National Park Service
U.S. Department of the Interior

Climate Change Response Program

Climate Change Impacts on Cultural Resources

Buildings in Gateway National Recreation Area's Fort Hancock Historic Landmark District were devastated by Hurricane Sandy in 2012.

Climate change is a global phenomenon that will affect, directly or indirectly, most aspects of human societies, including cultural resources. Cultural resources managed by the National Park Service (NPS) include archaeological sites, cultural landscapes, ethnographic resources, museum collections, and historic buildings and structures. These resources have always been subject to environmental forces. Climate change presents new risks for cultural resources as environmental forces become more extreme, recombine, and change. The impacts from these changes pose an especially acute problem for managing cultural resources as these resources are unique, have strong ties to place, and risk loss of integrity if moved or altered. Cultural resources are also in large part non-living and non-reproducing; once lost, they are lost forever.

Preserving our Cultural Heritage

Climate change impacts are being observed throughout the country, both in coastal zones and in the interior. Cultural resources are vulnerable to dramatic and well-publicized effects of climate change, such as sea level rise or storm surges. Evidence from across the NPS is beginning to indicate they are also vulnerable to other, longer-running processes, such as the impact of more freeze/thaw cycles on stone materials or more rapid wetting and drying cycles on adobe buildings, and the loss of traditional knowledge and lifeways. This table is a first step in identifying this broad range of impacts so that all of them can be included in stewardship practices. Given the diversity and uncertainty of climate change, this table cannot be exhaustive; other impacts and information such as thresholds will be identified as climate change develops. However, it can be used as a guide for identified impacts and motivation for continued research, monitoring, and understanding of all effects of climate change.

Hurricane Sandy debris, Gateway NRA, NY

Casa Grande Ruins National Monument, AZ

Tumacácori National Historical Park, AZ

Identifying Impacts to Cultural Resources

Purpose and Scope

The purpose of this impacts table is to succinctly describe how different manifestations of climate change will affect different types of cultural resources. The table is organized by major measurable trends of climate change, such as temperature and precipitation. Rows of the table are observable phenomena of these trends; in other words- how these trends will be felt and experienced. These phenomena are the forces to which cultural resources are being or will be exposed. Each entry within the table is an example of how a cultural resource is being or may be affected by those forces, also known as its sensitivity. The table does not include time frame or threshold information, such as when a given resource will begin to show damage from climate change stresses. In most cases, this information does not yet exist and is an important point for future research. While this table is designed to support resource managers and planners within the NPS, the resource types and associated impacts reach beyond the boundaries of parks and information throughout the table is broadly applicable to much cultural heritage around the world.

Data Sources

Climate change trends and the observable phenomena they generate (see Glossary) were derived from the U.S. National Climate Assessment (2014) and NPS unit-specific reports developed by the NPS Climate Change Response Program. The impacts in the table were identified through a combination of literature review and consultation with cultural resource management specialists. An initial draft table was compiled from literature review (Sabbioni et al. 2012 [16], Colette (ed.) 2007 [20])., which NPS experts then reviewed and expanded based on their field of expertise- Archeology, Cultural Landscapes, Ethnographic Resources, Museum Collections, Historic Buildings and Structures. Each resource section was developed by at least three experts in each field. Representatives from each field then reviewed the full table.

Further Reading

Climate Change and the Stewardship of Cultural Resources Policy Memo 14-02, National Park Service

Climate Change Response Strategy (2010), National Park Service

Climate Change Action Plan (2012-2014), National Park Service

Revisiting Leopold: Resource Stewardship in the National Parks (2012), National Park Service

Climate Change Strategy and Action Plan 2011-2014 (2011), Northeast Region, National Park Service

Applying National Park Service Management Policies in the Context of Climate Change Policy Memo 12-02, National Park Service

Alaska Region Climate Change Response Strategy 2010-2014 (2010), National Park Service

Using Scenarios to Explore Climate Change (2013) National Park Service, Climate Change Response Program

Green Parks Plan (2012), National Park Service

Glossary

Changes in Seasonality and Phenology- changes in the timing of seasonal temperatures and precipitation, which also alters the patterns and interactions of seasonal life cycle events in plants and animals.

Extreme Weather Events- weather events at high or low ends (+/-10%) of observed/"normal" range; includes storms and drastic temperature swings.

Higher Relative Humidity- increased amounts of water vapor in the air, expressed as a percentage of the amount of vapor needed for saturation of the air at the same temperature.

Higher Storm Surges/Tide- rise in sea level above normal high tide during a storm which is caused primarily by storm winds and may be exacerbated by astronomical tides.

Higher Water Table- rise in ground water levels due to higher sea levels and faster aquifer recharge rates.

Increased Coastal Erosion- the wearing away of land by wave action, river and tidal currents, rain, and wind.

Increased Flooding Events- additional and more severe flooding events due to increased or more intense rainfall and saturated water tables.

Increased Freeze/Thaw Cycles- an increase in the number of times the temperature moves back and forth across the freezing point.

Increased Global Temperatures- rise in average temperatures worldwide as a result of increased greenhouse gases in the atmosphere.

Increased Wildfire- additional and more severe fire events, fed by warmer and drier trends; increased length of fire season.

Increased Wind- more frequent and/or severe winds and wind events as a result of drastic temperature swings.

Inundation and Increased Flooding Events (Sea Level Rise)- higher standing water levels resulting from higher tides and/or decreased drainage following precipitation events.

Invasive Species/Pests- non-native species that occupy park lands directly or indirectly as the result of human activities.

Less Rainfall/Drought- a decrease in the average amount of precipitation/ a prolonged and marked period of dryness associated with less precipitation.

More Rainfall and/or Heavier Downpours- an increase in the average amount of rainfall and/or intensity of precipitation events.

Ocean Acidification- lowering of ocean pH levels due to absorption of atmospheric carbon dioxide.

