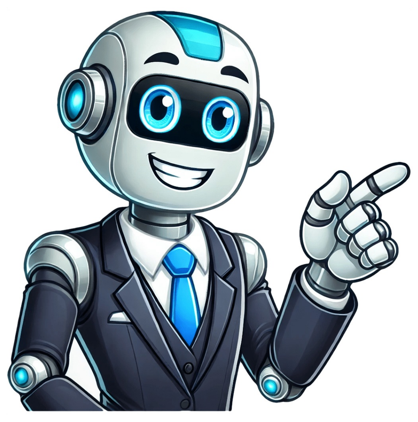

The environment of the Northwest Coast was characterized by a unique combination of factors that fostered an extraordinarily rich and complex ecosystem. This region, stretching from the Gulf of Alaska to the Oregon-California border, presented a landscape dominated by temperate rainforests, a mild, maritime climate, and an abundance of marine life. Imagine towering spruce, hemlock, and fir trees, underlain by a lush understory thriving in the plentiful rainfall. The coastal waters teemed with salmon, seals, whales, and shellfish, providing a bounty of resources that shaped the lives of the indigenous peoples who inhabited this area. The overall picture was one of remarkable biological diversity and abundance, where land and sea interconnected to create a powerful and life-sustaining environment. Key Features of the Northwest Coast Environment A Temperate Climate The climate of the Northwest Coast is largely governed by the Pacific Ocean. Characterized by cool, wet winters and warm, dry summers, this maritime influence ensures that temperatures remain relatively moderate throughout the year. Extreme temperatures and precipitation are rare, contributing to the stable environment that supported the rainforest ecosystem. This contrasts sharply with the more variable conditions found inland, emphasizing the profound impact of the Pacific on the region's climate. Rich Marine Ecosystem The abundance of marine life was a critical element of the Northwest Coast environment. The coastal waters were, and continue to be, rich with various species of salmon, which were a staple food source for both humans and animals. Additionally, the presence of seals, sea otters, and whales provided further sustenance and resources. The intertidal zones were also filled with clams, mussels, and other shellfish, creating a diverse and reliable food web. This marine bounty was foundational to the development of the complex and prosperous societies that flourished along the coast. Lush Rainforests The temperate rainforests of the Northwest Coast were an equally essential component of the region's environment. The heavy rainfall, coupled with the moderate temperatures, provided ideal conditions for the growth of dense forests dominated by coniferous trees such as spruce, hemlock, and fir. These towering trees, some of the largest in the world, provided essential materials for housing, canoes, tools, and art. The understory was abundant with diverse plant life and animal species, contributing to the overall biodiversity of the region. These forests were not only a source of material wealth but also integral to the spiritual and cultural lives of the local populations. Diverse Landscapes The landscape of the Northwest Coast is surprisingly diverse, including not only the coastal strip but also features such as coastal mountains, river valleys, volcanic snow-capped mountains, and arid high desert regions further inland. The dramatic coastal hills often descend steeply to the shore or riverbanks. The abundance of water further contributes to the lushness of the area, while the interplay between various geological features creates micro-climates and habitats that contribute to the incredible diversity of life. Frequently Asked Questions (FAQs) 1. What are the primary landforms of the Pacific Northwest? The Pacific Northwest is home to various landscape regions including the Basin & Range, Blue-Wallowa Mountains, Cascade Range, Central Oregon Plateau, Coast Ranges, Columbia Plateau, Okanogan Highlands, and Puget-Willamette Lowland. Each of these regions presents unique geographical features, contributing to the area's overall diversity. 2. How did the environment of the Northwest Coast influence the development of the societies there? The abundant resources of the sea and forests enabled the people of the Northwest Coast to establish complex social structures with social classes based on wealth. The ease of access to these resources meant that the focus could be put on art, ceremonies, and social hierarchies, rather than struggling for mere subsistence. 3. What types of shelter did the people of the Northwest Coast construct? Unlike the teepees of other regions, the indigenous peoples of the Northwest Coast lived in longhouses constructed of thick cedar planks. These plank houses provided durable and spacious shelters for extended families and communities. 4. What did the Northwest Coast people eat? The diet of the Northwest Coast people was rich and varied. It primarily included salmon, shellfish, and other fresh seafood. Additionally, they consumed game meats, such as moose, elk, and caribou, as well as wild mushrooms, berries, and other edible plants. 5. What role did cedar play in the lives of the Northwest Coast people? Cedar trees were essential to the Northwest Coast culture. They were used to build longhouses and large canoes, and were also a source of wood for carving totem poles, masks, and other cultural artifacts. Their versatility made them a critical component of daily life. 6. How did the Northwest Coast people travel on water? The Northwest Coast people were skilled boatbuilders, creating large canoes from cedar or spruce trees. These boats were capable of carrying 30 people, enabling them to travel extensively on the waterways to hunt, fish, trade and communicate. 7. What were the common clothing styles of the Northwest Coast people? Women in the Northwest Coast generally wore skirts or gowns made of buckskin, soft leather, woven wool, or plant fibers. Men's clothing was often minimal, particularly in warmer weather, and varied depending on the tribe. Ornaments were frequently worn by both men and women. 8. How does the climate of the Northwest Coast impact its forests? The cool, wet climate supports the growth of thick, temperate rainforests. The combination of consistent moisture and moderate temperatures has allowed some of the largest trees in the world to thrive. 9. How did the environment affect the economies of the Northwest Coast people? The abundance of fish and other resources facilitated trade and the development of sophisticated economic systems. Communities could focus on producing surpluses and engage in regional exchange. 10. Where exactly did the Northwest Coast people live? The Northwest Coast people lived along a narrow strip of the North American Pacific Coast, from southern Alaska to northern California, including the offshore islands. Their world stretched from Yakutat Bay in the Gulf of Alaska to Cape Mendocino in present-day California. 11. What is the relationship between the Pacific Ocean and the Northwest Coast climate? The Pacific Ocean is the major influence on the Northwest Coast's climate. It creates the mild temperatures, wet winters, and warm, dry summers. The ocean's moderate influence makes the area unique compared to more inland environments. 12. What types of wildlife were common in the rainforests? The dense forests of the Northwest Coast are home to a variety of animal species, including deer, bears, wolves, beavers, and various species of birds. These animals were not only important for their natural role in the ecosystem, but also for providing food, furs, and other resources for human use. 13. How did the Northwest Coast people practice environmental stewardship? Historically, the Northwest Coast people held a deep respect for their environment. This respect was embedded in their cultural practices and spirituality, ensuring the sustainable use of the resources around them. It was, and remains a deeply ingrained ethic. 14. What are some ongoing environmental challenges in the Northwest Coast today? The Northwest Coast faces numerous environmental challenges such as rising temperatures, sea-level rise, extreme weather events, and nutrient run-off causing large dead zones in the ocean. These changes pose a threat to both the natural ecosystem and human communities. 15. How has climate change affected the Northwest Coast? Long-term warming has significantly impacted the region. The annual average temperature has risen, and some of the hottest years on record have occurred in recent decades. Climate change continues to disrupt ecosystems, alter weather patterns, and threaten the delicate balance of the Northwest Coast. The environment of the Northwest Coast was, and continues to be, a place of remarkable abundance and diversity. Its unique combination of climate, landscape, and rich resources supported the development of complex societies and a rich cultural heritage that continues to captivate and inform us. The ongoing challenges highlight the importance of continued stewardship and conservation efforts. The Northwest Coast had moderate weather, about maximum of 18 degrees Celsius in July. This allowed them to fish all year. The northern coast and upper island got about 155-655 cm of rain annually. The more protected areas received about 65-175 cm, mostly in winter. The winters were cold and hard, well under freezing. The summers were rainy and warm, and fishing was done especially then. The climate was not proper for agriculture, though many marine animals suitable for fishing were in the surrounding waters. The Northwest Coast, as you can tell from the name, has very coastal land. It contains a variety of other landforms, such as mountains, plateaus, valleys, wide beaches and a few plains. It is rugged, with thick undergrowth and many forests. Many islands are to be found, and the coast is broken up by bays, inlets, channels and rivers. Everyone lived near a water source, either a inland river or lake, or the Pacific Ocean, for survival. The excess of trees were also used, especially cedar, for everything, from clothing to houses to massive totem poles. Mountains, forests, inland lake Northwest Coast climate is dependent on the Pacific Ocean. It is generally