BAMS
Meeting Summary

Synthesizing Ecological Impacts and Management Responses from the 2021 Pacific Northwest Heat Wave to Prepare for Future Extreme Heat Events

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Managing the Ecological Impacts of Extreme Heat in the Northwest

What: The Northwest Climate Adaptation Science Center convened 92 researchers and practitioners from 37 different organizations across Washington, Oregon, and Idaho to create a community of practice around the ecological impacts of extreme heat in the region, using the record-breaking 2021 Pacific Northwest heat wave to explore potential impacts and adaptation responses. Through a kick-off meeting, workgroups, and final workshop, participants synthesized the state of knowledge around the biophysical, management and practice, and policy and human dimensions of this topic and identified research and capacity needs to help the region better prepare for future extreme heat events.

When: 10 and 12 June 2025

Where: Virtual, hosted by the Northwest Climate Adaptation Science Center

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1. Introduction and process

During the summer of 2021, an unprecedented extreme heat wave extended across the Pacific Northwest (hereafter referred to as the "2021 PNW heat wave") (Thompson et al. 2022; Heeter et al. 2023). Air temperatures exceeded 43°C and even 49°C in some locations (Loikith and Kalashnikov 2023), in many cases greatly exceeding previous all-time maximum temperature records (Heeter et al. 2023). This heat wave had significant negative effects on ecosystems and organisms (Fig. 1) (Fleishman et al. 2025), including widespread shellfish mortality (Raymond et al. 2022), tree scorch (Klein et al. 2022; Still et al. 2023; Williams 2021; Sibley et al. 2025), and heat-stressed birds (Hindmarch and Clegg 2024). These impacts presented novel challenges to ecosystem managers throughout the region, raising questions of how to better prepare as warming temperature baselines increase the likelihood and extremity of similar heat waves in the future (Bartusek et al. 2022; Chen et al. 2023; Terray 2023).

Fig. 1. Ecological impacts of the 2021 PNW heat wave included (a) shellfish mortality from heat stress (image credit: Rana Brown) and (b) heat-scorched foliage (image credit: David Shaw). (c) Workshop participants emphasized the importance of data collection efforts, such as this oyster long-line monitoring experiment in Willapa Bay, Washington, to understand and better prepare for the impacts of extreme heat events (image credit: Christine Nolan).

To facilitate knowledge synthesis and information sharing, the Northwest Climate Adaptation Science Center (NW CASC) hosted an online workshop on 10 and 12 June 2025 that included researchers and practitioners from federal and state agencies, Tribes, nonprofit and private organizations, and other entities across Washington, Oregon, and Idaho. The workshop objectives were to assess the state of knowledge around the ecological impacts of extreme heat, share experiences and understand strategies for reducing impacts, and develop an actionable science agenda to guide investments in research and capacity building.

The NW CASC hosted a kick-off webinar on 19 February 2025 to a curated audience of researchers and natural resource managers across the Northwest. During this webinar, NW CASC staff introduced the workshop topic, and three resource managers shared how the 2021 PNW heat wave affected their work. The webinar ended with an invitation for attendees to join any of three separate workgroups: (i) biophysical, (ii) management and practice, and (iii) policy and human dimensions. Each workgroup met three times to guide syntheses of available knowledge and information relevant to understanding and managing ecological impacts of extreme heat from three complementary perspectives. The same curated audience of researchers and natural resource managers from the kick-off webinar invitation were then invited to attend the online workshop in June, during which preliminary findings of the three syntheses were presented. Workshop participants provided written and verbal feedback on these findings via breakout group discussions and Mural, an online, interactive, note-taking tool. The outcomes of workshop discussions and asynchronous feedback opportunities were integrated into the three syntheses and then compiled into a final report published online in August 2025 (Colberg et al. 2025).

2. Key findings

a. Understanding the impacts of extreme heat on Northwest organisms and ecosystems. The biophysical workgroup reviewed published literature on the effects of the 2021 PNW heat wave on Northwest species and ecosystems. They found primarily negative, short-term impacts on organism growth and survival, although longer-term impacts may continue to emerge. Most impacts were documented in forest (e.g., Klein et al. 2022; Still et al. 2023; Williams 2021) or coastal ecosystems (Raymond et al. 2022), with less information available on the responses of nonforest terrestrial ecosystems and freshwater organisms.