Permafrost Melt- the thawing or melting of subsurface soil and rock that were previously frozen year round.

Saltwater Intrusion- the movement of salt water into fresh groundwater.

Species Shift- shifts of geographic limits of suitable habitat for plants and animals in response to temperature and/or precipitation changes.

	Impact on Cultural Resources				
	Archaeological Resources	**Cultural Landscapes**	**Ethnographic Resources**	**Museum Collections**	**Buildings & Structures**
Increased Global Temperature	· Microcracking of site contexts from thermal stress[1] · Faster deterioration of newly exposed artifacts and sites[2] · Deterioration of newly exposed materials from melting alpine snow patches[3] · Accelerated rusting in submerged and littoral resources from warmer ocean temperatures[1] · More rapid decay of organic materials[1] · Damage from increased biological activity at shallow (~<100m) underwater sites[61] · Increased risk of damage due to decline/loss of protective sea grass or nearby coral reefs[61,62]	· Decline/disappearance of some vegetation species, other species favored[4] · Heat stress on culturally significant vegetation[4] · Increased stress (e.g. desiccation, warping, cracking, etc.) on constructed landscape features[4]	· Loss of necessary habitat for culturally significant species[4] · Potential loss of culturally significant species due to increased disease threat[5] · Changes in prevalence of culturally relevant plant and animal species[60] · Changes to crop yields and food security[6] · Limited winter hunting from increased winter snows[5] · Limited access to hunting areas due to reduced sea ice[7] · Altered place meaning due to loss of snow pack[7]	**Facilities** · Increased stresses on HVAC systems in storage facilities[8] · Increased space constraints due to more items requiring protection in storage facilities[8] · Increased need for environmental controls in facilities/house collections[9] **Collections (without appropriate climate controls)** · Increased rate of chemical decay[11] · Increased stress due to fluctuations in environmental conditions[10]	· Increased crystallization of efflorescent salts due to increased evaporation rates, leading to increased rates of structural cracking, deterioration[1] · Increased demand for complex air conditioning systems that can add stress to the building envelope and often requires significant alterations to a structure (including insulation, routing of extensive ducts and pipes, etc.)[12]
Increased Freeze/Thaw Cycles	· More rapid decay of organic materials[1] · Disruption of soil structure, especially in permafrost[26] · Destruction of archaeological deposits due to increased soilifluction (downhill flow of saturated soil) activity[3] · Increased rates of deterioration in metals from thermal stress[27]	· Decline/disappearance of some vegetation species due to recurrent freezing[4] · More rapid deterioration of constructed materials of landscape features (e.g. corrosion, decay, desiccation)[4]	· Food stress or starvation of foraging animals (horse, caribou) from impenetrable ice layers more likely to form on grazing fields[5]	**Facilities** · Surface cracking, flaking, and sugaring building stone and spalling of brick due to increase in wet-frost[1,10, 16] · Greater structural damage due to fluctuating environment, causing cracks in building that allow more access for pests to invade and damage collections[10]	· Surface cracking, flaking, and sugaring of building stone and spalling of brick due to increase in wet-frost[1,10,16] · Damage to foundations due to increased frost heave action[1] · Spalling and collapse of caves and bedrock alcoves onto structures inside them[22] · Increased absorption of salts from road and sidewalk treatments which can lead to efflorescence, cracking, and spalling, etc.[12]
Permafrost Melt	· Loss of artifacts and contexts from increased erosion[6] · More rapid decay of organic materials[26] · Disruption of stratigraphy from changed soil structure, solifluction[52]	· Decline/disappearance of some vegetation species[4] · More rapid decay, dessication of constructed materials of landscape features[4]	· Destruction of land and buildings due to increased coastal erosion[6] · Forced relocation of communities[5] · Loss of access to wildlife corridors due to terrain that can no longer be traversed by foot or vehicle[15]	**Facilities** · Destabilization of buildings from cracks in foundations and other infrastructure[10]	· Destabilization of buildings; settlement into the ground[6,16] · More rapid decay of organic building materials[16,48] · Change in use or abandonment due to changes in access as the surrounding ground becomes boggy[22]
Higher Relative Humidity	· More rapid decay of organic materials[16] · Increased corrosion of vulnerable/less stable metals[2] · Increased mold, especially in enclosed sites (e.g. vaults, tumuli, and caves)[2]	· Decline/disappearance of critical vegetation species, other species favored[4] · Increased desiccation, warping, and cracking of constructed landscape features[4]	· Decline/disappearance of important vegetation species, other species favored[4] · Increase/spread of some vegetation species[4]	**Facilities** · Increased wear on HVAC systems, and energy use to stabilize drastic changes in humidity[28] **Collections (without appropriate climate controls)** · Increased rusting/corrosion of metals[16] · Damage to paintings[8] · Warping, cracking of wood[16] · Damage to archival, paper, book, and photo collections[10] · Increased risk of mold, especially organic collections[10] · Increased salt damage to ceramics with humidity fluctuations[11] · Increase in pest populations[29] · Accelerated deterioration of museum items exhibited outside[19]	· For brick and porous stone, increased moisture absorption, leading to increased risk of frost damage, mold growth, and stress from salt crystalization[16] · Decrease in crystallization and dissolution of salts within stone and masonry[16] · Sulfur dioxide deposits on wet/damp surfaces, corroding stone, metal, and glass[16] · Swelling and cracking of wooden building materials and architectural features[16] · Increased growth of destructive organisms (e.g. mold, algae) for wood, stone, and masonry[16,22] · Increased potential for rot in wood and other organic material[16]
Increased Wind	· Increased moisture penetration into porous materials[20] · Burial through redistribution of soil[14] · Abrasion of petroglyph and pictoglyphs[14] · Erosion and deflation archeological deposits[2]	· Damage or loss of culturally significant plants[4] · Change in historic/culturally significant vegetation patterns[4] · Increase in need for protective structures that shelter landscapes[4]	· Reduced access to marine hunting grounds due to stronger/unusual wind patterns and shifting sea ice[7] · Reduced access to animals in open spaces due to wind chills that drop temperatures[15]	**Collections** · Damage to wooden, paper, textile and organic objects from decreased relative humidity[10]	· Direct wind damage[16] · Scouring/abrasion of exterior surfaces[1] · Increased cracking, spalling, splintering, weathering of buildings due to accelerated drying[1] · Damage from wind borne debris[2]