mild, with cool wet winters and warm dry summers. Extreme temperatures and precipitation are unusual in this region. What is the climate in the North West? The climate in the Northwest United States is characterized by tall, snowy mountains and large, cool rivers. West of the Cascade Mountains, there is a maritime climate with mild seasonal temperatures and wet winters. East of the Cascades, the climate is drier, with colder winters and hotter summers. What is the geography of Northwest Coast? The Northwest Coast region includes diverse landscapes such as rugged-mystical Pacific Coast, temperate Coastal Mountain rainforests, emerald green river valleys, imposing volcanic snow-capped mountains, and an expansive, arid, and sunbathed high desert. What is the climate of the west coast of North America? Along the western side of the Coast Range, the climate is dominated by the Pacific Ocean. The weather in this area is characterized by warm winters, cool summers, small daily and seasonal temperature ranges, and high relative humidities. The maritime influence decreases with increasing distance from the ocean. What are the Northwest Native American climate? Native American tribes in the Pacific Northwest enjoyed a wet and mild climate, which allowed for ample agriculture and fishing. Many tribes inhabited the modern-day states of Oregon and Washington, as well as northern California. Along the coast, these tribes relied heavily on the Pacific salmon for food. Ford Gets SHOCKED As Its Own Dealers SLAM The Brand as UNRELIABLE Due To Its EV Fiasco! There is no information related to this topic in the given article. What is the climate and geography of the Northwest? The Northwest region of the United States has diverse climates and geographies. The coastal areas have coastal, or temperate, rainforests, while the inland areas are more dry and warm. The rainforests in this area are among the rainiest places on Earth. On the other hand, there are parts of Washington that are so dry they are considered to be a desert. What did the Northwest Coast live in? The dwellings of the Northwest Coast Native American tribes were rectilinear structures built of timber or planks. These structures were usually quite large as they housed multiple members of a corporate "house" living together in one building. Where is the West Coast climate? The West Coast climate is found along a relatively narrow strip of coastal Oregon, Washington, British Columbia, and southern Alaska in North America. It is also found along coastal Chile in South America. What kinds of climates exist along the West Coast? Along the West Coast, there are five major climate types that occur in close proximity. These climate types include the Desert, Cool Interior, Highland, Steppe, and Mediterranean climates. What are the West Coast climate regions? The three climate zones of the West Coast in the United States are the Marine West Coast, Mediterranean, and Midlatitude Desert. What is the Northwest Coast called? The Northwest Coast region is called the Pacific Northwest in the American context. In anthropology, it refers to the groups of Indigenous people residing along the coast of present-day British Columbia, Washington State, parts of Alaska, Oregon, and Northern California. Does the Northwest Coast have mountains? Yes, the Northwest Coast region includes mountains such as the Coast Range and the Cascades. These mountains add to the diverse landscapes found in the area. What landforms were in the Northwest Coast? The Northwest Coast region is characterized by various landforms, including the Basin & Range, Blue-Wallowa Mountains, Cascade Range, Central Oregon Plateau, Coast Ranges, Columbia Plateau, Okanogan Highlands, and Puget-Willamette Lowland. Is Northwest hot or cold? The climate in the Northwest region can vary, but generally, the temperatures are relatively moderate. Summer days rarely rise above 79°F (26°C), and winter days are seldom below 45°F (8°C) during the day. However, temperatures can dip into the 20s and 30s (-6°C to -1°C) at night in winter. What is the climate in Oregon? Most of Western Oregon has a warm-summer Mediterranean climate, featuring warm, dry summers and wet winters with frequent overcast and cloudy skies. Eastern Oregon falls into the cold semi-arid climate, which experiences drier weather. Is North West wind cold? Winds from the northwest, north, or north-east usually bring cold, showery weather to the British Isles. Why is the West Coast so temperate? The temperate climate on the West Coast of the United States is influenced by the cool ocean currents moving south from the Gulf of Alaska. Prevailing winds are onshore from the northwest, bringing moisture and moderating temperature extremes. Why is the West Coast temperate? The temperate climate on the West Coast is largely influenced by the Pacific Ocean. The ocean moderates temperatures, leading to milder and more stable weather patterns. How is the climate along the coast? The climate along the coast is influenced by the presence of the ocean. It often leads to increased humidity and consistent precipitation in coastal regions. The ocean also helps reduce temperature extremes, resulting in cooler summers and milder winters. What are temperate West Coast climates? Temperate West Coast climates are a type of oceanic climate. They are characterized by cool summers and mild winters, with a relatively narrow annual temperature range and few temperature extremes. What is the climate of the west coast of Washington? In Western Washington, the weather is relatively mild. Summer days rarely surpass 79°F (26°C), and winter days seldom drop below 45°F (8°C) during the day. While snow is rare, winter temperatures can reach the 20s and 30s (-6°C to -1°C) at night. Is the West Coast dry or humid? The West Coast is less humid compared to the eastern seaboard due to the cool ocean currents and the clockwise flow of currents in the Atlantic and Pacific Oceans. What are some facts about the Northwest Coast region? The Northwest Coast region stretches from the southern border of Alaska to northwestern California. It is characterized by diverse Page snapshot: Introduction to the climate of the western states of the contiguous United States (California, Nevada, Oregon, and Washington), including present, past, and future climate. For the climate of Alaska, see the Climate of Alaska page.Topics covered on this page: Present climate of the western U.S.; Present temperature; Present precipitation; Regional climate variation; Past climate of the western U.S.; Paleozoic; Mesozoic; Cenozoic; Future climate of the western U.S.; Resources. Credits: Much of the text on this page comes from "Climate of the Western US" by Ingrid H. H. Zabel, Judith T. Parrish, Alexandra Moore, and Gary Lewis, chapter 9 in The Teacher-Friendly Guide to the Earth Science of the Western US, edited by Mark D. Lucas, Robert M. Ross, and Andrielle N. Swaby (published in 2014 by the Paleontological Research Institution; currently out of print). The book was adapted for the web by Elizabeth J. Hermsen, Jonathan R. Hendricks, and Ingrid Zabel in 2022. Changes include formatting and revisions and additions to the text and images. Credits for individual images are given in figure captions. Updates: Page last updated June 8, 2022. Image above: Smoke rising from the Carr Fire in northern California on July 26, 2018. The Carr Fire was started by a flat tire on a trailer (the metal tire rim hit the pavement and produced sparks, igniting the fire). It eventually burned more than 90,000 hectares (more than 200,000 acres) of land before being extinguished. Photo by Eric Coulter, BLM (Bureau of Land Managment California on flickr, public domain). This page covers the climate of the western states of the contiguous U.S.: California, Nevada, Oregon, and Washington. For the climate of Alaska, see the Climate of Alaska page.Because of its wide latitudinal range, the proximity of the Pacific Ocean, and the presence of long, north-south mountain ranges, the western states have an enormous variety of climatic areas. These include hot, dry deserts in the Basin and Range, a Mediterranean climate (a climate with dry summers and relatively warm, wet winters) along the southern Pacific Border, and rainforests in the northern Pacific Border. Even individual states can have tremendous climate diversity. The lives of the residents of this region are tied to climate in critical ways. People in Southern California's coastal area and Central Valley enjoy a pleasant climate, but they depend on water from elsewhere—mostly from snowmelt—for their everyday needs and for agricultural irrigation. As of May 2022, much of California, Nevada, and Oregon were experiencing a severe to exceptional drought. Climate is also linked to energy resources. In the Pacific Northwest, the combination of topographical variation and abundant precipitation creates an ideal environment for hydropower. However, drought conditions that lower water levels can imperil the production of hydroelectricity. With such diverse climate types, a wide range of temperatures are experienced throughout the West. Generally, temperatures tend to decrease northward and also from west to east, with cooler temperatures at higher elevations and across the region's north-south mountain ranges. Temperatures in coastal areas are moderated by the Pacific Ocean and, in the northwest, by the Rocky Mountains, which prevent cold Arctic air from reaching the coast. Average lows and highs in Southern California range from 3° to 46°C (37° to 114°F) inland in Death Valley and 9° to 24°C (49° to 76°F) on the coast in San Diego. Statewide average lows and highs in Oregon run from -3° to 28°C (26° to 82°F), while in Washington, temperature ranges from -1° to 32°C (29° to 89°F). Nevada experiences average temperatures spanning