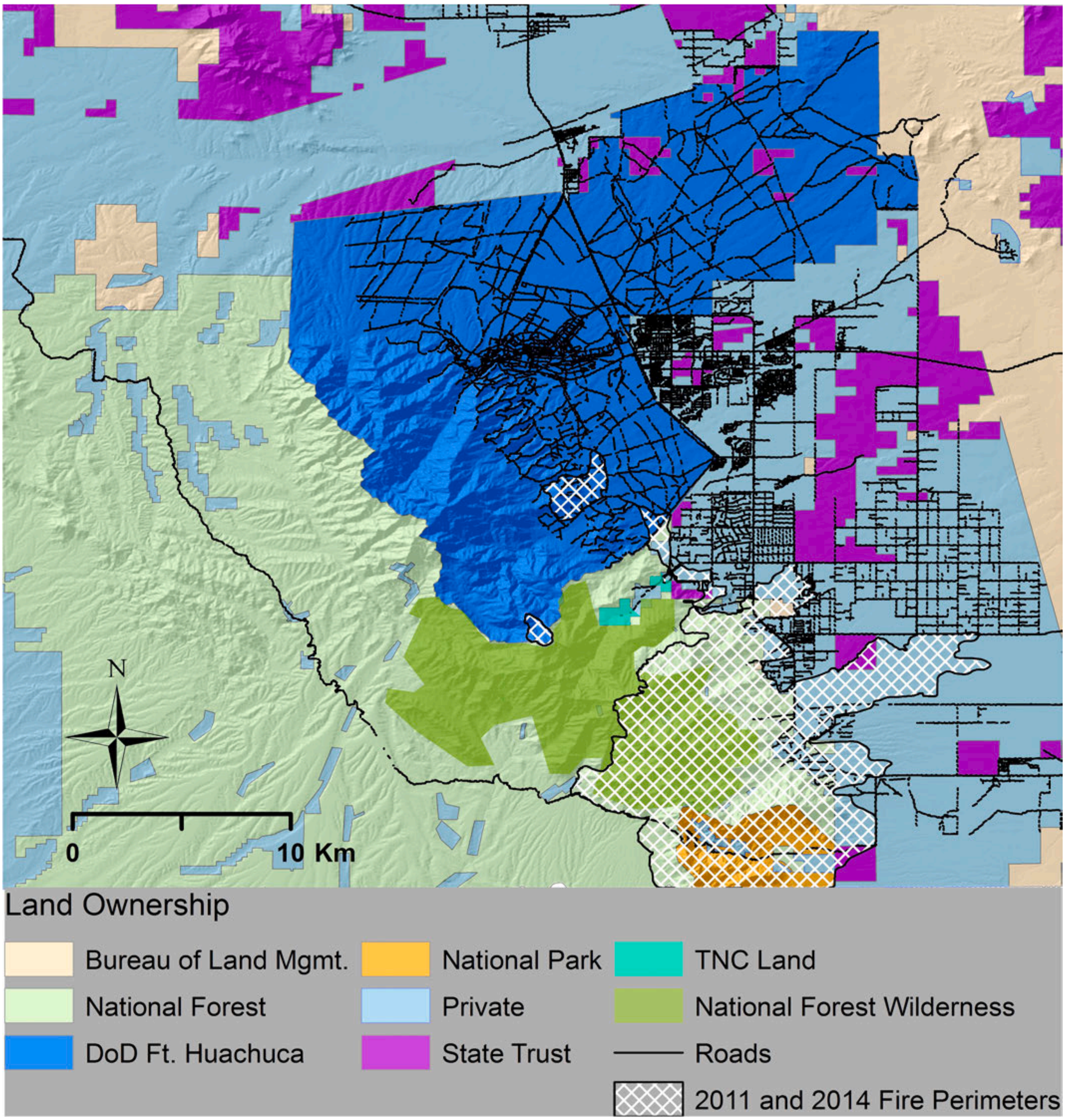

Fig. 4. Mosaic of landownerships near the Army installation at Fort Huachuca, Arizona. The Fort shares boundaries with the USFS Coronado National Forest (Coronado N.F.), Private landowners in and around the city of Sierra Vista, the State of Arizona, and the Bureau of Land Management. Wildland fires and floods starting in any of the adjacent ownerships is likely to affect neighboring landowners.

2011 fire that started on nearby Coronado National Monument burned 12,230 ha of federal, private, and city lands, including a section of The Fort (Fig. 5); almost 50% of the fire burned at moderate to high severity (Monitoring Trends in Burn Severity [MTBS]; MTBS Data Access, 2017), resulting in significant post-fire flooding and debris flows during monsoon rains immediately following the fire (Youberg and Pearthree, 2011). Climate projections for the region suggest that warming and drying conditions will result in a longer fire season over the next several decades (Kitzberger et al., 2017).