	Impact on Cultural Resources				
	Archaeological Resources	Cultural Landscapes	Ethnographic Resources	Museum Collections	Buildings & Structures
Increased Wildfire	**During Fire** · Damage or destruction of associated structures[30] · Heat alteration of artifacts[30] · Heat fracturing of stone artifacts[30] · Paint oxidation, color change[30] · Physical damage from firefighting efforts (fire lines)[30] · Decreased accuracy of carbon-14 dating due to carbon contamination[30] **Post-Fire** · Damage from fire-killed tree fall[30] · Increased susceptibility to erosion and flooding[31] · Increased looting after fire exposure[31]	· Loss or damage of associated structures[23] · Change in vegetation density and composition[4] · Bedrock and border spalls[23] · Increased susceptibility to erosion and flooding[23] · Loss of soil fertility due to high heat[23] · Damage to structure and/ or associated cultural lindscape from fire retardants[22]	**During Fire** · Discoloration, exfoliation, spalling, and smudging of culturally significant rock images, geoglyphs[30] · Change in subsistence resources over large areas[15] · Loss of traditional knowledge due to change/ loss of culturally significant resources[15] · Loss of critical and/or culturally significant species due to decreased soil fertility from high heat[30] **Post-Fire** · Altered migratory patterns of traditionally hunted animals[6] · Significant alteration of landscape features critical for navigating during foraging, hunting, or other necessary movements[30]	**Facilities** · Damage to storage facilities and contents[8] · Increased strain on existing museum facility and staff due to increased advance preparation and salvage operations[32] · Smoke damage, strain on HVAC systems[29] **Collections** · Damage to items and disassociation of materials and records during emergency evacuations[11]	**During Fire** · Damage or loss of whole structures, or combustible components[22] · Cracking, physical damage of masonry components from extreme thermal stress[30] · Discoloration caused by smoke and/or heat[30] · Damage from fire-killed tree fall[30] · Damage to structure and/or associated cultural landscape from fire retardants[22] **Post-Fire** · Buildings may shift or settle due to associated erosion[33,22] · Pressure to change character defining features such as wood shake roofing to fire resistant alternatives[34]
Changes in Seasonality and Phenology	· Site disruption from longer growing seasons and/or changing land use (irrigation use, harvest times)[13] · Changes in site or regional accessibility[14] · Reductions or alterations in length and timing of archaeological field seasons, affecting capacity for identification or mitigation of climate and other impacts[14] · Possible reductions in site visibility[14]	· Loss of synchronicity between species[54] · Altered landscapes due to shifts in blooming times[54] · Loss of pollinators reduces plant fertility in historic agricultural landscapes[4]	· Loss of synchronicity between species[54] · Potential loss or reduction of plants used for medicine and ceremonies performed at particular times of the year[15] · Loss of plants used for ceremonies, medicine, and food due to early frosts[15] · Shifts in migratory patterns of significant marine animals due to changes in sea ice[7] · Limited access to winter marine hunting areas due to longer summers[7] · Food sources threatened by shifts in harvest time (esp. feed for herd animals)[5]	**Facilities, Collections** · Increased stress on buildings and materials due to increased range of temperature swings during seasonal transitions (particularly collections without appropriate climate controls)[9]	· Longer growing seasons lead to increased growth of invasive vegetation[12]
Species Shift	· Physical damage, loss of integrity, and spatial coherence from new/ increased plant growth[16] · Physical impacts from associated adaptive behavior of animals following plant species movements[2] · Disruption from new foraging or nesting animals, including insects[2] · Changes in soil chemistry due to root penetration of new vegetation[17] · Increased shrub growth on former tundra, may obscure features and artifacts[3] · Possible reductions in site visibility[14]	· Changes in historic/ culturally significant vegetation patterns[4] · Emigration and/or local extinction of culturally significant species[5] · Changes in landscape appearance from altered growth patterns of lichen[16]	· Loss of major food sources[42] · Loss of culturally significant plant and animal species[5] · Altered appearance of important ceremonial sites[42] · Breaks in memory, traditions, and context due to loss of species, species access, resource predictibility[18]	**Collections** · Increased need to expand voucher specimens (used for reference) in collection[19] · Increased need to identify existing voucher specimens, many uncatalogued in non-federal repositories, to serve as baselines[19]	· Increased growth of destructive organisms as temperatures warm (e.g. mold, algae)[1] · New threats to historic structures as incoming/ colonizing species use them as habitat[22] · Spread of destructive vegetative species (like kudzu) farther north into new areas[12] · Loss of species that are necessary for historically appropriate repairs[20] · New/different micro-organisms cover surfaces of stone buildings - may reduced deterioration (possible benefit)[21]
Invasive Species/Pests	· Physical damage, loss of integrity and spatial coherence from altered habitat structure[16] · Data loss, subsidence, feature collapse, structural damage from invasive consuming organics[2] · Damage from new and increased number of burrowing animals[23] · Possible reductions in site visibility[14]	· Potential loss of significant plants due to introduction of new pests[4] · Potential biological selection pressure for incompatible vegetation or other biotic species [4] · Changes in viewsheds (e.g. battlefield parks)[24]	· Damage to distribution of subsistence crops, culturally significant plants[5] · Loss of culturally important animals due to changes in habitat from invasive plant spieces[15]	**Facilities** · Need for updated integrated pest management plans to account for new pest risks[11] · Invasion of pests via new routes created by thermal stress on facility[11] **Collections** · Increase in pest populations that damage organic materials (animal skins, wool)[11]	· New threats to wood structures and wooden architectural features as termites and other pests expand territory due to warmer, longer summers[25] · Spread of destructive vegetative species (like kudzu) farther north into new areas[12]