from 4° to 40°C (39° to 104°F).Average annual temperatures for the western states of the contiguous U.S. Image adapted from an image by Scenarios for Climate Assessment and Adaptation, first published in The Teacher-Friendly Guide to the Earth Science of the Western US. The spectacular mountain ranges in the western states run from north to south. These ranges—the Coast Ranges, the Cascades, the Rockies, and the Sierra Nevada—create a pronounced east-west precipitation gradient across the region. The overall effect is to produce wet areas on the western sides of the West's mountain ranges and dry rain shadows on the eastern sides. This effect is most pronounced from Northern California north through Washington, since the jet stream is often located over this area—especially in winter—and brings moist ocean air inland. Average annual precipitation for the western U.S. Image adapted from an image by Scenarios for Climate Assessment and Adaptation, first published in The Teacher-Friendly Guide to the Earth Science of the Southwestern US.Köppen climate map of the 48 contiguous states of the continental United States. The first letter of each zone in the key indicates its major classification. A = Tropical (equatorial), B = Arid, C = Temperate (warm temperate), D = Continental (cold), E = polar. Modified from a map by Adam Peterson (Wikimedia Commons, Creative Commons Attribution-ShareAlike 4.0 International license). California's climate is influenced by its proximity to the Pacific Ocean and its mountain ranges, including the Coast Ranges in the west and the Sierra Nevada in the east. Mount Whitney in southeastern California is the highest point in the state, at 4421 meters (14,505 feet) above sea level, whereas Badwater Basin in Death Valley is the lowest point at 86 meters (282 feet) below sea level. The long Central Valley extends roughly north-south through the center of the state, separating the coastal and inland mountain ranges. Much of California is classified as having a Mediterranean climate, although the southeastern part of the state is desert. The mild Mediterranean climate makes California an important agricultural region and a popular place to live, although limited water supplies are increasingly posing problems for agriculture and even for towns and urban areas in the state. The extreme topographic variation in California contributes to its place in the weather record books. The official hottest temperature ever recorded worldwide was at Furnace Creek in Death Valley, at 56.7°C (134°F) in 1913. This record was nearly broken during an extreme heat wave in 2021, and the highest average temperature in the world over a 24-hour period comes from Stovepipe Wells in Death Valley, at 47.8°C (118.1°F) on July 11, 2021. In the meantime, the Sierra Nevada mountains are known for their deep winter snow, which is important to maintaining water supplies in California. The highest 24-hour snowfall recorded in California is slightly more than 170 centimeters (67 inches).Snow near Lake Tahoe, a lake on the California-Nevada border, in February 2019. Photo by Jonathan Cook-Fisher (flickr, Creative Commons Attribution 2.0 Generic license, image resized). Almost all of Nevada is within the Basin and Range physiographic province, with north-south trending mountain ranges separated by basins. The Sierra Nevada mountains rise on the western side of the state along the California-Nevada border. The highest point is Boundary Peak near the western border; it reaches 4007 meters (13,147 feet); the lowest point is on the Colorado River at 147 meters (481 feet). Unlike the other western states, Nevada does not border the ocean. Given its position east of the Sierra Nevada Mountains, the state is very dry. Much of Nevada is classified as semi-arid to desert; only the northeastern part of the state has a Mediterranean climate. In fact, Nevada is the most arid state in the U.S., receiving only about 24 centimeters (9.5 inches) of rainfall a year. Aerial view of Great Basin National Park, Nevada, showing Wheeler Peak at the lower right. Photo by Doc Searls (Wikimedia Commons, Creative Commons Attribution 2.0 Generic license, image resized).Red Rock Escarpment, Red Rock Canyon National Conservation Area, southern Nevada. Joshua trees (Yucca brevifolia) stand in the foreground. Photo by Bob Wick, BLM (Bureau of Land Management Nevada on flickr, Creative Commons Attribution 2.0 Generic license, image resized). Oregon's climate is influenced by its proximity to the Pacific Ocean and its mountain ranges, particularly the Oregon Coast Range and the Cascades that run north-south through western Oregon. Mt. Hood, a volcano in northwestern Oregon near Portland, is the highest peak at 3425 meters (11,239 feet). The lowest point is the coastline, which is at sea level. Much of Oregon has a Mediterranean climate, although some areas, particularly in the southeastern part of the state, have a cold semi-arid climate. As in Washington, temperate rain forest occurs in western Oregon due to moist air carried in from the Pacific Ocean causing rainfall on the mountains near the coast. Eastern Oregon is much drier due to the rain shadow on the leeward side of the mountains.False-color image showing the difference in precipitation and vegetation cover in western and eastern Oregon. The two blue spots are volcanic peaks in the Cascades: Mt. Hood (upper) and Mt. Jefferson (lower). NASA Earth Observatory image by Jesse Allen and Robert Simmon (used following NASA's image use policy). Washington's climate is influenced by its proximity to the Pacific Ocean and its mountain ranges, including the Olympic Mountains on the Olympic Peninsula (located in west-central Washington), the Cascades that run north-south through western Washington, and the Rockies found in northeastern Washington. Mt. Rainier, a volcano in western Washington, is the highest peak at 4394 meters (14,417 feet). The lowest point is the coastline, which is at sea level. Much of Washington state has a Mediterranean climate, although the south-central part of the state has a cold semi-arid climate. Due to its western mountain ranges, Washington experiences extreme differences in precipitation from west to east. For example, Olympic National Park in Washington receives over 190 centimeters (75 inches) of rain annually on average, whereas communities only 400 kilometers (250 miles) to the east in Washington receive 18 to 20 centimeters (7 to 8 inches) annually. Moss hanging from a tree in Hoh Rain Forest, Olympic National Park, west-central Washington. Photo by John Walker (flickr, Creative Commons Attribution 2.0 generic license, image resized). This section covers the climate of the contiguous western U.S. through the Phanerozoic, from about 541 million years ago to the recent. For the climate on early Earth prior to 541 million years ago, see the Introduction to Climate section. Throughout much of the Paleozoic, North America's terrestrial western margin ran through Idaho, Arizona, and easternmost Utah, with the continental shelf extending out through California, Oregon, and Washington. Western Washington, all of Oregon, and most of northwestern California are almost entirely composed of ancient terranes and volcanic island arcs that drifted together at different times during Earth's history and accreted onto the edge of the continent at its western subduction zone. Most of these terranes appear to have experienced warm, wet climates, and geologists have concluded that they all originated in tropical areas of what is now the Pacific Ocean. In the Cambrian, the western states had a warm climate. Fossils such as trilobites, brachiopods, and archaeocyathids (extinct reef builders) found in eastern California and western Nevada provide evidence of warm, shallow seas.The globe about 485 million years ago, near the Cambrian-Ordovician boundary. Reconstruction created using basemap from the PALEOMAP PaleoAtlas for GPlates and the PaleoData Plotter Program, PALEOMAP Project by C. R. Scotese (2016); map annotations by Jonathan R. Hendricks for PRI's Earth@Home project (CC BY-NC-SA 4.0 license).Archaeocyathids (the lighter-colored, tube-like structures), Early Cambrian Wood Canyon Formation, Inyo County, California. Photo by Bob Day (University of California Museum of Paleontology/UCMP (Creative Commons Attribution 3.0 Unported license, accessed via GBIF.org).A trilobite (Nevadia parvoconica), Indian Springs Lagerstätte, Early Cambrian Poleta Formation, Esmeralda County, Nevada. Photo by Paleontological Research Institution (PRI) on GBIF.org (CC0 1.0 Universal/Public Domain Dedication).Sea level rose in the Ordovician, and both deep- and shallow-water marine deposits are known from that time. Conodonts and graptolites are found in deep-water deposits from northeastern Washington and shallow-water marine rocks throughout Nevada and southeastern California, revealing that the climate remained warm during the Ordovician. At the end of the Ordovician, from 460 to 430 million years ago, the Earth fell into another ice age, but corals found in California indicate it remained warm enough for tropical seas to exist there. Silurian-age rocks tell us much the same story. From 430 to 300 million years ago, North America moved north across the equator, and the cycle of warming and cooling was repeated yet again. In the Devonian, sea level was higher than it had been earlier. Devonian rocks are relatively scarce in the West, with small areas widely scattered across Nevada. The most extensive outcrops of Devonian rocks are located on accreted tropical terranes and include some very large reefs.Devonian marine invertebrate fossils from Nevada. Left: A trilobite, Paciphacops claviger, Early Devonian Wenban Limestone, Cortez Range. Photo by Daderot (Wikimedia Commons, CC0 1.0 Universal/Public Domain Dedication). Left: An