



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 archeological 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 Advisory Board, Science Committee

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

More Precipitation and/or Heavier Precipitation- an increase in the average amount of rain or snow 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				
	Archeological Resources	Cultural Landscapes	Ethnographic Resources	Museum Collections	Buildings & Structures
Increased Global Temperature	<ul style="list-style-type: none"> Microcracking of site contexts from thermal stress¹ Faster deterioration of newly exposed artifacts and sites² Deterioration of newly exposed materials from melting alpine snow patches³ Accelerated rusting in submerged and littoral resources from warmer ocean temperatures¹ More rapid decay of organic materials¹ Damage from increased biological activity at shallow (~<100m) underwater sites⁵¹ Increased risk of damage due to decline/loss of protective sea grass or nearby coral reefs^{61,62} 	<ul style="list-style-type: none"> Decline/disappearance of some vegetation species, other species favored⁴ Heat stress on culturally significant vegetation⁴ Increased stress (e.g. desiccation, warping, cracking, etc.) on constructed landscape features⁴ 	<ul style="list-style-type: none"> Loss of necessary habitat for culturally significant species⁴ Potential loss of culturally significant species due to increased disease threat⁵ Changes in prevalence of culturally relevant plant and animal species⁵⁰ Changes to crop yields and food security⁶ Limited winter hunting from increased winter snows⁵ Limited access to hunting areas due to reduced sea ice⁷ Altered place meaning due to loss of snow pack⁷ 	<p>Facilities</p> <ul style="list-style-type: none"> Increased stresses on HVAC systems in storage facilities⁸ Increased space constraints due to more items requiring protection in storage facilities⁸ Increased need for environmental controls in facilities/house collections⁹ <p>Collections (without appropriate climate controls)</p> <ul style="list-style-type: none"> Increased rate of chemical decay¹¹ Increased stress due to fluctuations in environmental conditions¹⁰ 	<ul style="list-style-type: none"> Increased crystallization of efflorescent salts due to increased evaporation rates, leading to increased rates of structural cracking, deterioration¹ 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
Increase Freeze/Thaw Cycles	<ul style="list-style-type: none"> More rapid decay of organic materials¹ Disruption of soil structure, especially in permafrost²⁶ Destruction of archeological deposits due to increased solifluction (downhill flow of saturated soil) activity³ Increased rates of deterioration in metals from thermal stress²⁷ 	<ul style="list-style-type: none"> Decline/disappearance of some vegetation species due to recurrent freezing⁴ More rapid deterioration of constructed materials of landscape features (e.g. corrosion, decay, desiccation)⁴ 	<ul style="list-style-type: none"> Food stress or starvation of foraging animals (horse, caribou) from impenetrable ice layers more likely to form on grazing fields⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> 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 collections¹⁰ 	<ul style="list-style-type: none"> 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 action¹ Spalling and collapse of caves and bedrock alcoves onto structures inside them²² Increased absorption of salts from road and sidewalk treatments which can lead to efflorescence, cracking, and spalling, etc.¹²
Permafrost Melt	<ul style="list-style-type: none"> Loss of artifacts and contexts from increased erosion⁵ More rapid decay of organic materials²⁶ Disruption of stratigraphy from changed soil structure, solifluction⁵² 	<ul style="list-style-type: none"> Decline/disappearance of some vegetation species⁴ More rapid decay, dessication of constructed materials of landscape features⁴ 	<ul style="list-style-type: none"> Destruction of land and buildings due to increased coastal erosion⁶ Forced relocation of communities⁵ Loss of access to wildlife corridors due to terrain that can no longer be traversed by foot or vehicle¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Destabilization of buildings from cracks in foundations and other infrastructure¹⁰ 	<ul style="list-style-type: none"> Destabilization of buildings; settlement into the ground^{5,16} More rapid decay of organic building materials^{16,48} Change in use or abandonment due to changes in access as the surrounding ground becomes boggy²²