The biophysical workgroup used a climate change vulnerability framework (Foden et al. 2019; Thurman et al. 2020) to understand the impacts and potential management strategies for extreme heat events, considering exposure, sensitivity, and adaptive capacity to temperature extremes. Exposure to high temperatures during the 2021 PNW heat wave varied within and across ecosystems; in the intertidal zone, temperatures varied with geographic location and environmental conditions such as wave exposure and low tides (Miner et al. 2025). During the same event in forests, denser canopy cover buffered understory exposure to extreme temperatures (John et al. 2024) and downed woody debris cooled microsite soil surface temperatures (Swanson et al. 2023). The degree to which organisms are affected by such exposure, i.e., sensitivity, varies within and among species; regionally important canopy species like western redcedar, western hemlock, and Sitka spruce exhibited disproportionate amounts of canopy scorch from the 2021 PNW heat wave (Sibley et al. 2025). Sensitivity to the 2021 PNW heat wave also varied with phenological stage, with greater amounts of foliar scorch in areas where budburst occurred earlier that year (Still et al. 2023). Adaptive capacity, or the ability of organisms to adjust to and withstand a stressor, can also mitigate the impacts of extreme heat. For example, butter clams burrow more deeply than other co-occurring bivalve species, which may have helped reduce their exposure to extreme heat during the 2021 PNW heat wave (Raymond et al. 2022).

Despite limited availability of information on management options specifically designed to address ecological vulnerability to extreme heat, workshop participants identified a few broad approaches. In some cases, managers may proactively identify, protect, and cultivate areas of lower exposure to extreme heat, including climate change refugia (Morelli et al. 2016) and features that contribute to thermal buffering, such as forest canopy cover and structural complexity (Brackett et al. 2024; Davis et al. 2019; De Frenne et al. 2021; Frey et al. 2016). An understanding of species' and populations' sensitivity and adaptive capacity to extreme heat may also inform management actions to better enable organisms to withstand exposure (Thurman et al. 2022), such as increasing population heterogeneity and the prevalence of heat-tolerant species or genotypes through manipulating community composition during planting efforts. Workshop participants also noted that ecological monitoring can provide pre-, during-, and postevent data for assessing the impacts of extreme heat events and accompanying management strategies and emphasized the importance of establishing and sustaining robust monitoring programs to capture site- and population-specific variation. For example, long-term monitoring data from Washington Sea Grant's Crab Team have allowed comparison of the impacts of the 2021 PNW heat wave on nearshore estuarine communities to other years (Rubinoff et al. 2025).

To assist in these efforts, the biophysical workgroup compiled a list of datasets and tools, including geospatial datasets that could help estimate exposure to extreme heat, ecological monitoring datasets that could help evaluate the impacts of extreme heat on focal ecosystems and organisms, and predictive tools that could be used to forecast the occurrence and impacts of extreme heat. However, participants also critiqued the usability and accessibility of these tools, none of which incorporate exposure, sensitivity, and adaptive capacity for a comprehensive view of ecological vulnerability to extreme heat.

b. Approaches to managing the ecological impacts of extreme heat in the Northwest. The management and practice workgroup reviewed existing natural resource management documents in the region but primarily focused on responses to a survey sent to workshop invitees in April 2025 assessing management concerns and actions. The workgroup designed the survey to provide insight into workshop invitees' actions, considerations, and challenges rather than to representatively assess activity in the region (respondent characteristics can be found in the workgroup's final synthesis).

Survey respondents reported that the 2021 PNW heat wave resulted in mass mortality and stress to a variety of species and habitats including shellfish, fish, trees, insects, birds, and terrestrial mammals across benthic, intertidal, riparian, forested, and alpine ecosystems. They described that these impacts negatively affected the shellfish industry and Tribal cultural resources in the region. Participants also reported that extreme heat disrupted management and planning efforts, including delaying planned activities, such as plantings; removing staff from the field for safety reasons; and redirecting limited resources to address heat impacts. Additionally, they emphasized that the impacts of extreme heat events can vary greatly depending on the specific location, timing, intensity, and duration of high temperatures. The concurrence of peak temperatures during the 2021 PNW heat wave with low tides is suspected to have increased shellfish thermal stress (Raymond et al. 2022; Miner et al. 2025), but participants advised that future events of the same magnitude might produce different impacts due to different specific conditions. They suggested pursuing greater ecological resilience to the impacts of extreme heat by developing a better understanding of ecological thresholds and drawing general guidance from more frequent, less extreme heat events.