early starfish (Protasteridae), Late Devonian Devil's Gate Formation, Eureka County. Photo of YPM IP 227114 by Susan H. Butts (Yale Peabody Museum of Natural History/YPM, CC0 1.0 Universal/Public Domain Dedication, accessed via GBIF.org). By the Early Carboniferous, ice capped the South Pole and began to expand northward. Although the Earth's temperature fell during this time and the frozen water far to the south caused sea levels to drop, the West still remained relatively warm because of North America's low-latitude position. Mountain-building in Nevada raised the sea bottom, dividing the marine environment into shallow water to the east and deep water to the west. Nevada's shallow-water deposits contain reefs, indicating that the climate there was still warm. By the late Carboniferous, North America had collided with Gondwana, leading to the formation of Pangaea, a supercontinent composed of nearly all the landmass on Earth. Carboniferous and Permian rocks in Oregon, northern California, and western Washington originated on tropical terranes. Some contain lush, tropical floras that are completely dissimilar to those on the main part of the continent, a testament to their continued isolation in the ocean far from the western margin of North America.Earth 300 million years ago, during the end of the Carboniferous Period (Pennsylvanian). Pangaea was completed when North America finally collided with Gondwana. Reconstruction created using basemap from the PALEOMAP PaleoAtlas for GPlates and the PaleoData Plotter Program, PALEOMAP Project by C. R. Scotese (2016); map annotations by Jonathan R. Hendricks & Elizabeth J. Hermsen for PRI's Earth@Home project (CC BY-NC-SA 4.0 license).A chaetetid (enigmatic organisms now considered to be sponges) cut to show its internal structure. Carboniferous Bird Spring Formation, Spring Mountains, Nevada. Photo by Mark A. Wilson (Wikimedia Commons, CC0 1.0 Universal Public Domain Dedication).Brachiopods from the Permian of Clark County, Nevada. Left: Spirifer rockymontanus (YPM IP 235602). Right: Productus inflatus (YPM IP 235604). All photos by Jessica Utrup (Yale Peabody Museum of Natural History/YPM, CC0 1.0 Universal/Public Domain Dedication, accessed via GBIF.org). Around 220 million years ago, the West moved north from the equator. Pangaea began breaking up into continents that would drift toward their modern-day positions. The Earth remained warm until worldwide temperatures began to dip again in the Late Jurassic, around 150 million years ago. At this time, the western states were still largely underwater, but the Sierra Nevada Mountains had begun to form as a volcanic island arc close to the edge of the continent. Nevada's Triassic rocks contain both deep-water marine and terrestrial deposits. Its Triassic seas were rich with ichthyosaurs and other marine reptiles, while its terrestrial rocks reflect the aridity and seasonality of the climate farther inland. As mountain building continued into the Jurassic, the seas became shallower, while terrestrial deposits expanded. By this time, terranes were beginning to collide with the continent; some of these collisions included volcanic islands ringed with corals, indicating that the climate remained warm.The large ichthyosaur Shonisaurus popularis from the Triassic of Nevada. Specimen on display in the Nevada State Museum, Las Vegas, Nevada. Photo by Kenneth Carpenter (Wikimedia Commons, Creative Commons Attribution-ShareAlike 4.0 International license, image cropped and resized).Pangaea began to break up during the Jurassic, rifting apart into continents that would drift toward their modern-day positions. The supercontinent was split by spreading along the mid-Atlantic ridge, initiating the formation of the Atlantic Ocean. Jurassic rocks are widely scattered through Oregon and Washington, where they contain coral-ringed volcanic arcs with associated deeper marine sediments. Jurassic rocks in California reflect both shallow-water marine and terrestrial environments. A large area of shallow-water marine deposits was laid down just off of the rising Sierra Nevada, in what is now the eastern Central Valley. The terrestrial rocks of southeastern California contain ginkgoes and cycads that indicate a warm, moderately wet climate. Terrestrial Jurassic rocks in southern Nevada, however, show that the climate on land was still arid.Earth 150 million years ago, near the end of the Jurassic Period. North America and Europe are part of Laurasia, and South America and Africa are part of Gondwana. Notice that North America has separated from Africa and there is a spreading center in the Central Atlantic Ocean. Reconstruction created using Paleomap (by C. Scotese) for GPlates. Reconstruction created using basemap from the PALEOMAP PaleoAtlas for GPlates and the PaleoData Plotter Program, PALEOMAP Project by C. R. Scotese (2016); map annotations by Jonathan R. Hendricks and Elizabeth J. Hermsen for PRI's Earth@Home project (CC BY-NC-SA 4.0 license). As a result of displacement due to continental rifting and seafloor spreading, sea level throughout the Cretaceous was much higher than it is today. Global temperatures during the Cretaceous were very warm, as much as 10°C (18°F) above those at present. There was likely little or no glacial ice anywhere on Earth, and temperatures were highest in lower latitudes. Shallow seaways spread over many of the continents, including South America, Africa, Eurasia, and North America. Mountain-building continued throughout the West with the formation of volcanic mountains in the Sierra Nevada region as well as uplift of the Rocky Mountains further to the east. Erosion predominated, and Nevada and Oregon have a very sparse record of Cretaceous sedimentation and climate; the few outcrops from this time period show that Nevada was terrestrial and Oregon was still largely marine. Washington and California have a slightly better record, showing that they, too, were still principally marine. Global climate was warm, but reefs did not form, probably due to the intense mountain building and erosion that shed a great amount of sediment into the interior embayments and the Pacific Ocean. The climate temporarily cooled again at the end of the Cretaceous, 66 million years ago.An ammonoid (Acanthoplites subbigoti) from the Early Cretaceous Budden Canyon Formation, Shasta County, California. Photo of LACMIP 9951.2 by Natural History Museum of Los Angeles County (Creative Commons Attribution 4.0 International license, image cropped).The giant bivalve Inoceramus from the Cretaceous of Little Sucia Island, San Juan Islands, Washington. Photo by Kevmin (Wikimedia Commons, Creative Commons Attribution-ShareAlike 3.0 Unported license, image cropped). In the early Paleogene, the climate warmed once more. By around 50 million years ago, the West's climate was actually hot, with palm trees growing as far north as northwestern Washington, western Canada, and southern Alaska. The sea withdrew from most of Oregon and Washington, and plant fossils are found throughout these states.Impressions of fossil palm leaves (Sabalites), Eocene Chuckanut Formation, Whatcom County, Washington. Source: From Figure 4 in Mustoe (2019) Geosciences 9(7): 321 (Creative Commons Attribution 4.0 International license, image cropped).A leaf (left) and fruits (right) of an extinct relative of the katsura (Cercidiphyllum) from Republic, Ferry County, Washington. Leaf = 7.2 cm long (about 2.8 inches). Fruits = each up to 2 centimeters long (about 0.8 inches). Left photo and right photo by Kevmin (Wikimedia Commons, Creative Commons Attribution-ShareAlike 4.0 International license, images cropped and resized).One of the best records of the contiguous western states' Paleogene climate is found in Oregon's John Day Fossil Beds. Here, plant and animal fossils indicate that from 50 to 35 million years ago this area was home to a subtropical rainforest with banana and citrus trees. Between 35 and 20 million years ago, however, the climate became cooler and drier, and prairies and deciduous trees such as oak, maple, and alder flourished. This change coincided with the initial uplift of the Cascade Range (37–7 million years ago), which began to create a rain shadow to the east.Alder (Alnus) leaves and "cones" (groups of female flowers or fruits, but not true cones) from the Oligocene John Day Formation, Oregon. Fossils on display at the Thomas Condon Paleontology Center, John Day Fossil Beds National Monument. Left photo and right photo by National Park Service/NPS (public domain).The final uplift of the Cascades and Sierra Nevada created the intense rain shadow that is responsible for the aridity of eastern Washington, eastern Oregon, and Nevada today. Moist Pacific Ocean air moves eastward with the prevailing winds, and it is pushed upward and cools when it encounters a mountain chain. Water vapor condenses from this cool air and falls as rain or snow on the western side of the mountain. The air that continues to move east over the mountains is now much drier, and it warms as it moves down the eastern side of the mountain range, promoting evaporation.The rain shadow effect occurs when moisture-laden air rises up the windward side of a mountain, only to release this moisture as precipitation due to cooling and condensation. Once the air reaches the leeward side, it warms due to compression, promoting evaporation and a lack of precipitation. Diagram by Wade Greenberg-Brand, originally published in the Teacher Friendly Guide to Earth Science series, modified for Earth@Home.Mount Whitney, the highest peak in California and also in the Sierra Nevada mountains at 4421 meters (14,505 feet) above sea level. Photo by Geographer (Wikimedia Commons, Creative Commons Attribution 1.0 Generic license).Late in the Cenozoic, eruptions in eastern Oregon produced enormous quantities of