Acknowledging the significant overlap in shared fire risk with surrounding landowners, FTH requested an assessment of projected changes to vegetation, fire, and flood risk over the next several decades. Our group developed scenario projections of climate change and fire effects on the Huachuca Mountains landscape (O'Connor et al., 2020), using the modeling system FireBGCv2 (Keane et al., 2011). Model results suggested a significant reduction in total plant biomass and an increase in peak flow flood potential associated with increasing risk of high-severity fire in altered vegetation by mid-century (Garfin et al., 2017; O'Connor et al., 2020) (Fig. 6).

FTH leadership, spurred by concerns with carrying out their mission, i.e., achieving operational goals, meeting regulatory requirements, reducing interruptions to its training mission, and demonstration to the public of no adverse effects to safety, livelihoods, and natural resources, responded by initiating a pilot program to implement fuel reduction treatments and restore fire resilience to Madrean woodlands. This action served as a catalyst for cooperation among managers from surrounding ownerships, including The Nature Conservancy. This model of synergy among local, regional, and national resources to develop a cooperative climate change risk response can be adapted to other DoD installations, mainstreaming climate change considerations into existing plans, and strengthening ties to local communities and promoting sustainable, coordinated land management. Based on our FTH case study, we conclude

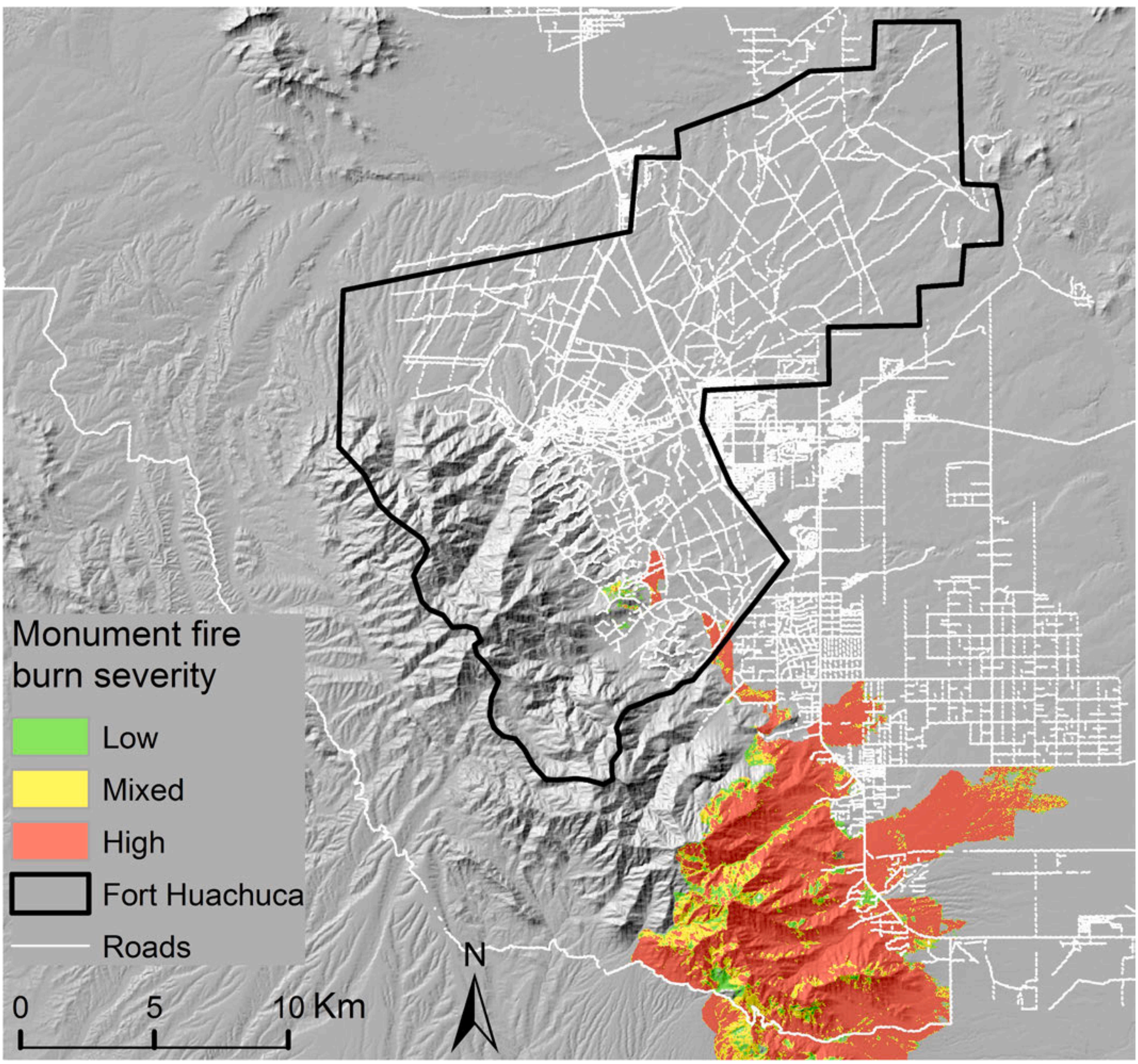

Fig. 5. The 2011 Monument fire narrowly missed Fort Huachuca, and threatened the town of Sierra Vista, Arizona to the south. Vegetation burn severity classes are relativized difference Normalized Burn Ratio (RdNBR) classified using values from Miller and Thode (2007).