Precipitation Change

	Impact on Cultural Resources				
	Archaeological Resources	**Cultural Landscapes**	**Ethnographic Resources**	**Museum Collections**	**Buildings & Structures**
Less Rainfall/Drought	· Loss of stratigraphic integrity due to crack/heave damage in drier soils[17] · Destabilization of wetland or waterlogged sites[13] · Exposure of submerged sites due to lower water levels in lakes[14] · Sites more vulnerable to fire and wind[14] · Increased exposure from vegetation loss and erosion[14]	· Water stress may inhibit growth of some species[4] · Decline/disappearance of some vegetation species; other species favored[4] · Soil infertility due to decreased microbial activity[4] · Limited water supply inhibits established maintenance practices[17] · Increased soil erosion[4] · Challenges to current irrigation practices[4]	· Stress on culturally significant species impacts subsistence practices[6] · Indirect effects to ceremonial cycles and religious practices involving weather control[15] · Decline/disappearance of important vegetation species, other species favored[23] · Loss of some harvestable animals[15] · Disruption of social networks dependent upon regular water supplies (transportation)[15] · Loss of regular sources of water for drinking, medicine, ceremony, paints, etc.[15] · Loss of culturally relevant plants and animals[15] · Limitation on travel due to loss of water sources[15]	**Facilities** · Limited water supply for cooling, landscaping, other equipment[8] · Reduced humidity stress on building (possible benefit)[23] **Collections (without appropriate climate controls)** · Damage to wooden, paper, textile and organic objects from drying due to lower relative humidity[10]	· Increase in dry salt deposits near masonry and porous stone which hydrate and infiltrate during infrequent rain events causing spalls and fractures[12,1] · Reduced humidity stress on buildings (possible benefit)[23] · Cracking and splitting of wooden/organic features due to complete drying[12]
More Rainfall and/or Heavier Downpours	· Site erosion from overflow and new flood channels[17] · Soil destabilization/shifting (ground heave, landslide, subsidence)[14] · Damage to unexcavated artifact and site integrity from direct force of water[35]	· Increased tree fall due to waterlogging[17] · Limited ability to plant in waterlogged soil[4] · Loss of historical integrity with improved drainage systems[17] · Decline/disappearance of some vegetation species[4] · Decreased soil fertility from erosion, waterlogging, leaching[4] · Loss of landscape features[4] · Increased susceptibility to destructive fungi[36] · Erosion of earthworks[24] · Disruption or delay of traditional maintenance practices (e.g. burning)[24]	· Altered harvest times, especially haying in herd cultures due to changes in precipitation patterns[5] · Delays in planting cycles, shifting whole agricultural calendar[6] · Increasing difficulty in predicting storms[37] · Indirect effects to ceremonial cycles and religious practices involving weather control[15]	**Facilities** · Added strain on existing museum facilities and staff due to salvage operations[32] · Potential leaks in collection storage areas and potential wetting of museum objects[10] · Increased cracking associated with ground heave and subsidence; destabilization of buildings and pipes[10] **Collections (without appropriate climate controls)** · Increase risk of mold, especially organic collections[10] · Increase rusting/corrosion of metals[10] · Humidity damage to paintings[10] · Warp, crack, damage wood[10] · Humidity damage to archival, paper, book, and photo collections[10]	· Swelling/distortion of wooden building materials and architecture features due to wetness and damp[38] · Increased risk of rot and fungal/insect attack[38] · Historic building drainage systems unable to cope with downpours[17] · Erosion of supporting ground around structure[38] · Sewage backup and overflow leading to saturation and related flooding, contamination and damage[22] · Increased rates of deterioration due to increase frost events in cold regions that were formerly dry[21] · Accelerated decay of masonry units and mortars due to increased extremes of wetting and drying[39] · Cracks in building infrastructure and associated destabilization of buildings and pipes due to ground heave and subsidence/ shrink swell soils[10] · Severe damage and loss of historic structures made of adobe[12] · Spalling, weathering of wood, brick, and stone materials due to salt infiltration during drying[1] · Corrosion of external masonry from agricultural runoff[40] · Increased pressure to relocate or elevate structures, and/or surrounding structures[23]
Increased Flooding Events	**During Flood** · Direct physical damage to site, from floating materials during floods[14] · Destruction/loss of artifacts during flooding[16] · Site erosion from overflow and new flood channels[17] **Post-Flood** · Increased risk of post-flood subsidence[17] · Impacts from post-flood mitigation (clean up, construction)[14]	· Wash out or damage to roads, trails, and landscape features throughout parks[4] · Decline/disappearance of important vegetation species, other species favored[4] · Loss of landscape features[4]	· Loss of cultural places due to inundation/saturation[5] · Loss/disruption of the use of foraging grounds[5] · Loss of both plant and animal species for subsistence, medicine, ceremony, etc[15] · Degradation of vital coral reef habitats from increased sediment discharge[42]	**Facilities** · Added strain on existing museum facilities and staff due to salvage operations[32] · Damage to items and disassociation of materials and records during emergency evacuations[19] · Structural collapse from moving force of floodwaters, particularly from flash floods[41] · Sewage backup and overflow leading to saturation and related flooding, contamination and damage[22] · Walls "implode" from hydrostatic force of standing water[41] · Damage to utilities, generators, and electrical systems[51] **Collections** · Increased rusting/corrosion of metals[10] · Increased risk of rot/insect attack, mold and mildew[10,16] · Swelling/distortion of absorbent objects (such as wood) due to wetting[10,38] · Widespread, unpredictable direct damage and destruction from flood waters[10]	**During Flood** · Structural collapse from moving force of floodwaters particularly during flash floods[41] · Sewage backup and overflow leading to saturation and related flooding , contamination and damage[22] · Walls "implode" from hydrostatic force of standing water[41] · Damage to utilities, generators and electrical systems[51] **Post-Flood** · Increased risk of rot, fungal/insect attack, mold and mildew[38] · Swelling/distortion of wooden building materials and architecture features due to inundation[38] · Spalling, weathering of wood, brick, and stone materials due to salt infiltration during drying[1] · Corrosion of external masonry from agricultural runoff[40] · Increased pressure to relocate or elevate structures, and/or surrounding structures (may also be pre-flood)[23]