basalt that flowed north and west, filling the Columbia River basin. These are some of the largest such eruptions in the history of the Earth, and they took place several times over a span of about 11 million years. While evidence that these eruptions influenced global climate is ambiguous, climatic changes are recorded in soils that formed atop some of the lava flows. These soils indicate a decrease in temperature after a period known as the Middle Miocene Climatic Optimum, a brief warming episode that occurred around 16 million years ago.Original caption: "Map of the northwestern U.S., showing the approximate locations of Yellowstone hotspot volcanic fields (orange) and Columbia River Basalts (gray). Boundary of Yellowstone National Park is shown in yellow. Modified from Barry et al. (GSA Special Paper 497, p. 45-66, 2013), Smith and Siegel (Windows into the Earth: the geologic story of Yellowstone and Grand Teton National Parks: Oxford University Press, 2000), and Christiansen (USGS Professional Paper 729-G, 2001)." Source: USGS (public domain). Eventually, a sheet of sea ice formed over the Arctic, and ice sheets spread over northern Asia, Europe, and North America, signaling the start of the most recent ice age. Since 800,000 years ago, an equilibrium has been reached between warming and cooling, with the ice caps growing and retreating primarily due to the influence of astronomical forces (i.e., the combined gravitational effects of the Earth, Sun, moon, and planets). During the last glacial maximum, ice covered the northern part of Washington State. During periods of ice advance, the western states were colder than they are today, with extensive mountain glaciers occurring throughout the region; in fact, Yosemite Valley was carved out at this time. Microfossil evidence from the Rancho La Brea Tar Pits in Los Angeles tells us that southern California's climate around 40,000 years ago was similar to San Francisco's today. Around 12,000 years ago, all of Washington east of the Cascades was inundated and scoured by numerous enormous, violent floods. These occurred when an ice sheet alternately blocked and retreated from what is now the Clark Fork River in northwestern Montana and northern Idaho. When the river was blocked, an enormous lake—Glacial Lake Missoula—built up behind the ice dam. When the ice dam later failed, the water was released catastrophically, shaping and scouring the landscape. Today, many of the glaciers that remain in the West are in retreat and much of the area is becoming more arid. Only one true glacier, Maclure Glacier, still exists in Yosemite National Park. Yosemite Valley and Half Dome (the projecting rock formation on the right), Yosemite National Park, eastern California. Yosemite Valley was carved by glaciers in the Pleistocene. Photo by James St. John (flickr, Creative Commons Attribution 2.0 Generic license, image resized).Map showing the extent of glacial Lake Missoula and the Channeled Scablands. Map modified from a map by Wade Greenberg-Brand, adapted from image by the Montana Natural History Center, originally published in The Teacher-Friendly Guide to the Earth Science of the Northwest Central US.Lyell Glacier in 1883 compared to Lyell ice patch in 2015, Yosemite National Park, California. Photos by Israel Russell/USGS (1883) and Keenan Takahashi/NPS (2015). Source: NPS Climate Change Response on flickr (public domain). The western states contribute significantly to climate change. The population of any industrialized and particularly wealthy country produces pollution. The more than 51 million residents of California, Nevada, Oregon, and Washington use electricity, transportation, and products that come from carbon-rich fossil fuels. Burning fossil fuels releases carbon into the atmosphere, which warms the Earth. Of the western states, California emits by far the most greenhouse gases. In 2019, California was the second highest carbon dioxide emitter in the nation, behind only Texas. The majority of California's emissions came from transportation. On the other hand, the contiguous western states are making changes to reduce human impact on the climate, including decarbonization of energy sources and electrification efforts such as adoption of electric vehicles. The city of Seattle was an early adopter of the 2030 Challenge, an effort by cities to reduce fossil fuel use in buildings so that both new and renovated buildings would qualify as carbon neutral by the year 2030. In 2021, California was the U.S.'s top producer of electricity from solar, geothermal, and biomass sources, and Nevada was 6th in the nation in solar power generation. Washington and Oregon are both large hydropower producers, and in 2020 wind power accounted for 14% of Oregon's utility-scale electricity generation. Studies show that the climate of the contiguous western states is changing right now, and that change has accelerated in the latter part of the 20th century. These changes include the following: Temperatures have increased since the 1980s during all seasons. Nighttime temperatures have increased by almost 1.7°C (3°F) since 1900. The average annual number of wildfires of over 400 hectares (1000 acres) has doubled in California since the 1970s. The freeze-free season in the Pacific Northwest is on average 11 days longer for the period of 1991–2010, compared with that of 1961–1990. Heavy downpours have increased by 18% in the Pacific Northwest from 1948 to 2006. Future temperature Climate models predict that the climate of the western states will continue to warm, and that the average annual temperature will rise by 2° to 6°C (3° to 10°F) by the end of the 21st century. Summer heat waves will become hotter and longer. These increased temperatures lead to a whole host of other effects, including a decrease in snowpack, declines in river flow, drier soils from more evaporation, and the increased likelihood of drought and fires. The West is already feeling the effects of increased temperature combined with decreasing precipitation. In 2021, the Northwest experienced an unprecedented "heat dome" that brought record-high temperatures, with Seattle reaching about 42°C (108°F) and Portland 46.7°C (116°F) in June. Heat map showing land surface temperature in the northwestern U.S. and adjacent Canada during the June 2021 heat dome event. Excerpt from original caption: "The extent of the heatwave can be seen in this map, which shows the land surface temperature of parts of Canada and the US on 29 June. The data show that surface temperatures in Vancouver reached 43°C [over 109°F], and Calgary and Portland recorded 43°C [over 109°F]. The hottest temperatures recorded are in the state of Washington (visible in deep red) with maximum land surface temperatures of around 69°C [over 156°F]." Image and caption by the European Space Agency on flickr (Creative Commons Attribution-ShareAlike 2.0 Generic license, image resized). Water supply is a critical issue in the western states, and communities will need to adapt to changes in precipitation, snowmelt, and runoff as the climate changes. Models predict that winter and spring storms in Nevada will shift northward, dropping less rain and snow in already arid areas. California will likely be faced with less water flowing in its rivers and declining high-elevation forests, along with increased pressure on the water supply for agriculture and cities. Drought conditions in the West are already severely affecting water supplies in California and Nevada. In early 2022, water levels as Lake Mead, a reservoir on the Arizona-Nevada border that supplies water to parts of Arizona, California, Nevada, and New Mexico, were critically low. As a result, stringent water conservation measures were instituted in some places, including limits on outdoor lawn watering. In order to conserve water, Las Vegas has begun efforts to replace much of the grass in the city with arid-adapted plants or other landscaping that does not require frequent watering. In 2021, the town of Mendocino Village, California, faced a severe water shortage and had to have water trucked in from Ukiah, a distance of almost 113 kilometers (70 miles).Lake Mead, the lake created by the Hoover Dam, at two points in time about 21 years apart. Images by Lauren Dauphin, NASA Earth Observatory (used following NASA's image use policy).Satellite images of Lake Oroville, a reservoir in northern California. Left: At capacity (highest level), June 2019. Right: At a much lower water level due to drought, June 2021. In August 2021, the Edward Hyatt Power Plant, a hydroelectric plant on Lake Oroville, was shut down because water levels were too low for it to operate. Source: USGS (public domain).Mendocino Village, California, in 2015. In 2021, the village experienced a severe water shortage and water had to be delivered by truck from inland. Photo by btwashburn (flickr, Creative Commons Attribution 2.0 Generic license, image resized). The Northwest is expected to see less summer precipitation and more winter precipitation, and more of winter precipitation falling as rain rather than snow. Over the past 40 to 70 years, the Cascade Range has experienced a 25% decline in snowpack measured on April 1, a trend that is expected to continue. This means less water from snowmelt in the warm season. Spring runoff in streams is expected to occur nearly 20 to 40 days earlier during the 21st century. Sea level rise from melting glaciers and the thermal expansion of a warmer ocean will be a concern for cities such as Seattle, Tacoma, and Olympia.Washington Pass Summit (elevation 1669 meters or 5477 feet), Cascade Mountains, Washington. This photo was taken on March 10, 2015; the snow was about 1.5 meters (5 feet) deep. Photo by Washington State Department of Transportation on flickr (Creative Commons Attribution-NonCommercial-NoDerivs 2.0 Generic