Higher Relative Humidity	<ul style="list-style-type: none"> More rapid decay of organic materials¹⁶ Increased corrosion of vulnerable/less stable metals² Increased mold, especially in enclosed sites (e.g. vaults, tumuli, and caves)² 	<ul style="list-style-type: none"> Decline/disappearance of critical vegetation species, other species favored⁴ Increased desiccation, warping, and cracking of constructed landscape features⁴ 	<ul style="list-style-type: none"> Decline/disappearance of important vegetation species, other species favored⁴ Increase/spread of some vegetation species⁴ 	<p>Facilities</p> <ul style="list-style-type: none"> Increased wear on HVAC systems, and energy use to stabilize drastic changes in humidity²⁸ <p>Collections (without appropriate climate controls)</p> <ul style="list-style-type: none"> Increased rusting/corrosion of metals¹⁶ Damage to paintings⁸ Warping, cracking of wood¹⁶ Damage to archival, paper, book, and photo collections¹⁰ Increased risk of mold, especially organic collections¹⁰ Increased salt damage to ceramics with humidity fluctuations¹¹ Increase in pest populations²⁹ Accelerated deterioration of museum items exhibited outside¹⁹ 	<ul style="list-style-type: none"> For brick and porous stone, increased moisture absorption, leading to increased risk of frost damage, mold growth, and stress from salt crystallization¹⁶ Decrease in crystallization and dissolution of salts within stone and masonry¹⁶ Sulfur dioxide deposits on wet/damp surfaces, corroding stone, metal, and glass¹⁶ Swelling and cracking of wooden building materials and architectural features¹⁶ 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 material¹⁶
Increased Wind	<ul style="list-style-type: none"> Increased moisture penetration into porous materials²⁰ Burial through redistribution of soil¹⁴ Abrasion of petroglyph and pictoglyphs¹⁴ Erosion and deflation of archeological deposits² 	<ul style="list-style-type: none"> Damage or loss of culturally significant plants⁴ Change in historic/culturally significant vegetation patterns⁴ Increase in need for protective structures that shelter landscapes⁴ 	<ul style="list-style-type: none"> Reduced access to marine hunting grounds due to stronger/unusual wind patterns and shifting sea ice⁷ Reduced access to animals in open spaces due to wind chills that drop temperatures¹⁵ 	<p>Collections</p> <ul style="list-style-type: none"> Damage to wooden, paper, textile and organic objects from decreased relative humidity¹⁰ 	<ul style="list-style-type: none"> Direct wind damage¹⁶ Scouring/abrasion of exterior surfaces¹ Increased cracking, spalling, splintering, weathering of buildings due to accelerated drying¹ Damage from wind borne debris²

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	Archeological Resources	Cultural Landscapes	Ethnographic Resources	Museum Collections	Buildings & Structures
Increased Wildfire	<p>During Fire</p> <ul style="list-style-type: none"> • Damage or destruction of associated structures³⁰ • Heat alteration of artifacts³⁰ • Heat fracturing of stone artifacts³⁰ • Paint oxidation, color change³⁰ • Physical damage from firefighting efforts (fire lines)³⁰ • Decreased accuracy of carbon-14 dating due to carbon contamination³⁰ <p>Post-Fire</p> <ul style="list-style-type: none"> • Damage from fire-killed tree fall³⁰ • Increased susceptibility to erosion and flooding³¹ • Increased looting after fire exposure³¹ 	<ul style="list-style-type: none"> • Loss or damage of associated structures²³ • Change in vegetation density and composition⁴ • Bedrock and border spalls²³ • Increased susceptibility to erosion and flooding²³ • Loss of soil fertility due to high heat²³ • Damage to structure and/or associated cultural landscape from fire retardants²² 	<p>During Fire</p> <ul style="list-style-type: none"> • Discoloration, exfoliation, spalling, and smudging of culturally significant rock images, geoglyphs³⁰ • Change in subsistence resources over large areas¹⁵ • Loss of traditional knowledge due to change/loss of culturally significant resources¹⁵ • Loss of critical and/or culturally significant species due to decreased soil fertility from high heat³⁰ <p>Post-Fire</p> <ul style="list-style-type: none"> • Altered