# Project: Summarizing and Analyzing Research Papers

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**Topic**: Impact of climate change on biodiversity

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**Abstract**

[Climate change](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/climate-change) is a pervasive and growing global threat to biodiversity and ecosystems. Here, we present the most up-to-date assessment of [climate change impacts](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/climate-change-impact) on biodiversity, ecosystems, and ecosystem services in the U.S. and implications for [natural resource management](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/natural-resource-management). We draw from the 4th National Climate Assessment to summarize observed and projected changes to ecosystems and biodiversity, explore linkages to important ecosystem services, and discuss associated challenges and opportunities for [natural resource management](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/natural-resources-management). We find that species are responding to climate change through changes in morphology and behavior, [phenology](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/phenology), and geographic range shifts, and these changes are mediated by plastic and evolutionary responses. Responses by species and populations, combined with direct effects of climate change on ecosystems (including more extreme events), are resulting in widespread changes in productivity, species interactions, vulnerability to biological invasions, and other emergent properties. Collectively, these impacts alter the benefits and services that natural ecosystems can provide to society. Although not all impacts are negative, even positive changes can require costly societal adjustments. [Natural resource](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/natural-resource) managers need proactive, flexible adaptation strategies that consider historical and future outlooks to minimize costs over the long term. Many organizations are beginning to explore these approaches, but implementation is not yet prevalent or systematic across the nation.

Introduction:

Climate change is a pervasive and growing global threat to biodiversity and ecosystems (Díaz et al., 2019). Climate change affects individual species and the way they interact with other organisms and their habitats, which alters the structure and function of ecosystems and the goods and services that natural systems provide to society (Díaz et al., 2019). Understanding the direction and magnitude of ecological responses allows human communities to better anticipate these changes and adapt as necessary. Periodic assessments of current and future climate change impacts on ecosystems are important for developing and updating natural resource management plans and evaluating adaptation actions (West et al., 2009). The National Climate Assessment (NCA) is a key assessment in the United States, required by the Global Change Research Act to summarize current and projected impacts of climate change on a variety of sectors and regions in the U.S. every four years (USGCRP, 2018). Here, we draw upon the recently published Fourth NCA (NCA4) Volume II to present the most up-to-date assessment of climate change impacts on biodiversity, ecosystems, and ecosystem services in the U.S. (USGCRP, 2018). We synthesize, extend, and integrate the NCA4 chapters focused on natural resources: “Ecosystems, Ecosystem Services, and Biodiversity” (Ch. 7); “Forests” (Ch.6); “Oceans and Marine Resources” (Ch. 9); “Coastal Effects” (Ch. 8); and “Tribes & Indigenous Peoples” (Ch.15) (USGCRP, 2018). We provide a more in-depth, technical analysis of topics of interest to scientists and practitioners, and review climate change impacts at multiple scales, including: 1) the individual organisms, populations, and species of biodiversity which comprise ecosystems; 2) the properties and processes that characterize ecosystems; and 3) the goods and services that ecosystems provide which support human economies and well-being (Fig. 1). Further, we explore natural resource management challenges posed by climate change and present examples of on-the-ground adaptation actions. Many topics covered in this review are complex and deserve a review of their own. However, by covering multiple scales in one place, we provide a holistic overview of how climate change is affecting different ecosystems and how these changes may in turn affect human well-being, including impacts to vulnerable communities, tribes, and Indigenous peoples.

Individuals, populations, and species

Although [climate change impacts](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/climate-change-impact) are widespread, they are not uniform, and accumulating evidence indicates that climate change responses vary as a function of relative vulnerability due to differences in exposure, sensitivity, and adaptive capacity ([Beever et al., 2016](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0135); [Foden and Young, 2016](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0525); [Glick et al., 2011](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0585); [Kovach et al., 2019](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0830)). Below, we discuss major impacts observed at the scale of individuals, populations, and species, and review the mechanisms driving changes.

Behavior and morphology

One way that organisms cope with changes in their environment is by altering their behavior or morphology. Behavioral responses to climate change can result from changes in temperature and manifest before changes at the population and species level, such as distribution changes or population declines ([Beever et al., 2017](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0140)). Behavioral responses include seeking shade or refuge, altering feeding times, changing site use, and shifting circadian or circannual rhythms (e.g., hibernation, migration; [Beever et al., 2017](https://www.sciencedirect.com/science/article/pii/S0048969720312948#bb0140); [Bradshaw and Holzapfel, 2007](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0205); [McCann et al., 2017](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0980)).

Vulnerability of human communities

The adaptive capacity of human communities to deal with changes in ecosystem services will partly determine the magnitude of impacts on well-being. While some human communities have been proactive in identifying and planning for changes, others are more vulnerable due to a reduced ability to adapt.