	Impact on Cultural Resources				
	Archaeological Resources	Cultural Landscapes	Ethnographic Resources	Museum Collections	Buildings & Structures
Inundation and Increased flooding events	· Total submersion of coastal sites[20] · Downstream movement of items due to undercut shoreline sediments[4] · Changes in pH of buried artifacts and/or buried environments[20] · Reduced site integrity due to ground heave and subsidence[14] · Increased risk of looting from exposure[14] · Increased erosion of sites due to encroaching water levels, wave action exposure, and increased exposure to wet/dry cycles[36]	· Variable damage/ loss of organic and inorganic materials and landscape features[20] · Decline/ disappearance of some vegetation species, other species favored[4] · Soil erosion[4] · Soil infertility due to waterlogged, anaerobic conditions[4]	· Loss of or limited access to traditional places[43] and culturally important sites (e.g. burial grounds, subsistence areas)[48] · Loss of plant and animal species for subsistence, medicine, ceremony, etc[15,20] · Submersion of homelands in island and coastal communities[42] and corresponding stresses to and loss of social connections and interactions [20]	**Facilities** · Added strain on existing museum facilities and staff due to salvage operations[32] · Increased cracking associated with ground heave and subsidence[10] · Potential leaks in collection storage areas and potential wetting of museum objects[10] **Collections** · Increase risk of mold[10] · Increase rusting/corrosion of metals[10] · Damage and destruction post-flood from humidity and moisture[28]	**During Flood** · Submersion of coastal sites[22] · Increase in nuisance flooding leading to problems of access and higher likelihood of range of flood damage[53] · Damage to or overwhelming of drainage systems, leading to associated building damage[53] **Post-Flood** · Deterioration/corrosion of infrastructure not designed for inundation or salt water exposure[53] · Increased cracking due to associated ground heave and subsidence[10] · Crystalization of salts introduced to buildings by seawater[22] · Disassociation of historic districts, settings due to increased pressure to relocate or elevate structures or surrounding structures[23] · Loss of access leading to loss of use[60] (See also: Precipitation: More Rainfall/Heavier Downpours, Increased Flooding Events; Sea Level Rise: Storm Surge)
Increased Frequency and/or Severity of Storm Surges	**During Surge:** · Destruction - total site loss[17] · Erosion from wave action[17] **Post-Surge** · Disturbance or removal during response and clean-up[14] (See also: Precipitation: Increased Flooding Events)	· Immediate alteration/ destruction of historic landscape[44] · Decline/ disappearance of some vegetation species, other species favored[4] · Soil infertility from soil erosion, loss of topsoil[4] · Loss of landscape features[4]	· Increased risk of inundation of homes and towns, esp. during unpredictable and extreme weather[42] · Increased risk of loss of natural and cultural resources[15] · Increased risk of loss of traditional knowledge associated with natural and cultural resources affected[15]	**Facilities** · Added strain on existing museum facilities and staff due to emergency operations[22,54] · Damage to utilities, generators and electrical systems[51] · Structural collapse from moving force of storm surge[41] · Changes to surrounding landforms or vegetation, which may affect future drainage[38] **Collections** · Damage to items and dissociation of materials and records during emergencyevacuations[19] · Increase risk of rot, fungal/insect attack, mold and mildew[10] · Increase rusting/corrosion of metals[10] · Widespread damage and dissociation from flood waters[10] (See also: Precipitation: Increased Flooding Events)	**During Surge** · Structural damage or collapse from moving force of storm surge[41] · Damage to utilities, generators and electrical systems[51] **Post-Surge** · Cracks in building and associated destabilization of buildings and pipes due to ground heave and subsidence/shrink-swell soils[10] · Erosion of supporting ground around structure[38] · Changes to surrounding landforms, which may affect future drainage[38] · Increased pressure to relocate or elevate structures, and/or surrounding structures (may also be pre-flood)[23] (See also: Precipitation: More Rainfall/Heavier Downpours, Increased Flooding Events)
Increased Coastal Erosion	· Full loss of coastal sites and artifacts[17] · Partial loss of sites and artifacts[14] · Exposure of new and known archeological sites[16] · Altered erosion patterns from reduction/changes in Arctic sea ice[3] · Increased risk of looting from exposure[14]	· Decline/ disappearance of some vegetation species, other species favored[4] · Soil infertility from loss of topsoil[4] · Loss or compromise of associated structures[23]	· Loss of cultural memory and connections to homeland due to increased migration and splitting of traditional communities[42] · Loss of culturally significant symbols, plants, and animals[6] · Increased risk of loss of traditional knowledge associated with both natural and cultural resources[15]	**Facilities** · Limited storage capacity to protect growing numbers of at-risk artifacts[54] · Added strain on existing museum facilities and staff due to salvage operations[32]	· Loss or compromise of structure[23] · Increased pressure to relocate or elevate structures, and/or surrounding structures[23] · Increased rusting, corrosion, and salt deposits due to increased salt in the environment as the coastline encroaches[12]
Higher Water Table	· Damage to artifacts, stratigraphy, soil features from saturation of site from below[14]	· Decline disappearance of important vegetation species, other species favored[4] · Soil infertility due to waterlogged, anaerobic conditions[4]	· Loss of or limited access to culturally important sites (eg burial grounds)[18] · Decrease in productivity of arable land[15]	**Facilities** · Potential for higher relative humidity levels in collections storage areas[10] · Increased risk of rising damp/rot from higher water tables[17]	· Rising damp, often marked by efflorescence/ salt deposits[12] · Rot of subsurface components from higher water table[17] · Flooding damage in basements and other below grade features[22] · Structural damage due to buoyant forces[12]