Reported responses to extreme heat generally fit into three, often interconnected, categories: changing management activities, pursuing data collection, and preparing and planning.

There were also distinct phases of response: immediate responses during events, reactive responses following them, and proactive responses anticipating future events. Participants suggested that better understanding the unique needs at these different points in time would support efforts to share and make the best use of existing resources in the region. Workshop discussions revealed that the species or ecosystems participants worked with influenced the extent to which they were able to identify the effects of the 2021 PNW heat wave. In particular, those working with shellfish had already assessed impacts and started proactively planning for future events, while those working in forestry described more time was needed to understand how forests were affected.

Participants reported utilizing a wide variety of tools, data, and information to inform their management in the face of extreme heat. Technical data like real-time or local-scale monitoring, climate projections, and species heat-tolerance data were used most commonly, but some organizations also used community- and place-based knowledge. However, currently available tools require that managers interpret and synthesize different outputs themselves. Similarly, they reported using best management practices, emergency protocols, and a variety of existing plans (i.e., resource management, species management, and local/municipal/state plans). However, very few plans or protocols in the region explicitly address extreme heat events. The need for managers to put extra time into interpreting, synthesizing, and adapting existing scientific and policy resources to fit their unique decision-making needs is particularly challenging given that staff time, availability, and training/expertise were identified by respondents as the primary barriers to their efforts to respond to extreme heat events. Collective coordination and resource sharing through continuous, proactive, and transparent collaboration can lighten the individual burdens of Northwest managers and better address their shared needs.

c. Exploring the policy and human dimensions of the ecological impacts of extreme heat. The policy and human dimensions workgroup sought to understand the policy landscape around the ecological impacts of extreme heat, including available policy tools, and the human dimensions of the ecological impacts of extreme heat, such as social impacts and responses, and public perceptions of each. The workgroup found inconsistencies among existing extreme heat policy frameworks due to the fragmentation of heat governance and ecosystem management across multiple institutions and jurisdictional scales. For example, workshop participants noted wide variation in defining what kind of measurable changes constitute an extreme heat event—e.g., warmest day of the year, number of days temperatures exceeded a threshold, or rise in average daytime or nighttime temperatures. Lack of clarity in defining extreme heat events and subsequent policies to address them also limits assessments of public perceptions around event impacts and responses, but efforts to understand differences in community perspectives and perceptions are vital for informing future policy interventions. Existing heat policies tend to focus on human health and infrastructure rather than the ecological impacts of extreme heat, though some natural resource or species management plans include policies that address temperature stressors and extreme heat events, e.g., for fish-bearing lakes and streams. In urban areas, human responses to the ecological impacts of extreme heat focus primarily on urban tree canopy. Finally, the workgroup identified a range of policy tools for addressing the ecological impacts of extreme heat, ranging from planning and regulatory tools to data services and technical guidance.

There are many social, cultural, and economic ramifications of the ecological impacts of extreme heat. A majority of respondents from the management and practice workgroup's survey reported impacts on farming, forestry, fisheries, and other natural resource–based livelihoods (75%) and on culturally significant resources for Tribes (80%). Fisheries make up a significant portion of the region's tourism and food industries, and extreme heat events can cause large reductions in revenue for fishing-dependent and coastal communities. For example, the 2021 PNW heat wave caused mass die-offs of shellfish, which are commercially important in the Northwest and of cultural importance to Tribes (Raymond et al. 2022). Municipal and agricultural communities may also intensify water usage during extreme heat events, which may reduce water availability needed to keep fisheries viable and lead to salvage orders. This occurred during the 2021 PNW heat wave, when fisheries management officials closed a dam and enacted a fish salvage order for the Mormon and Fish Creek Reservoir (Magic Valley Regional Office of Fish and Game 2021). Some first foods—traditional foods integrated into Indigenous cultures that connect them with their pre-European contact lands and lifeways—are less productive under high temperatures (Fisher 2024), and workshop participants noted that the 2021 PNW heat wave caused crop losses for Tribes and other agricultural producers. Huckleberry, a culturally important food for Tribes and regional identity, has experienced range contraction along drier, lower-elevation portions of its current range (Prevéy et al. 2020); there was a smaller and more labor-intensive huckleberry harvest in 2021 following the heat wave (The Spokesman-Review 2021). Tribal, public, and private forestry resources are also affected by extreme heat. A workshop participant described increased mortality of western redcedar, and the Coeur d'Alene Tribe's Forestry Program's loss of 85% of planted seedlings in 2021 was attributed to the compounding impacts of the heat wave and chronic drought conditions (Coeur d'Alene Tribe 2023). Extreme heat can also influence people to seek cooling opportunities at natural areas, such as water bodies or higher elevations, potentially compounding ecological impacts through incidental habitat harm and stress from increased visitation.