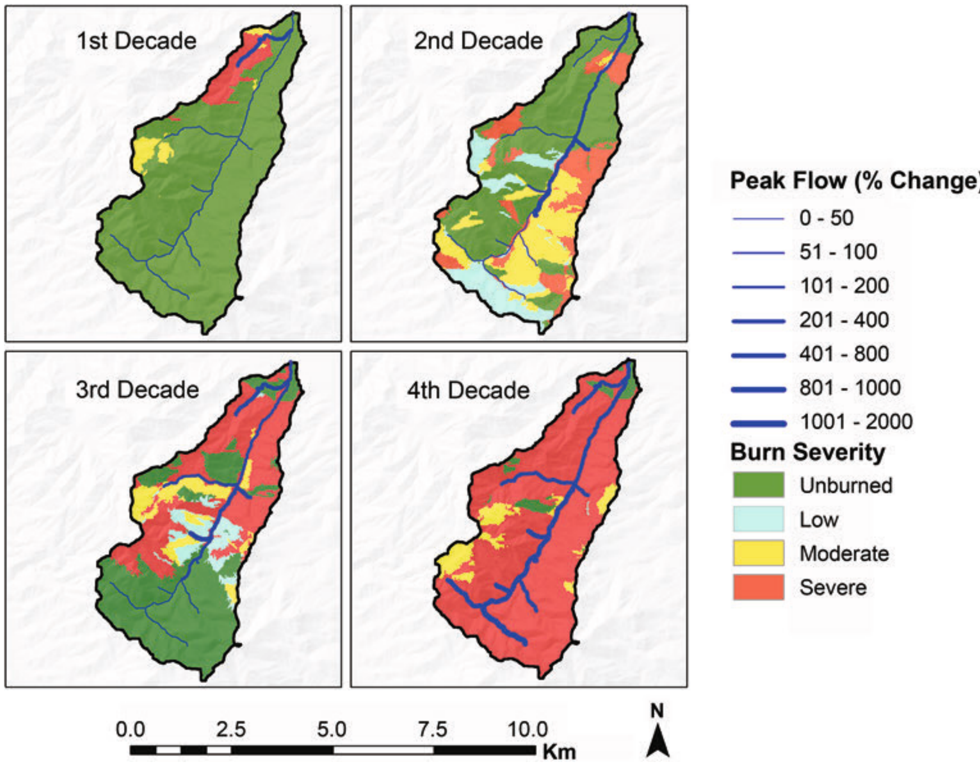

Fig. 6. Simulated flood intensity (peak flow, percent change from 2010 baseline) projected one to four decades following climate-driven increases in fire severity and changes in vegetation (fuel type) in Huachuca Canyon, Fort Huachuca, Arizona. Figure adapted from Garfin et al. (2017) courtesy of Brian S. Sheppard.

that the combination of articulating operations-specific climate challenges (i.e., tapping into DoD's mission-orientation), along with studies that contrast imminent risks with projected risks, can spur momentum for both low-cost partnerships and mainstreaming adaptation planning into installation operations.

5. Conclusions

Based on the findings of multiple climate assessments (IPCC, 2014; Jay et al., 2018), many widespread climate impacts are currently affecting all regions of the world, with implications for multiple areas of DoD activities. This includes training and operational readiness, facilities management, emergency preparedness, personnel protection and safety, environment stewardship and regulatory compliance, and relations with other agencies and local communities. It is clear that DoD needs to escalate climate risk management efforts in order to meet its mission and ensure the safety and security of its employees and facilities. To meet this grand challenge, interdisciplinary approaches are needed to encourage adaptation to current and future climate impacts within the complex social and policy structures of the DoD. We conclude that success in working with DoD installations hinges on "mainstreaming" climate awareness and adaptation, with an emphasis on linking the threat of ever-increasing climate-related impacts to DoD's ability to achieve its own mission objectives. Whereas directives from the Pentagon are a strong motivator, integration of climate-smart strategies into day-to-day practices and long-term planning processes by military and civilian employees at the installations will be needed to manage physical climate risks. Integrating top-down and bottom-up strategies, combined with the flexibility to partner and gain expertise from networks of researchers and stakeholders, will help navigate the complex terrain of DoD's new mission to adapt to climate change.