migratory patterns of traditionally hunted animals⁶ • Significant alteration of landscape features critical for navigating during foraging, hunting, or other necessary movements³⁰ 	<p>Facilities</p> <ul style="list-style-type: none"> • Damage to storage facilities and contents⁸ • Increased strain on existing museum facility and staff due to increased advance preparation and salvage operations³² • Smoke damage, strain on HVAC systems²⁹ <p>Collections</p> <ul style="list-style-type: none"> • Damage to items and disassociation of materials and records during emergency evacuations¹¹ 	<p>During Fire</p> <ul style="list-style-type: none"> • Damage or loss of whole structures, or combustible components²² • Cracking, physical damage of masonry components from extreme thermal stress³⁰ • Discoloration caused by smoke and/or heat³⁰ • Damage from fire-killed tree fall³⁰ • Damage to structure and/or associated cultural landscape from fire retardants²² <p>Post-Fire</p> <ul style="list-style-type: none"> • 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 alternatives³⁴
Changes in Seasonality and Phenology	<ul style="list-style-type: none"> • Site disruption from longer growing seasons and/or changing land use (irrigation use, harvest times)¹³ • Changes in site or regional accessibility¹⁴ • Reductions or alterations in length and timing of archeological field seasons, affecting capacity for identification or mitigation of climate and other impacts¹⁴ • Possible reductions in site visibility¹⁴ 	<ul style="list-style-type: none"> • Loss of synchronicity between species⁵⁴ • Altered landscapes due to shifts in blooming times⁵⁴ • Loss of pollinators reduces plant fertility in historic agricultural landscapes⁴ 	<ul style="list-style-type: none"> • Loss of synchronicity between species⁵⁴ • Potential loss or reduction of plants used for medicine and ceremonies performed at particular times of the year¹⁵ • Loss of plants used for ceremonies, medicine, and food due to early frosts¹⁵ • Shifts in migratory patterns of significant marine animals due to changes in sea ice⁷ • Limited access to winter marine hunting areas due to longer summers⁷ • Food sources threatened by shifts in harvest time (esp. feed for herd animals)⁵ 	<p>Facilities, Collections</p> <ul style="list-style-type: none"> • Increased stress on buildings and materials due to increased range of temperature swings during seasonal transitions (particularly collections without appropriate climate controls)⁹ 	<ul style="list-style-type: none"> • Longer growing seasons lead to increased growth of invasive vegetation¹²
Species Shift	<ul style="list-style-type: none"> • Physical damage, loss of integrity, and spatial coherence from new/increased plant growth¹⁶ • Physical impacts from associated adaptive behavior of animals following plant species movements² • Disruption from new foraging or nesting animals, including insects² • Changes in soil chemistry due to root penetration of new vegetation¹⁷ • Increased shrub growth on former tundra, may obscure features and artifacts³ • Possible reductions in site visibility¹⁴ 	<ul style="list-style-type: none"> • Changes in historic/culturally significant vegetation patterns⁴ • Emigration and/or local extinction of culturally significant species⁵ • Changes in landscape appearance from altered growth patterns of lichen¹⁶ 	<ul style="list-style-type: none"> • Loss of major food sources⁴² • Loss of culturally significant plant and animal species⁵ • Altered appearance of important ceremonial sites⁴² • Breaks in memory, traditions, and context due to loss of species, species access, resource predictability¹⁸ 	<p>Collections</p> <ul style="list-style-type: none"> • Increased need to expand voucher specimens (used for reference) in collection¹⁹ • Increased need to identify existing voucher specimens, many uncatalogued in non-federal repositories, to serve as baselines¹⁹ 	<ul style="list-style-type: none"> • 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 habitat²² • Spread of destructive vegetative species (like kudzu) farther north into new areas¹² • Loss of species that are necessary for historically appropriate repairs²⁰ • New/different micro-organisms cover surfaces of stone buildings - may reduce deterioration (possible benefit)²¹