3. Research and capacity gaps

Each workgroup proposed several research and capacity needs to advance evidence-based management of the ecological impacts of extreme heat in the Northwest, which workshop participants ranked in order of priority using a live web poll. Workshop participants split into smaller groups to brainstorm ideas for projects to address their top-ranked research and capacity-building needs. Further refinement to reduce redundancy and reflect feedback from workshop participants resulted in a final list of eight key research needs and seven key capacity-building needs (Colberg et al. 2025). Here, we highlight a subset of those needs.

Workshop participants identified a need for deeper and more mechanistic research relating to the impacts of the 2021 PNW heat wave on species and ecosystems and potential interactions of extreme heat with other stressors. Participants identified a need to establish baseline monitoring programs and standardize techniques for measuring the impacts of future extreme heat events on species and ecosystems. They also expressed a need for more accessible predictive tools, especially ones that could provide longer-term projections of the occurrence of extreme heat events. Predictions of the 2021 PNW heat wave began with predictions of a possible heat wave eight days prior to its onset and announcements of an extreme heat wave 5 days prior to its onset (Lin et al. 2022). During the workshop, a meteorology expert mentioned that the 2021 PNW heat wave had been predicted well in advance, but practitioners responded that they were not aware of these warnings. Thus, developing and evaluating options to predict, prepare for, and manage the impacts of extreme heat were also identified as research needs. Additionally, the social and human dimensions of the ecological impacts of extreme heat were identified as a general research need, encompassing identifying and predicting impacts and adaptation response options for Tribes as well as understanding public preferences and attitudes toward management options. Finally, capacity-building needs included support for long-term and postevent monitoring, improved accessibility and communication of predictive models and decision-support tools, development of knowledge-sharing and response networks, funding for proactive management actions, and guidance in preparing for future extreme heat events.

Workshop discussions highlighted the Shellfish Rapid Response Network as an example of local groups mobilizing resources to learn from the 2021 PNW heat wave and build capacity to prepare for future events. Currently led by representatives from the Squaxin Island Tribe, the Washington Department of Fish and Wildlife, and Washington Sea Grant, the Shellfish Rapid Response Network coordinates the Puget Sound shellfish community's responses to the 2021 PNW heat wave. Conversations with network leaders helped produce a case study describing how the network has leveraged and deepened existing cross-sectoral relationships to prioritize actions; develop, implement, and adjust protocols to assess the impact of heat waves; and test management strategies to share limited resources and protect shellfish populations during future events.

4. Conclusions and outcomes

This workgroup process and culminating workshop generated valuable knowledge and insight into the ecological impacts of extreme heat events in the Pacific Northwest, while building capacity and a community of practice for advancing the science and management needed to build resilience to future events. Ecological impacts of the 2021 PNW heat wave, including mass mortality and stress across a range of species and ecosystems, were found to be primarily negative and short term, though longer-term impacts may emerge over time. Responses by natural resource managers varied by target species and ecosystem but broadly included changing management activities, collecting data, and preparing and planning for future extreme heat events. Key research and capacity-building priorities identified in this workshop will help inform and direct funding for future efforts by the Northwest Climate Adaptation Science Center and other entities as they work to reduce risks posed by extreme heat to the Northwest's natural and human systems.

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