Combined Stressors

	Impact on Cultural Resources				
	Archaeological Resources	**Cultural Landscapes**	**Ethnographic Resources**	**Museum Collections**	**Buildings & Structures**
Salt Water Intrusion	· Deterioration of some artifacts due to change in surrounding soil and water chemistry[14,20] · Compromise of the site due to changes in soil and water chemistry[14,22]	· Decline/disappearance of important vegetation species[4] · Soil infertility[4]	· Reduction in or loss of habitat for culturally significant pants and animals[6] · Loss of drinking water supplies[6] · Loss of arable land for growing crops[15] · Loss of some harvestable animals[15]	**Collections** · Increased risk of corrosion/ rusting[10]	· Increased risk of corrosion/rusting[16] · Introduction of additional salts into the ground and into building materials[22]
Extreme Weather Events	· Erosion of coastal sites due to higher, stronger storm surges[17] · Disturbance/exposure/ burial due to stronger wave action[45] · Deflation or abrasion due to stronger winds[2,14] · Disturbance or removal during response and clean-up[14] · Destabilization/damage to underwater sites through movement of sediment and/or protective vegetation[62] (See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)	· Immediate alteration/ destruction of historic landscape[44], particularly trees[57] · Decline/dissappearance of some vegetation species, other species favored[4], particularly colonizing species in disturbed areas[57] · Reduction in or loss of access due to washing out or damage to roads, trails, and landscape features[4] (See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)	· Potential straining of connections between traditional knowledge and extreme events[37,47] · Limited access to cultural sites due to increased closures of parks and other areas[13] · Need for new emergency response plans due to changes in hurricane strengths and tracks[9], and surrounding land use practices[49] (See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours, Increased Flooding Events; Sea Level Rise: Increased Storm Surge)	**Facilities** · Direct damage from wind and wind-blown rain[8,54] · Damage from wind-borne debris[2] · Limited relocation opportunities due to growing demands for storage facilities[51] · Added strain on existing museum facilities and staff due to salvage operations[32] · Cracked pipes and swelling due to large and rapid temperature swings[54] (See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)	· Added stress from sudden thermal expansion/shock[16] · Direct damage from wind-blown rain[54] · Damage from wind-borne debris[2] · Cracked pipes and swelling due to large temperature swings[54] (See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)
Pollution	· Rusting due to increased CO2 exposure[16] · Artifacts threatened by pesticides used to combat invasive species[59]	· Dissolution of stone due to increases in acid rain, particulate matter, and ground-level ozone[26] · Decline/disappearance of some vegetation species inc. favored[4] · Soil infertility due to toxicity and depletion of nutrients[4] · Loss of landscape features, especially plantings, buildings[4]	· Bleaching/damage to coral reefs[42] · Reduction or loss of culturally significant view sheds[4] · Increased difficulty for young and elderly people to perform outdoor harvesting tasks[15] · Potential erosion or deterioration of pictographs still visited by contemporary peoples for prayer or ceremony[15]	**Facilities** · Increased need for special air filtration for repositories[19] **Collections** · Corrosion of metal objects and films: pitting and perforation, deterioration/ loss of coating[48]	· Erosion of carbonate stones due to acidic precipitation[1] · Continued stone blackening[1] · Increased chemical weathering of stone materials due to altered atmospheric composition[21] · Cracked walls and increased water penetration due to corrosion[48]
Development	· Disruption/damage from fire management (eg fire lines)[30] · Disruption/damage from changing land use[30] · Degraded site integrity due to climate change mitigation (eg construction of levees and dams, dredging)[35] · Increased risk of looting or vandalism[23] · Heightened vulnerability to landslides due to land use changes and increased rainfall and runoff pressures[50]	· Increased abundance of invasive species along roadways[4] · Degraded integrity of historic viewsheds[4] · Loss of undeveloped buffer areas around cultural landscapes[4] · Loss of culturally significant plants from soil compaction, limited root zones, temperature stress from heat island effect, high urban soil contaminant levels[36] · Loss of adjacent natural habitat for native species[36]	· Increased development in Arctic due to warmer conditions[6] · Loss of food sources due to habitat loss, fragmentation, over-exploitation[46] · Reduction or loss of adaptive flexibility due to development encroachment[6] · Loss of access to traditional cultural places, including landscapes[15] · Loss of coral reefs critical for tropical fish habitats needed for local subsistence and marine tourism[42] · Loss of ancestral homelands that are considered sacred[15] · Loss of traditional knowledge associated with natural and cultural features on the landscape[15]	**Facilities** · Added strain on existing museum facilities and staff due to environmental research compliance and salvage operations[32,23] · Potential for fracking-induced earthquake damage[29]	· Increased conflicts of land-use needs due to population growth/ urbanization[58] · Loss of historic character due to changes to the site or setting[63]

Increased GHG Emissions

	Impact on Cultural Resources				
	Archaeological Resources	**Cultural Landscapes**	**Ethnographic Resources**	**Museum Collections**	**Buildings & Structures**
Ocean Acidification	· Metal corrosion in submerged resources[45] · Degradation of stonework, especially limestone and mortar in coastal areas[2] · Possible acceleration in cliff erosion where cliffs have lime or shell components[55] · Increased risk of damage to shipwrecks due to loss/decline of protective concretions and/ or nearby coral reefs[61,62]	· Coastal soil erosion/ infertility[4] · Loss or deterioration of culturally significant landscape features[4]	· Decline in reefs, vital to subsistence cultures, from coral bleaching[56] · Physical abnormalities, including weakened shells, in traditional food sources[42] · Weakened/destroyed local economies dependent on shellfish supplies[51] · Possible increased degradation of rock art along shores that is sacred to and visited by contemporary peoples[15]	*Impacts not identified*	*Impacts not identified*

Citations

1. Stein, Eric and Kendall, Rick. 2013. "Historic Structures and Climate Change: How Long is Perpetuity?" Saint-Gaudens National Historical Site, National Park Service.