Invasive Species/Pests	<ul style="list-style-type: none"> • Physical damage, loss of integrity and spatial coherence from altered habitat structure¹⁶ • Data loss, subsidence, feature collapse, structural damage from invasive consuming organics² • Damage from new and increased number of burrowing animals²³ • Possible reductions in site visibility¹⁴ 	<ul style="list-style-type: none"> • Potential loss of significant plants due to introduction of new pests⁴ • Potential biological selection pressure for incompatible vegetation or other biotic species⁴ • Changes in viewsheds (e.g. battlefield parks)²⁴ 	<ul style="list-style-type: none"> • Damage to distribution of subsistence crops, culturally significant plants⁵ • Loss of culturally important animals due to changes in habitat from invasive plant species¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> • Need for updated integrated pest management plans to account for new pest risks¹¹ • Invasion of pests via new routes created by thermal stress on facility¹¹ <p>Collections</p> <ul style="list-style-type: none"> • Increase in pest populations that damage organic materials (animal skins, wool)¹¹ 	<ul style="list-style-type: none"> • New threats to wood structures and wooden architectural features as termites and other pests expand territory due to warmer, longer summers²⁵ • Spread of destructive vegetative species (like kudzu) farther north into new areas¹²

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Less Precipitation/Drought	<ul style="list-style-type: none"> Loss of stratigraphic integrity due to crack/heave damage in drier soils¹⁷ Destabilization of wetland or waterlogged sites¹³ Exposure of submerged sites due to lower water levels in lakes¹⁴ Sites more vulnerable to fire and wind¹⁴ Increased exposure from vegetation loss and erosion¹⁴ 	<ul style="list-style-type: none"> Water stress may inhibit growth of some species⁴ Decline/disappearance of some vegetation species; other species favored⁴ Soil infertility due to decreased microbial activity⁴ Limited water supply inhibits established maintenance practices¹⁷ Increased soil erosion⁴ Challenges to current irrigation practices⁴ 	<ul style="list-style-type: none"> Stress on culturally significant species impacts subsistence practices⁵ Indirect effects to ceremonial cycles and religious practices involving weather control¹⁵ Decline/disappearance of important vegetation species, other species favored²³ Loss of some harvestable animals¹⁵ 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 animals¹⁵ Limitation on travel due to loss of water sources¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Limited water supply for cooling, landscaping, other equipment⁸ Reduced humidity stress on building (possible benefit)²³ <p>Collections (without appropriate climate controls)</p> <ul style="list-style-type: none"> Damage to wooden, paper, textile and organic objects from drying due to lower relative humidity¹⁰ 	<ul style="list-style-type: none"> 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 drying¹²
More Precipitation and/or Heavier Precipitation	<ul style="list-style-type: none"> Site erosion from overflow and new flood channels¹⁷ Soil destabilization/shifting (ground heave, landslide, subsidence)¹⁴ Damage to unexcavated artifact and site integrity from direct force of water³⁵ 	<ul style="list-style-type: none"> Increased tree fall due to waterlogging¹⁷ Limited ability to plant in waterlogged soil⁴ Loss of historical integrity with improved drainage systems¹⁷ Decline/disappearance of some vegetation species⁴ Decreased soil fertility from erosion, waterlogging, leaching⁴ Loss of landscape features⁴ Increased susceptibility to destructive fungi³⁶ Erosion of earthworks²⁴ Disruption or delay of traditional maintenance practices (e.g. burning)²⁴ 	<ul style="list-style-type: none"> Altered harvest times, especially haying in herd cultures due to changes in precipitation patterns² Delays in planting cycles, shifting whole agricultural calendar⁶ Increasing difficulty in predicting storms³⁷ Indirect effects to ceremonial cycles and religious practices involving weather control¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Added strain on existing museum facilities and staff due to salvage operations³² Potential leaks in collection storage areas and potential wetting of museum objects¹⁰ Increased cracking associated with ground heave and subsidence; destabilization of buildings and pipes¹⁰ <p>Collections (without appropriate climate controls)</p> <ul