Tribes and Indigenous peoples in the U.S. (groups whose exercise of self-determination as governing entities pre-dates the establishment of the U.S.; [Jantarasami et al., 2018](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0755)) have over 800 climate change initiatives and have led or participated in numerous climate change studies; many have developed their own climate change plans ([Jantarasami et al., 2018](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0755)). Since 1998, tribes and Indigenous peoples have collaborated on the NCA, focusing on Indigenous concerns, knowledge of vulnerability, and goals for adaptation and mitigation.

Although tribes and Indigenous peoples continue to exercise self-governance, federal policies provide uneven levels of political engagement and support. Indigenous leadership is critical to addressing climate change; however, federal, state, and local governments pose barriers to tribal and Indigenous mitigation and adaptation efforts ([Jantarasami et al., 2018](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0755)). Historical and contemporary land-reduction, land-use restrictions, and poorly implemented treaty rights and consultation requirements exacerbate economic and health risks, which in many cases are associated with threats to Indigenous cultural maintenance. For example, climate-driven range shifts in culturally important species pose challenges to tribes and Indigenous peoples when [tribal land](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/tribal-lands) areas are small and have limited connectivity ([Rapp et al., 2019](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb1290)). Indigenous peoples [face](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/face) risks related to resettlement due to the impacts of climate change, such as [coastal erosion](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/coastal-erosion) and sea ice loss in Alaska. Despite a history of forced relocations, there are structural barriers for Indigenous peoples to participate in current policy processes trying to plan for climate-driven resettlement ([Jantarasami et al., 2018](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0755)).

 Implications for natural resource management

Natural resource management traditionally focuses on maintaining or restoring to historical conditions (e.g., [National Park System Advisory Board, 2012](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb1100)). While historical context may still motivate management decisions, restoring to historical baselines may not be realistic as the climate changes ([Stein et al., 2014](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb1430)). In some cases, management practices to resist change may be effective; in others, managers may choose to accept ecosystem changes or to alter management practices to direct changes in order to minimize loss of valued species and services as ecosystems transform ([Aplet and Mckinley, 2017](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0065); [Millar and Stephenson, 2015](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb1020); [Stein et al., 2013](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb1425)).

Adaptive and proactive approaches that are continually updated to reflect emerging and anticipated climate change impacts will be needed ([Bradford et al., 2018](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0195); [Holsman et al., 2019](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0710); [Stein et al., 2014](https://www.sciencedirect.com/science/article/pii/S0048969720312948#bb1430); [Table 1](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "t0005)). For example, the U.S. has a rigorous, science-based system for detecting changes in [fish abundance](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/fish-abundance), productivity, and catch, which informs fishery management decisions such as seasonal and spatial closures, annual quotas, and stock rebuilding plans ([Pinsky and Mantua, 2014](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb1240)). Collection of this type of information is important for future assessment and updating of management objectives ([Stein et al., 2014](https://www.sciencedirect.com/science/article/pii/S0048969720312948#bb1430)). NOAA Fisheries has developed adaptation strategies that incorporate climate and ecosystem-related factors into fishery decision-making ([Busch et al., 2016](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0225); [Hare et al., 2016a](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0635); [Link et al., 2015](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0895)). Decision support tools, including scenario planning ([Cobb and Thompson, 2012](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0310); [Mahmoud et al., 2009](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0950); [Peterson et al., 2003](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb1235)) and structured decision-making ([Gregory et al., 2012](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "bb0605)) can help decision-makers explore broad scenarios of risk and develop and prioritize actions that account for uncertainty, optimize tradeoffs, and reflect institutional capacity. Below, we discuss strategies for increasing resilience of ecosystems and human communities.

**Conclusion**

Climate change is a pervasive and growing threat to biodiversity, ecosystems, and ecosystem services in the U.S. Climate impacts have been and will continue to be observed at the level of individuals, populations, and species through changes in behavior and morphology, phenology, and range shifts, and at the ecosystem level through changes in [primary production](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/primary-production), species interactions and emergent properties, and extreme events. Ecosystems and biodiversity underpin important services to people, thus these changes impact provisioning, regulating, supporting, and cultural services, with implications for human well-being. Effective management will require flexible, proactive approaches that account for potential climate change impacts ([Box 3](https://www.sciencedirect.com/science/article/pii/S0048969720312948" \l "b0015)). Managers are beginning to implement these strategies, but face challenges due to lack of information and institutional barriers. Widespread incorporation of climate change into natural resource management is yet to be achieved, but examples are emerging that help increase awareness and provide [case studies](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/case-study) in different sectors. Moving forward, evaluations of effectiveness and demonstrative case studies of adaptation success stories are needed to promote and guide climate-smart management.

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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