2. David Gadsby, Archaeologist, National Park Service. Personal communication, March 19, 2014.

3. Jeffrey Rasic, Chief of Resources, Gates of the Arctic National Park & Preserve, National Park Service. Personal communication, March 13, 2014.

4. Susan Dolan, Program Manager, Park Cultural Landscapes, National Park Service. Personal communication, December 12, 2013.

5. Crate, Susan A. 2008. "Gone the Bull of Winter? Grappling with Cultural Implications of and Anthropology's Role(s) in Global Climate Change." *Current Anthropology* 49(4):569-95.

6. Nakashima, D. J., K. Galloway McLean, H. D. Thulstrup, A. Ramos Castillo, and J. T. Rubis. 2012. *Weathering Uncertainty: Traditional Knowledge for Climate Change Assessment and Adaptation*. Paris: UNESCO and Darwin: UNU.

7. Ford, James D., Barry Smith, Johanna Wandel, Allurut Mishak, Kik Shappa, Harry Ittursarjuat, and Kevin Qrunnut. 2008. "Climate Change in the Arctic: Current and Future Vulnerability in Two Inuit Communities in Canada." *The Geographic Journal* 174(1):55.

8. Ron Wilson, Chief Curator, National Park Service. Personal communication, November 21, 2013.

9. Stephanie Stephens, Senior Curator, Alaska Regional Office, National Park Service. Personal Communication, March 26, 2014.

10. Linda A. Blaser, Associate Manager, Museum Conservation Services, Harpers Ferry Center, National Park Service. Personal communication, December 10, 2013.

11. Brynn Bender, Senior Conservator, Conservation Laboratory, National Park Service. Personal communication, April 18, 2014.

12. Jenny Parker, Architectural Historian, National Park Service. Personal communication, March 3, 2015.

13. Hyslop, Ewan. 2013. "Climate Change and Cultural Heritage: The Challenge Facing Historic Scotland." Lecture at Centre for Sustainable Heritage, University College London, March 21.

14. Teresa Moyer, Archaeologist, National Park Service. Personal communication. February 17, 2015.

15. Mark Calamia, Cultural Resources Program Manager & Tribal Liaison, Pipestone National Monument, National Park Service. Personal communication, February 27, 2015.

16. Sabbioni, C, Peter Brimblecombe, May Cassar, and Noah's Ark (Project). *The Atlas of Climate Change Impact on European Cultural Heritage: Scientific Analysis and Management Strategies*. London; New York: Anthem 2010: 22.

17. Cassar, May. 2005. *Climate Change and the Historic Environment*. London: Centre for Sustainable Heritage, University College London.

18. Rachel Mason, Senior Cultural Anthropologist, Alaska Regional Office, National Park Service. Personal communication, March 25, 2014.

19. Tef Rodeffer, Program Manager, Museum Services, Western Archaeological Conservation Center, National Park Service. Personal communication, February 27, 2015.

20. Colette, Augustin (editor). 2007. *Climate Change and World Heritage: Report on Predicting and Managing the Impacts of Climate Change on World Heritage and Strategy to Assist State Parties to Implement Appropriate Management Response*. Paris: UNESCO World Heritage Centre.

21. Viles, Heather A. 2002. Implications of Future Climate Change for Stone Deterioration. In Natural Stone, Weathering Phenomena, Conservation Strategies and Case Studies, Special Publication 205, edited by S. Siegesmund, S. A. Vollbrecht and T. Weiss, 407-18. London: Geological Society of London.

22. Randy Skeirik, Historical Architect, Vanishing Treasures Program, National Park Service. Personal communication, February 23, 2015.

23. Marcy Rockman, Climate Change Adaptation Coordinator for Cultural Resources, National Park Service. Personal communication, April 29, 2014.

24. Kristen Allen, Resource Manager, Richmond National Battlefield Park, National Park Service. Personal communication, February 28, 2014.

25. Lang, Sang Hee and Tae Soon Chon. 2011. "Effects of Climate Change on Subterranean Termite Territory Size: A Simulation Study." *Journal of Insect Science* 11(80):1-14.

26. Grossi, C. M. and P. Brimblecombe. 2007. "Effect of Long-Term Changes in Air Pollution and Climate on the Decay and Blackening of European Stone Buildings." Special Publications 127:117-130. London: Geological Society.

27. Jay Sturdevant, Archaeologist, Midwest Archaeological Center, National Park Service. Personal communication, March 19, 2014.

28. Samantha Richert, Curator, North Cascades National Park, National Park Service. Personal communication, March 27, 2014.

29. Stephen Damm, Museum Specialist, National Park Service. Personal communication, February 23, 2015.

30. Ryan, Kevin C., Ann Trinkle Jones, Cassandra L. Koerner, Kristine M. Lee (eds). 2012. *Wildland Fire in Ecosystems: Effects of Fire on Cultural Resources and Archeology*. General Technical Report RMRS-GTR-42 volume 3. Fort Collins: Forest Service.

31. Yosemite National Park. 2015. "Cultural Resources and Fire."Accessed November 12. http://www.nps.gov/yose/historyculture/cultural-fire.htm

32. Christopher Houlette, Museum Curator, Yukon-Charley Rivers National Preserve, National Park Service. Personal communication, March 26, 2014.