style="list-style-type: none"> Increase risk of mold, especially organic collections¹⁰ Increase rusting/corrosion of metals¹⁰ Humidity damage to paintings¹⁰ Warp, crack, damage wood¹⁰ Humidity damage to archival, paper, book, and photo collections¹⁰ 	<ul style="list-style-type: none"> Swelling/distortion of wooden building materials and architecture features due to wetness and damp³⁸ Increased risk of rot and fungal/insect attack³⁸ Historic building drainage systems unable to cope with downpours¹⁷ Erosion of supporting ground around structure³⁸ Sewage backup and overflow leading to saturation and related flooding, contamination and damage²² Increased rates of deterioration due to increase frost events in cold regions that were formerly dry²¹ Accelerated decay of masonry units and mortars due to increased extremes of wetting and drying³ Cracks in building infrastructure and associated destabilization of buildings and pipes due to ground heave and subsidence/shrink swell soils¹⁰ Severe damage and loss of historic structures made of adobe¹² Spalling, weathering of wood, brick, and stone materials due to salt infiltration during drying¹ Corrosion of external masonry from agricultural runoff⁴⁰ Increased pressure to relocate or elevate structures, and/or surrounding structures²³
Increase of Flooding Events	<p>During Flood</p> <ul style="list-style-type: none"> Direct physical damage to site, from floating materials during floods¹⁴ Destruction/loss of artifacts during flooding¹⁶ Site erosion from overflow and new flood channels¹⁷ <p>Post-Flood</p> <ul style="list-style-type: none"> Increased risk of post-flood subsidence¹⁷ Impacts from post-flood mitigation (clean up, construction)¹⁴ 	<ul style="list-style-type: none"> Wash out or damage to roads, trails, and landscape features throughout parks⁴ Decline/disappearance of important vegetation species, other species favored⁴ Loss of landscape features⁴ 	<ul style="list-style-type: none"> Loss of cultural places due to inundation/saturation⁵ Loss/disruption of the use of foraging grounds⁵ Loss of both plant and animal species for subsistence, medicine, ceremony, etc¹⁵ Degradation of vital coral reef habitats from increased sediment discharge⁴² 	<p>Facilities</p> <ul style="list-style-type: none"> Added strain on existing museum facilities and staff due to salvage operations³² Damage to items and disassociation of materials and records during emergency evacuations¹⁹ Structural collapse from moving force of floodwaters, particularly from flash floods⁴¹ Sewage backup and overflow leading to saturation and related flooding, contamination and damage²² Walls "implode" from hydrostatic force of standing water⁴¹ Damage to utilities, generators, and electrical systems⁵¹ <p>Collections</p> <ul style="list-style-type: none"> Increase rusting/corrosion of metals¹⁰ Increase 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 waters¹⁰ 	<p>During Flood</p> <ul style="list-style-type: none"> Structural collapse from moving force of floodwaters particularly during flash floods⁴¹ Sewage backup and overflow leading to saturation and related flooding, contamination and damage²² Walls "implode" from hydrostatic force of standing water⁴¹ Damage to utilities, generators and electrical systems⁵¹ <p>Post-Flood</p> <ul style="list-style-type: none"> Increased risk of rot, fungal/insect attack, mold and mildew³⁸ Swelling/distortion of wooden building materials and architecture features due to inundation³⁸ Spalling, weathering of wood, brick, and stone materials due to salt infiltration during drying¹ Corrosion of external masonry from agricultural runoff⁴⁰ Increased pressure to relocate or elevate structures, and/or surrounding structures (may also be pre-flood)²³

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Inundation and Increased Flooding events	<ul style="list-style-type: none"> Total submersion of coastal sites²⁰ Downstream movement of items due to undercut shoreline sediments⁴ Changes in pH of buried artifacts and/or buried environments²⁰ Reduced site integrity due to ground heave and subsidence¹⁴ Increased risk of looting from exposure¹⁴ Increased erosion of sites due to encroaching water levels, wave action exposure, and increased exposure to wet/dry cycles³⁶ 	<ul style="list-style-type: none"> Variable damage/ loss of organic and inorganic materials and landscape features²⁰ Decline/ disappearance of some vegetation