license). The risk of dangerous wildfires is currently very high in parts of the West. The reasons for this are complex and involve a combination factors. Weather conditions, particularly hot, dry weather and wind that spreads flames, contribute significantly to the ignition and growth of wildfires. Other elements involved in the ignition and growth of fires and the risks they pose to people living in the West include (but are not limited to) forest management practices, development patterns, infrastructure maintenance, and human behavior (intentionally or unintentionally starting fires). As average temperatures rise and the west becomes drier with a longer annual fire season (season conducive to the ignition and spread of wildfires), the number and intensity of wildfires is expected to increase. The result may be more deadly, fast-moving fires like the Camp Fire that devastated Paradise, California, in 2018. The Camp Fire killed 85 people, destroyed more than 18,000 buildings, and burned more than 62,000 hectares (more than 150,000 acres) of land. Investigators determined that the fire was started by Pacific Gas and Electric (PG&E) electrical transmission lines. Warm and dry conditions and high winds spread the fire rapidly, causing the catastrophe in Paradise.Wildfire risk map for the United States. Source: FEMA National Risk Index.The Camp Fire as seen from a satellite, November 8, 2018. Infrared light provides the orange color that indicates where the fire is burning. Source: NASA Earth Observatory image by Joshua Stevens (NASA Earth Observatory, used following NASA's image use policy). Zabel, I.H.H., D. Haas, and R.M. Ross. 2017. The Teacher-Friendly Guide to Climate Change. Paleontological Research Institution Special Publication 53, Ithaca, NY, 294 pp. Find updated, digital versions of the chapters of this book on Earth@Home Climate. Allmon, W. D., T. A. Smrecak, and R. M. Ross. 2010. Climate change—past, present & future: a very short guide. Paleontological Research Institution Special Publication 38, Ithaca, NY, 200 pp. Websites Earth@Home Climate: Earth@Home: Quick guides & FAQ: Climate and Energy: Earth@Home: Here on Earth: Introduction to Climate: to the full list of resources about the climate of the western U.S.Go to the full list of general resources about climateBack to western U.S. main page Top The National Climate Assessment summarizes the impacts of climate change on the United States, now and in the future. A team of more than 300 experts guided by a 60-member Federal Advisory Committee produced the report, which was extensively reviewed by the public and experts, including federal agencies and a panel of the National Academy of Sciences. Explore the effects of climate change Temperatures increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3°F.1 While precipitation has generally increased, trends are small as compared to natural variability. Both increasing and decreasing trends are observed among various locations, seasons, and time periods of analysis (Ch. 2: Our Changing Climate, Figure 2.12). Studies of observed changes in extreme precipitation use different time periods and definitions of "extreme," but none find statistically significant changes in the Northwest.2,3,4 These and other climate trends include contributions from both human influences (chiefly heat-trapping gas emissions) and natural climate variability, and consequently are not projected to be uniform or smooth across the country or over time (Ch. 2: Our Changing Climate, Key Message 3). They are also consistent with expected changes due to human activities (Ch. 2: Our Changing Climate, Key Message 1). Facebook Tweet An increase in average annual temperature of 3.3°F to 9.7°F is projected by 2070 to 2099 (compared to the period 1970 to 1999), depending largely on total global emissions of heat-trapping gases. The increases are projected to be largest in summer. This chapter examines a range of scenarios, including ones where emissions increase and then decline, leading to lower (B1 and RCP 4.5) and medium (A1B) total emissions, and scenarios where emissions continue to rise with higher totals (A2, A1FI, and RCP 8.5 scenarios). Change in annual average precipitation in the Northwest is projected to be within a range of an 11% decrease to a 12% increase for 2030 to 2059 and a 10% decrease to an 18% increase for 2070 to 20995 for the B1, A1B, and A2 scenarios (Ch. 2: Our Changing Climate). For every season, some models project decreases and some project increases (Ch. 2: Our Changing Climate, Key Message 5),1,5 yet one aspect of seasonal changes in precipitation is largely consistent across climate models: for scenarios of continued growth in global heat-trapping gas emissions, summer precipitation is projected to decrease by as much as 30% by the end of the century (Ch. 2: Our Changing Climate).1,5 Northwest summers are already dry and although a 10% reduction (the average projected change for summer) is a small amount of precipitation, unusually dry summers have many noticeable consequences, including low streamflow west of the Cascades6 and greater extent of wildfires throughout the region.7 Note that while projected temperature increases are large relative to natural variability, the relatively small projected changes in precipitation are likely to be masked by natural variability for much of the century.8 Ongoing research on the implications of these and other changes largely confirms projections and analyses made over the last decade, while providing more information about how climate impacts are likely to vary from place to place within the region. In addition, new areas of concern, such as ocean acidification, have arisen. Facebook Tweet Observed regional warming has been linked to changes in the timing and amount of water availability in basins with significant snowmelt contributions to streamflow. Since around 1950, area-averaged snowpack on April 1 in the Cascade Mountains decreased about 20%,20,21 spring snowmelt occurred 0 to 30 days earlier depending on location,22 late winter/early spring streamflow increases ranged from 0% to greater than 20% as a fraction of annual flow,23,24 and summer flow decreased 0% to 15% as a fraction of annual flow,22 with exceptions in smaller areas and shorter time periods.25 Hydrologic response to climate change will depend upon the dominant form of precipitation in a particular watershed, as well as other local characteristics including elevation, aspect, geology, vegetation, and changing land use.26,27 The largest responses are expected to occur in basins with significant snow accumulation, where warming increases winter flows and advances the timing of spring melt.23,28 By 2050, snowmelt is projected to shift three to four weeks earlier than the 20th century average, and summer flows are projected to be substantially lower, even for an emissions scenario that assumes substantial emissions reductions (B1).17 In some North Cascade rivers, a significant fraction (10% to 30%) of late summer flow originates as glacier melt;29 the consequences of eventual glacial disappearance are not well quantified. Basins with a significant groundwater component may be less responsive to climate change than indicated here.19 Changes in river-related flood risk depends on many factors, but warming is projected to increase flood risk the most in mixed basins (those with both winter rainfall and late spring snowmelt-related runoff peaks) and remain largely unchanged in snow-dominant basins.30 Regional climate models project increases of 0% to 20% in extreme daily precipitation, depending on location and definition of "extreme" (for example, annual wettest day). Averaged over the region, the number of days with more than one inch of precipitation is projected to increase 13% in 2041 to 2070 compared with 1971 to 2000 under a scenario that assumes a continuation of current rising emissions trends (A2),1 though these projections are not consistent across models.31 This increase in heavy downpours could increase flood risk in mixed rain-snow and rain-dominant basins, and could also increase stormwater management challenges in urban areas. Consequences and Likelihoods of Changes Reservoir systems have multiple objectives, including irrigation, municipal and industrial use, hydropower production, flood control, and preservation of habitat for aquatic species. Modeling studies indicate, with near 100% likelihood and for all emissions scenarios, that reductions in summer flow will occur by 2050 in basins with significant snowmelt (for example, Elsner et al. 201017). These reduced flows will require more tradeoffs among objectives of the whole system of reservoirs,32 especially with the added challenges of summer increases in electric power demand for cooling33 and additional water consumption by crops and forests.1,10 For example, reductions in hydropower production of as much as 20% by the 2080s could be required to preserve in-stream flow targets for fish in the Columbia River basin.34 Springtime irrigation diversions increased between 1970 and 2007 in the Snake River basin, as earlier snowmelt led to reduced spring soil moisture.35 In the absence of human adaptation, annual hydropower production is much more likely to decrease than to increase in the Columbia River basin; economic impacts of hydropower changes could be hundreds of millions of dollars per year.36 Region-wide summer temperature increases and, in certain basins, increased river flooding and winter flows and decreased summer flows, will threaten many freshwater species, particularly salmon, steelhead, and trout.30 Rising temperatures will increase disease and/or mortality in several iconic salmon species, especially for spring/summer Chinook and sockeye in the interior Columbia and Snake River basins.37 Some Northwest streams32 and lakes have