33. *Mesa Verde: Archeology and Fire*. 2007. National Park Service. Available at: https://www.nps.gov/meve/learn/management/upload/arch_fire_effects.pdf.

34. Sueann Brown, Historical Architect, Pacific West Region, National Park Service. Personal communication, February 24, 2015.

35. Howard, A. J., K. Challis, J. Holden, M. Kincey, and D. G. Passmore. 2008. "The Impact of Climate Change on Archaeological Resources in Britain: A Catchment Scale Assessment." *Climactic Change* 91(3-4):414

36. Barrett, Shannon Taylor. 2013. *Climate Change and Historic Trees: Adaptive Strategies for Land Managers*. Master's thesis, Middle State Tennessee University.

37. Berkes, Fikret and Dyanna Jolly. 2001. "Conservation Ecology: Adapting to Climate Change: Social-Ecological Resilience in a Canadian Western Arctic Community." *Conservation Ecology* 5(2):18.

38. Pickles, David. 2010. *Flooding and Historic Buildings*. London: English Heritage.

39. Historic Scotland. 2012. *A Climate Action Plan for Historic Scotland 2012-2017*. Edinburgh

40. Sanders, C. H. and M. C. Phillipson. 2003. "UK Adaptation Strategy and Technical Measures: The Impacts of Climate Change on Buildings." *Building Research & Information* 31(3-4):213.

41. Federal Emergency Management Agency (FEMA). 2008. *Floodplain Management Bulletin*. FEMA P-467-2.

42. Lefthand-Begay, Clarita, Kalei Nu'uhiwa, Ted Herrera, and Nelson Kanuk. 2012. *Witnesses to Climate Change: Our Reflections on the 2012 First Stewards Symposium*. Available at www.firststewards.org.

43. Holz, Debra, Adam Markham, Kate Cell, and Brenda Ekwurzel. 2014. *National Landmarks at Risk: How Rising Seas, Floods, and Wildfires are Threatening the United States' Most Cherished Historic Sites*. Washington, DC: Union of Concerned Scientists.

44. Caffrey, Maria and Rebecca Beavers. 2013. "Planning for the Impact of Sea Level Rise on U.S. National Parks." *Park Science* 30(1):6-13.

45. Dunkley, Mark. 2013. "Oceanic Climate Change and Underwater Archeology." September 12. *Heritage Calling: An Historic England Blog*. https://heritagecalling.com/2013/09/12/oceanic-climate-change-and-underwater-archeology/.

46. National Fish, Wildlife and Plants Climate Adaptation Partnership. 2012. *National Fish, Wildlife and Plants Climate Adaptation Strategy*. Washington, DC: Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service.

47. Shaw, Rajib, Noralene Uy, and Jennifer Baumwoll. 2008. *Indigenous Knowledge for Disaster Risk Reduction: Good Practices and Lessons Learned from Experiences in the Asia Pacific Region*. United Nations, Bangkok: International Strategy for Disaster Risk Reduction.

48. Watt, John, Johan Tidbald, and Vladimir Kucera. 2009. *The Effects of Air Pollution on Cultural Heritage*. New York: Springer

49. Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, (eds). 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. Washington, DC: U.S. Global Change Research Program.

50. National Geographic. 2014. "Surveying Landslides in the U.S." Accessed May 27, 2014. http://news.nationalgeographic.com/news/2014/04/140422-surveying-american-landslides-interactive/.

51. Jennifer Nersesian, Superintendent, Gateway National Recreation Area, National Park Service. Personal communication, August 19, 2014.

52. Brimblecombe, Peter and Carlota M. Grossi. 2007. "Damage to Buildings from Future Climate and Pollution." *APT Bulletin* 38(2-3):16.

53. Sweet, William, Joseph Park, John Marra, Chris Zervas, Stephen Gill. 2014. *Sea Level Rise and Nuisance Flood Frequency Changes around the United States*. NOAA Technical Report NOS CO-OPS 073. Silver Spring: National Oceanic and Atmospheric Administration.

54. Rick Kendall, Superintendent, Saint-Gaudens National Historic Site, National Park Service. Personal communication, August 12, 2012.

55. Newland, Michael. 2013. T*he Potential Effects of Climate Change on Cultural Resources with Point Reyes National Seashore, Marin County, California*. Rohnert Park: Archaeological Services Center, Sonoma State University.

56.Nature Conservancy. 2015. "Reef Resiliency: Bleaching Impacts." Accessed July 9. http://www.reefresilience.org/coral-reefs/ stressors/bleaching/bleaching-impacts/.

57. Britt, Tad. 2013. "Archeology Sites After Disasters." National Center for Preservation Technology and Training. Accessed August 27. https://ncptt.nps.gov/blog/archaeological-sites-after-disaters/.

58. Hsiang, Solomon M., Marshall Burke, and Edward Miguel. 2013. Quantifying the Influence of Climate on Human Conflict. *Science* 341: 1235367.

59. National Center for Preservation Technology and Training. 1998. *Archaeological Site Revegetation, Organochloride-Based Pesticides, PCBs and Their Relationships to Resource Preservation and Protection*. Natchitoches: National Park Service

60 Living on Earth. 2014. "Tangier: The Shrinking Island in the Chesapeake." Aired July 11. http://loe.org/shows/segments.html?programID=14-P13-00028&segmentID=6.

61 Jeneva Wright. in review. *Maritime Archeology and Climate Change: An Invitation*. Journal of Maritime Archeology.

62 Dave Conlin, Chief, Submerged Resources Center, National Park Service. Personal communication, April 27, 2016.

63 Weeks, Kay G. and Anne E. Grimmer. 1995. *The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring, & Reconstructing Historic Buildings. Washington, DC*: National Park Service, Heritage Preservation Services.

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