species, other species favored⁴ Soil erosion⁴ Soil infertility due to waterlogged, anaerobic conditions⁴ 	<ul style="list-style-type: none"> Loss of or limited access to traditional places¹³ 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 communities⁴² and corresponding stresses to and loss of social connections and interactions²⁰ 	<p>Facilities</p> <ul style="list-style-type: none"> Added strain on existing museum facilities and staff due to salvage operations³² Increased cracking associated with ground heave and subsidence¹⁰ Potential leaks in collection storage areas and potential wetting of museum objects¹⁰ <p>Collections</p> <ul style="list-style-type: none"> Increase risk of mold¹⁰ Increase rusting/corrosion of metals¹⁰ Damage and destruction post-flood from humidity and moisture²⁸ 	<p>During Flood</p> <ul style="list-style-type: none"> Submersion of coastal sites²² Increase in nuisance flooding leading to problems of access and higher likelihood of range of flood damage⁵³ Damage to or overwhelming of drainage systems, leading to associated building damage⁵³ <p>Post-Flood</p> <ul style="list-style-type: none"> Deterioration/corrosion of infrastructure not designed for inundation or salt water exposure³³ Increased cracking due to associated ground heave and subsidence¹⁰ Crystallization of salts introduced to buildings by seawater²² Disassociation of historic districts, settings due to increased pressure to relocate or elevate structures or surrounding structures²³ Loss of access leading to loss of use⁶⁰ <p>(See also: Precipitation: More Rainfall/Heavier Downpours, Increased Flooding Events; Sea Level Rise: Storm Surge)</p>
Increased Frequency and/or Severity of Storm Surges	<p>During Surge:</p> <ul style="list-style-type: none"> Destruction - total site loss¹⁷ Erosion from wave action¹⁷ <p>Post-Surge</p> <ul style="list-style-type: none"> Disturbance or removal during response and clean-up¹⁴ <p>(See also: Precipitation: Increased Flooding Events)</p>	<ul style="list-style-type: none"> Immediate alteration/ destruction of historic landscape⁴⁴ Decline/ disappearance of some vegetation species, other species favored⁴ Soil infertility from soil erosion, loss of topsoil⁴ Loss of landscape features⁴ 	<ul style="list-style-type: none"> Increased risk of inundation of homes and towns, esp. during unpredictable and extreme weather⁴² Increased risk of loss of natural and cultural resources¹⁵ Increased risk of loss of traditional knowledge associated with natural and cultural resources¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Added strain on existing museum facilities and staff due to emergency operations^{22,54} Damage to utilities, generators and electrical systems⁵¹ Structural collapse from moving force of storm surge⁴¹ Changes to surrounding landforms or vegetation, which may affect future drainage³⁸ <p>Collections</p> <ul style="list-style-type: none"> Damage to items and disassociation of materials and records during emergency evacuations¹⁹ Increase risk of rot, fungal/insect attack, mold and mildew¹⁰ Increase rusting/corrosion of metals¹⁰ Widespread damage and disassociation from flood waters¹⁰ <p>(See also: Precipitation: Increased Flooding Events)</p>	<p>During Surge</p> <ul style="list-style-type: none"> Structural damage or collapse from moving force of storm surge⁴¹ Damage to utilities, generators and electrical systems⁵¹ <p>Post-Surge</p> <ul style="list-style-type: none"> Cracks in building and associated destabilization of buildings and pipes due to ground heave and subsidence/shrink-swell soils¹⁰ Erosion of supporting ground around structure³⁸ Changes to surrounding landforms, which may affect future drainage³⁸ Increased pressure to relocate or elevate structures, and/or surrounding structures (may also be pre-flood)²³ <p>(See also: Precipitation: More Rainfall/Heavier Downpours, Increased Flooding Events)</p>