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CRediT authorship contribution statement

Gregg Garfin: Conceptualization, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Donald A. Falk:** Methodology, Validation, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Christopher D. O'Connor:** Software, Validation, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Katharine Jacobs:** Writing - original draft, Writing - original draft, Writing - review & editing, Supervision, Project administration. **Raphael D. Sagarin:** Conceptualization, Investigation, Writing - original draft, Supervision, Funding acquisition. **Arin C. Haverland:** Investigation, Data curation, Writing - review & editing, Project administration. **Anna Haworth:** Methodology, Investigation, Data curation, Writing - original draft. **Alastair Baglee:** Writing - review & editing. **Jeremy Weiss:** Investigation, Data curation, Writing - review & editing, Visualization. **Jonathan Overpeck:** Formal analysis, Writing - review & editing, Funding acquisition. **Adriana A. Zuñiga-Terán:** Investigation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A.1. Questions for semi-structured ethnographic interviews with DoD personnel.

- Describe your general duties and responsibilities or tasks associated within your service component.
- What types of events may interfere with your general duties, training exercises or overall mission readiness?
- Do you feel that your service component faces challenges specifically related to climate change?
- How well is your service component postured or prepared to address climate change mitigation (management of greenhouse gas emissions for example)?
- What sources of climate change information do you currently rely on?
- How do you currently identify and assess the risks associated with climate change that may interrupt or halt completion of your duties/training/daily operations/management of facilities/mission readiness?
- Who is responsible for developing new policy/procedural directives within your service component or installation?
- How does your service component communicate and implement new policy/procedural directives at various command levels?
- What are the barriers to implementing new policy/procedural directives?
- Are you familiar with the DoD Directive 4715.21 – Climate Change Adaptation and Resilience?
- How do you envision integrating new requirements related to managing climate risks (e.g. managing greenhouse gas emissions) that are included in DoD Directive 4715.21 and recent executive orders?
- What mechanism(s) does your service component use to ensure critical information is transferred during leadership transitions?
- Do you feel there is a need for personnel that focus specifically on climate change adaption at your installation or as part of your service component? (e.g., a civilian or active military personnel role similar to a natural resources liaison or scientific specialist who focuses on wildlife, water conservation, etc.)
- If so, what specific tasks would you expect them to focus on (what would be the priority) to best support your service component?
- What resources or tools would help your service component to be more prepared to take on adaptation measures?
- At what command level or professional development phase do you see an opportunity to include education and training components focused on climate change related risks?

Appendix B

Table B.1. Questions for semi-structured interviews with international military personnel.

1	• What are the primary drivers that led your organization to start managing risks from a changing climate? • What is the general level of awareness of climate risk management in your organization? • How does this compare to awareness of managing current weather-related risks?
2	• What is the level of appreciation that climate change is also an incremental risk over the longer term? Does your organization think about critical thresholds, and how financial, design, operational and safety margins may gradually be eroded / encroached over the longer term? (e.g. Air-conditioning / cooling power demand)
3	• What are the primary barriers your organization encountered when addressing climate change risks?
4	• What organizational change measures, if any, were implemented, to facilitate your evaluation of climate risks? • At what level were these changes implemented? • In your opinion, was this at the correct level, or should it have been higher up / lower down the chain of command? • Is it feasible for individual sites to take this challenge on themselves? Would this be seen as a positive innovative action, or, a negative distraction from daily duties?
5	• What climate risk assessment methodologies do you use, or know about? Are these stand alone, or designed to be integrated within your existing procedures? • Do you look to any other sectors for risk assessment best practice / steerage? If so, which sectors, and why?
6	• Which external stakeholders are involved in developing your risk assessment methodologies and procedures, and why? • Have any of your stakeholders specifically promoted / requested the inclusion of climate change as a risk consideration?
7	• In undertaking climate risk evaluation, how did your organization obtain a) information/ data, b) budget approval for the work, c) technical capacity to undertake the work? • Which internal personnel were consulted when undertaking your climate risk evaluation, and why? • Were external stakeholders involved in the climate risk evaluation, or decisions on adaptation actions that should be implemented?
8	• How are risk assessment outcomes reported, actions sanctioned and process/ success measured? • Who, if anyone, is involved in making the various decisions/ approvals within your organization specifically pertaining to climate risk management and adaptation?
9	• How do you deal generally with the concept of uncertainty in day-to-day activities and forward planning? • Do you think dealing with uncertainty helps with thinking through uncertainty related to climate change? If not, why do you think the conceptual thinking is not easily transferrable to climate change?
10	• How are implemented measures selected, monitored & evaluated? • How is success measured? Is there one success factor that outweighs all others?
11	• We are looking for case studies that demonstrate real action in this area to include in our review. Are there any examples you could supply (non-confidential reports etc.)?

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