already warmed over the past three decades, contributing to changes such as earlier Columbia River sockeye salmon migration38 and earlier blooms of algae in Lake Washington.39 Relative to the rest of the United States, Northwest streams dominated by snowmelt runoff appear to be less sensitive, in the short term, to warming due to the temperature buffering provided by snowmelt and groundwater contributions to those streams.40 However, as snowpack declines, the future sensitivity to warming is likely to increase in these areas.41 By the 2080s, suitable habitat for the four trout species of the interior western U.S. is projected to decline 47% on average, compared to the period 1978-1997.42 As species respond to climate change in diverse ways, there is potential for ecological mismatches to occur – such as in the timing of the emergence of predators and their prey.39 Adaptive Capacity and Implications for Vulnerability The ability to adapt to climate changes is strengthened by extensive water resources infrastructure, diversity of institutional arrangements,43 and management agencies that are responsive to scientific input. However, over-allocation of existing water supply, conflicting objectives, limited management flexibility caused by rigid water allocation and operating rules, and other institutional barriers to changing operations continue to limit progress towards adaptation in many parts of the Columbia River basin.44,45 Vulnerability to projected changes in snowmelt timing is probably highest in basins with the largest hydrologic response to warming and lowest management flexibility – that is, fully allocated, mid-elevation, temperature-sensitive, mixed rain-snow watersheds with existing conflicts among users of summer water. Regional power planners have expressed concerns over the existing hydroelectric system's potential inability to provide adequate summer electricity given the combination of climate change, demand growth, and operating constraints.46 Vulnerability is probably lowest where hydrologic change is likely to be smallest (in rain-dominant basins) and where institutional arrangements are simple and current natural and human demands rarely exceed current water availability.44,47,48,49,9 The adaptive capacity of freshwater ecosystems also varies and, in managed basins, will depend on the degree to which the need to maintain streamflows and water quality for fish and wildlife is balanced with human uses of water resources. In highly managed rivers, release of deeper, colder water from reservoirs could offer one of the few direct strategies to lower water temperatures downstream.50 Actions to improve stream habitat, including planting trees for shade, are being tested. Some species may be able to change behavior or take advantage of cold-water refuges.51,52 Facebook Tweet With diverse landforms (such as beaches, rocky shorelines, bluffs, and estuaries), coastal and marine ecosystems, and human uses (such as rural communities, dense urban areas, international ports, and transportation), the Northwest coast will experience a wide range of climate impacts. Description of Observed and Projected Changes Global sea levels have risen about 8 inches since 1880 and are projected to rise another 1 to 4 feet by 2100 (Ch. 2: Our Changing Climate, Key Message 10). Many local and regional factors can modify the global trend, including vertical land movement, oceanic winds and circulation, sediment compaction, subterranean fluid withdrawal (such as groundwater and natural gas), and other geophysical factors such as the gravitational effects of major ice sheets and glaciers on regional ocean levels. Much of the Northwest coastline is rising due to a geophysical force known as "tectonic uplift," which raises the land surface. Because of this, apparent sea level rise is less than the currently observed global average. However, a major earthquake along the Cascadia subduction zone, expected within the next few hundred years, would immediately reverse centuries of uplift and, based on historical evidence, increase relative sea level 40 inches or more.60,61,53 On the other hand, some Puget Sound locations are currently experiencing subsidence (where land is sinking or settling) and could see the reverse effect, witnessing immediate uplift during a major earthquake and lowered relative sea levels.55,62 Taking into account many of these factors and considering a wider range of emissions scenarios than are used in this assessment (Appendix 5: Scenarios and Models), a recent evaluation calculated projected sea level rise and ranges for the years 2030, 2050, and 2100 (relative to 2000) based on latitude for Washington, Oregon, and California (see Figure 21.3).53 In addition to long-term climate-driven changes in sea level projected for the Northwest, shorter-term El Niño conditions can increase regional sea level by about 4 to 12 inches for periods of many months.53,63 Northwest coastal waters, some of the most productive on the West Coast,64 have highly variable physical and ecological conditions as a result of seasonal and year-to-year changes in upwelling of deeper marine water that make longer-term changes difficult to detect. Coastal sea surface temperatures have increased65,66 and summertime fog has declined between 1900 and the early 2000s, both of which could be consequences of weaker upwelling winds.67 Projected changes include increasing but highly variable acidity,68,69,70 increasing surface water temperature (2.2°F from the period 1970 to 1999 to the period 2030 to 2059),71 and possibly changing storminess.72,73 Climate models show inconsistent projections for the future of Northwest coastal upwelling.5,74 Consequences and Likelihoods of Changes In Washington and Oregon, more than 140,000 acres of coastal lands lie within 3.3 feet in elevation of high tide.75 As sea levels continue to rise, these areas will be inundated more frequently. Many coastal wetlands, tidal flats, and beaches will probably decline in quality and extent as a result of sea level rise, particularly where habitats cannot shift inland because of topographical limitations or physical barriers resulting from human development. Species such as shorebirds and forage fish (small fish eaten by larger fish, birds, or mammals) would be harmed, and coastal infrastructure and communities would be at greater risk from coastal storms.76,77 Ocean acidification threatens culturally and commercially significant marine species directly affected by changes in ocean chemistry (such as oysters) and those affected by changes in the marine food web (such as Pacific salmon78). Northwest coastal waters are among the most acidified worldwide, especially in spring and summer with coastal upwelling69,70,79,80 combined with local factors in estuaries.68,69 Increasing coastal water temperatures and changing ecological conditions may alter the ranges, types, and abundances of marine species.81,82 Recent warm periods in the coastal ocean, for example, saw the arrival of subtropical and offshore marine species from zooplankton to top predators such as striped marlin, tuna, and yellowtail more common to the Baja area.83,84 Warmer water in regional estuaries (such as Puget Sound) may contribute to a higher incidence of harmful blooms of algae linked to paralytic shellfish poisoning,85,86,87 and may result in adverse economic impacts from beach closures affecting recreational harvesting of shellfish such as razor clams.88 Toxicity of some harmful algae appears to be increased by acidification.89,90 Many human uses of the coast – for living, working, and recreating – will also be negatively affected by the physical and ecological consequences of climate change. Erosion, inundation, and flooding will threaten public and private property along the coast; infrastructure, including wastewater treatment plants;91,92 stormwater outfalls;93,94 ferry terminals;95 and coastal road and rail transportation, especially in Puget Sound.96 Municipalities from Seattle93 and Olympia,94 Washington, to Neskowin, Oregon, have mapped risks from the combined effects of sea level rise and other factors. Adaptive Capacity and Implications for Vulnerability Human activities have increased the vulnerability of many coastal ecosystems, by degrading and eliminating habitat97,98 and by building structures that, along with natural bluffs, thwart inland movement of many remaining habitats. In Puget Sound, for example, seawalls, bulkheads, and other structures have modified an estimated one-third of the shoreline,99 though some restoration has occurred. Human responses to erosion and sea level rise, especially shoreline armoring, will largely determine the viability of many shallow-water and estuarine ecosystems.82,99,100 In communities with few alternatives to existing coastal transportation networks, such as on parts of Highway 101 in Oregon, sea level rise and storm surges will pose an increasing threat to local commerce and livelihoods. Finally, there are few proven options for ameliorating projected ocean acidification.101 Facebook Tweet Evergreen coniferous forests are a prominent feature of Northwest landscapes, particularly in mountainous areas. Forests support diverse fish and wildlife species, promote clean air and water, stabilize soils, and store carbon. They support local economies and traditional tribal uses and provide recreational opportunities. Description of Observed and Projected Changes Climate change will alter Northwest forests by increasing wildfire risk and insect and tree disease outbreaks, and by forcing longer-term shifts in forest types and species (see Ch 7: Forests). Many impacts will be driven by water deficits, which increase tree stress and mortality, tree vulnerability to insects, and fuel flammability. The cumulative effects of disturbance – and possibly interactions between