Increased Coastal Erosion	<ul style="list-style-type: none"> Full loss of coastal sites and artifacts¹⁷ Partial loss of sites and artifacts¹⁴ Exposure of new and known archeological sites¹⁶ Altered erosion patterns from reduction/changes in Arctic sea ice³ Increased risk of looting from exposure¹⁴ 	<ul style="list-style-type: none"> Decline/ disappearance of some vegetation species, other species favored⁴ Soil infertility from loss of topsoil⁴ Loss or compromise of associated structures²³ 	<ul style="list-style-type: none"> Loss of cultural memory and connections to homeland due to increased migration and splitting of traditional communities⁴² Loss of culturally significant symbols, plants, and animals⁵ Increased risk of loss of traditional knowledge associated with both natural and cultural resources¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Limited storage capacity to protect growing numbers of at-risk artifacts⁵⁴ Added strain on existing museum facilities and staff due to salvage operations³² 	<ul style="list-style-type: none"> Loss or compromise of structure²³ Increased pressure to relocate or elevate structures, and/or surrounding structures²³ Increased rusting, corrosion, and salt deposits due to increased salt in the environment as the coastline encroaches¹²
Higher Water Table	<ul style="list-style-type: none"> Damage to artifacts, stratigraphy, soil features from saturation of site from below¹⁴ 	<ul style="list-style-type: none"> Decline disappearance of important vegetation species, other species favored⁴ Soil infertility due to waterlogged, anaerobic conditions⁴ 	<ul style="list-style-type: none"> Loss of or limited access to culturally important sites (eg burial grounds)¹⁸ Decrease in productivity of arable land¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Potential for higher relative humidity levels in collections storage areas¹⁰ Increased risk of rising damp/rot from higher water tables¹⁷ 	<ul style="list-style-type: none"> Rising damp, often marked by efflorescence/ salt deposits¹² Rot of subsurface components from higher water table¹⁷ Flooding damage in basements and other below grade features²² Structural damage due to buoyant forces¹²

	Impact on Cultural Resources				
	Archeological Resources	Cultural Landscapes	Ethnographic Resources	Museum Collections	Buildings & Structures
Salt Water Intrusion	<ul style="list-style-type: none"> 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} 	<ul style="list-style-type: none"> Decline/disappearance of important vegetation species⁴ Soil infertility⁴ 	<ul style="list-style-type: none"> Reduction in or loss of habitat for culturally significant plants and animals⁶ Loss of drinking water supplies⁶ Loss of arable land for growing crops¹⁵ Loss of some harvestable animals¹⁵ 	<p>Collections</p> <ul style="list-style-type: none"> Increased risk of corrosion/rusting¹⁰ 	<ul style="list-style-type: none"> Increased risk of corrosion/rusting¹⁶ Introduction of additional salts into the ground and into building materials²²
Extreme Weather Events	<ul style="list-style-type: none"> Erosion of coastal sites due to higher, stronger storm surges¹⁷ Disturbance/exposure/burial due to stronger wave action⁴⁵ Deflation or abrasion due to stronger winds^{5,14} Disturbance or removal during response and clean-up¹⁴ Destabilization/damage to underwater sites through movement of sediment and/or protective vegetation⁶² <p>(See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)</p>	<ul style="list-style-type: none"> Immediate alteration/destruction of historic landscape⁴⁴, particularly trees⁵⁷ Decline/disappearance of some vegetation species, other species favored⁴, particularly colonizing species in disturbed areas⁵⁷ Reduction in or loss of access due to washing out or damage to roads, trails, and landscape features⁴ <p>(See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)</p>	<ul style="list-style-type: none"> 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 areas¹³ Need for new emergency response plans due to changes in hurricane strengths and tracks³, and surrounding land use practices⁴⁹ <p>(See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours, Increased Flooding Events; Sea Level Rise: Increased Storm Surge)</p>	<p>Facilities</p> <ul style="list-style-type: none"> Direct damage from wind and wind-blown rain^{6,54} Damage from wind-borne debris² Limited relocation opportunities due to growing demands for storage facilities⁵¹ Added strain on existing museum facilities and staff due to salvage operations³² Cracked pipes and swelling due to large and rapid temperature swings⁵⁴ <p>(See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)</p>	<ul style="list-style-type: none"> Added stress from sudden thermal expansion/shock¹⁶ Direct damage from wind-blown rain⁵⁴ Damage from wind-borne debris² Cracked pipes and swelling due to large temperature swings⁵⁴ <p>(See also: Temperature Change: Increased Wind; Precipitation: Heavier Downpours; Sea Level Rise: Increased Storm Surge)</p>
Pollution	<ul style="list-style-type: none"> Rusting due to increased CO2 exposure¹⁶ Artifacts threatened by pesticides used to combat invasive species⁵⁹ 	<ul style="list-style-type: none"> Dissolution of stone due to increases in acid rain, particulate matter, and ground-level ozone²⁶ Decline/disappearance of some vegetation species inc. favored⁴ Soil infertility due to toxicity and depletion of nutrients⁴ Loss of landscape features, especially plantings, buildings⁴ 	<ul style="list-style-type: none"> Bleaching/damage to coral reefs⁴² Reduction or loss of culturally significant view sheds⁴ Increased difficulty for young and elderly people to perform outdoor harvesting tasks¹⁵ Potential erosion or deterioration of pictographs still visited by contemporary peoples for prayer or ceremony¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Increased need for special air filtration for repositories¹⁹ <p>Collections</p> <ul style="list-style-type: none"> Corrosion of metal objects and films: pitting and perforation, deterioration/loss of coating⁴⁸ 	<ul style="list-style-type: none"> Erosion of carbonate stones due to acidic precipitation¹ Continued stone blackening¹ Increased chemical weathering of stone materials due to altered atmospheric composition²¹ Cracked walls and increased water penetration due to corrosion⁴⁸
Development	<ul style="list-style-type: none"> Disruption/damage from fire management (eg fire lines)³⁰ Disruption/damage from changing land use³⁰ Degraded site integrity due to climate change mitigation (eg construction of levees and dams, dredging)³⁵ Increased risk of looting or vandalism²³ Heightened vulnerability to landslides due to land use changes and increased rainfall and runoff pressures⁵⁰ 	<ul style="list-style-type: none"> Increased abundance of invasive species along roadways⁴ Degraded integrity of historic viewsheds⁴ Loss of undeveloped buffer areas around cultural landscapes⁴ Loss of culturally significant plants from soil compaction, limited root zones, temperature stress from heat island effect, high urban soil contaminant levels³⁶ Loss of adjacent natural habitat for native species³⁶ 	<ul style="list-style-type: none"> Increased development in Arctic due to warmer conditions⁵ Loss of food sources due to habitat loss, fragmentation, over-exploitation⁴⁶ Reduction or loss of adaptive flexibility due to development encroachment⁵ Loss of access to traditional cultural places, including landscapes¹⁵ Loss of coral reefs critical for tropical fish habitats needed for local subsistence and marine tourism⁴² Loss of ancestral homelands that are considered sacred¹⁵ Loss of traditional knowledge associated with natural and cultural features on the landscape¹⁵ 	<p>Facilities</p> <ul style="list-style-type: none"> Added strain on existing museum facilities and staff due to environmental research compliance and salvage operations^{32,23} Potential for fracking-induced earthquake damage²⁹ 	<ul style="list-style-type: none"> Increased conflicts of land-use needs due to population growth/urbanization⁵⁸ Loss of historic character due to changes to the site or setting⁶³

Increased GHG Emissions

	Impact on Cultural Resources				
	Archeological Resources	Cultural Landscapes	Ethnographic Resources	Museum Collections	Buildings & Structures
Ocean Acidification	<ul style="list-style-type: none"> Metal corrosion in submerged resources⁴⁵ Degradation of stonework, especially limestone and mortar in coastal areas⁴ Possible acceleration in cliff erosion where cliffs have lime or shell components⁵⁵ Increased risk of damage to shipwrecks due to loss/decline of protective concretions and/or nearby coral reefs^{61,62} 	<ul style="list-style-type: none"> Coastal soil erosion/infertility⁴ Loss or deterioration of culturally significant landscape features⁴ 	<ul style="list-style-type: none"> Decline in reefs, vital to subsistence cultures, from coral bleaching⁵⁶ Physical abnormalities, including weakened shells, in traditional food sources⁴² Weakened/destroyed local economies dependent on shellfish supplies⁵¹ Possible increased degradation of rock art along shores that is sacred to and visited by contemporary peoples¹⁵ 	<p><i>Impacts not identified</i></p>	<p><i>Impacts not identified</i></p>

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