insects and fires – will cause the greatest changes in Northwest forests.112,113 A similar outlook is expected for the Southwest region (see Ch. 20: Southwest, Key Message 3). Although wildfires are a natural part of most Northwest forest ecosystems, warmer and drier conditions have helped increase the number and extent of wildfires in western U.S. forests since the 1970s.7,113,114,115 This trend is expected to continue under future climate conditions. By the 2080s, the median annual area burned in the Northwest would quadruple relative to the 1916 to 2007 period to 2 million acres (range of 0.2 to 9.8 million acres) under the A1B scenario. Averaged over the region, this would increase the probability that 2.2 million acres would burn in a year from 5% to nearly 50%.7 Within the region, this probability will vary substantially with sensitivity of fuels to climatic conditions and local variability in fuel type and amount, which are in turn a product of forest type, effectiveness of fire suppression, and land use. For example, in the Western Cascades, the year-to-year variability in area burned is difficult to attribute to climate conditions, while fire in the eastern Cascades and other specific vegetation zones is responsive to climate.7 How individual fires behave in the future and what impacts they have will depend on factors we cannot yet project, such as extreme daily weather and forest fuel conditions. Higher temperatures and drought stress are contributing to outbreaks of mountain pine beetles that are increasing pine mortality in drier Northwest forests.116,110,117 This trend is projected to continue with ongoing warming.7,111,118,119 Between now and the end of this century, the elevation of suitable beetle habitat is projected to increase as temperature increases, exposing higher-elevation forests to the pine beetle, but ultimately limiting available area as temperatures exceed the beetles' optimal temperatures.7,111,118 As a result, the proportion of Northwest pine forests where mountain pine beetles are most likely to survive is projected to first increase (27% higher in 2001 to 2030 compared to 1961 to 1990) and then decrease (about 49% to 58% lower by 2071 to 2100).111 For many tree species, the most climatically suited areas will shift from their current locations, increasing vulnerability to insects, disease, and fire in areas that become unsuitable. Eighty-five percent of the current range of three species that are host to pine beetles is projected to be climatically unsuitable for one or more of those species by the 2060s,7,120 while 21 to 38 currently existing plant species may no longer find climatically appropriate habitat in the Northwest by late this century.121 Consequences and Likelihoods of Changes The likelihood of increased disturbance (fire, insects, diseases, and other sources of mortality) and altered forest distribution are very high in areas dominated by natural vegetation, and the resultant changes in habitat would affect native species and ecosystems. Subalpine forests and alpine ecosystems are especially at risk and may undergo almost complete conversion to other vegetation types by the 2080s (A2 and B1;122 A2;123 Ensemble A2, B1, B2;124). While increased area burned can be statistically estimated from climate projections, changes in the risk of very large, high-intensity, stand-replacing fires cannot yet be predicted, but such events could have enormous impacts for forest-dependent species.114 Increased wildfire could exacerbate respiratory and cardiovascular illnesses in nearby populations due to smoke and particulate pollution (Ch. 9: Human Health).125,126,127 These projected forest changes will have moderate economic impacts for the region as a whole, but could significantly affect local timber revenues and bioenergy markets.128 Adaptive Capacity and Implications for Vulnerability Ability to prepare for these changes varies with land ownership and management priorities. Adaptation actions that decrease forest vulnerability exist, but none is appropriate across all of the Northwest's diverse climate threats, land-use histories, and management objectives.112,129,130 Surface and canopy thinning can reduce the occurrence and effects of high severity fire in currently low severity fire systems, like drier eastern Cascades forests,131,132 but may be ineffective in historically high-severity-fire forests, like the western Cascades, Olympics, and some subalpine forests. It is possible to use thinning to reduce tree mortality from insect outbreaks,112,133 but not on the scale of the current outbreaks in much of the West. Facebook Tweet Agriculture provides the economic and cultural foundation for Northwest rural populations and contributes substantively to the overall economy. Agricultural commodities and food production systems contributed 3% and 11% of the region's gross domestic product, respectively, in 2009.134,135,136,137 Although the overall consequences of climate change will probably be lower in the Northwest than in certain other regions, sustainability of some Northwest agricultural sectors is threatened by soil erosion138,139 and water supply uncertainty, both of which could be exacerbated by climate change. Description of Observed and Projected Changes Northwest agriculture's sensitivity to climate change stems from its dependence on irrigation water, a specific range of temperatures, precipitation, and growing seasons, and the sensitivity of crops to temperature extremes. Projected warming will reduce the availability of irrigation water in snowmelt-fed basins and increase the probability of heat stress to field crops and tree fruit. Some crops will benefit from a longer growing season140 and/or higher atmospheric carbon dioxide, at least for a few decades.140,141 Longer-term consequences are less certain. Changes in plant diseases, pests, and weeds present additional potential risks. Higher average temperatures generally can exacerbate pest pressure through expanded geographic ranges, earlier emergence or arrival, and increased numbers of pest generations (for example, Ch. 6: Agriculture).142,143 Specifics differ among pathogen and pest species and depend upon multiple interactions (Ch. 6: Agriculture)144 preventing region-wide generalizations. Research is needed to project changes in vulnerabilities to pest, disease, and weed complexes for specific cropping systems in the Northwest. Consequences of Changes Because much of the Northwest has low annual precipitation, many crops require irrigation. Reduction in summer flows in snow-fed rivers (see Figure 21.2), coupled with warming that could increase agricultural and other demands, potentially produces irrigation water shortages.126 The risk of a water-short year – when Yakima basin junior water rights holders are allowed only 75% of their water right amount – is projected to increase from 14% in the late 20th century to 32% by 2020 and 77% by 2080, assuming no adaptation and under the A1B scenario.9 Assuming adequate nutrients and excluding effects of pests, weeds, and diseases, projected increases in average temperature and hot weather episodes and decreases in summer soil moisture would reduce yields of spring and winter wheat in rain-fed production zones of Washington State by the end of this century by as much as 25% relative to 1975 to 2005. However, carbon dioxide fertilization should offset these effects, producing net yield increases as great as 33% by 2080.140 Similarly, for irrigated potatoes in Washington State, carbon dioxide fertilization is projected to mostly offset direct climate change related yield losses, although yields are still projected to decline by 2% to 3% under the A1B emissions scenario.140 Higher temperatures could also reduce potato tuber quality.145 Irrigated apple production is projected to increase in Washington State by 6% in the 2020s, 9% in the 2040s, and 16% in the 2080s (relative to 1975 to 2005) when offsetting effects of carbon dioxide fertilization are included.140 However, because tree fruit requires chilling to ensure uniform flowering and fruit set and wine grape varieties have specific chilling requirements for maturation,146 warming could adversely affect currently grown varieties of these commodities. Most published projections of climate change impacts on Northwest agriculture are limited to Washington State and have focused on major commodities, although more than 300 crops are grown in the region. More studies are needed to identify the implications of climate change for additional cropping systems and locations within the region. The economic consequences for Northwest agriculture will be influenced by input and output prices driven by global economic conditions as well as by regional and local changes in productivity. Adaptive Capacity and Implications for Vulnerability Of the four areas of concern discussed here, agriculture is perhaps best positioned to adapt to climate trends without explicit planning and policy, because it already responds to annual climate variations and exploits a wide range of existing climates across the landscape.147 Some projected changes in climate, including warmer winters, longer annual frost-free periods, and relatively unchanged or increased winter precipitation, could be beneficial to some agriculture systems. Nonetheless, rapid climate change could present difficulties. Adaptation could occur slowly if substantial investments or significant changes in farm operations and equipment are required. Shifts to new varieties of wine grapes and tree fruit, if indicated, and even if ultimately more profitable, are necessarily slow and expensive. Breeding for drought- and heat-resistance requires long-term effort. Irrigation water shortages that necessitate shifts away from more profitable commodities could exact economic penalties.126 Facebook Tweet