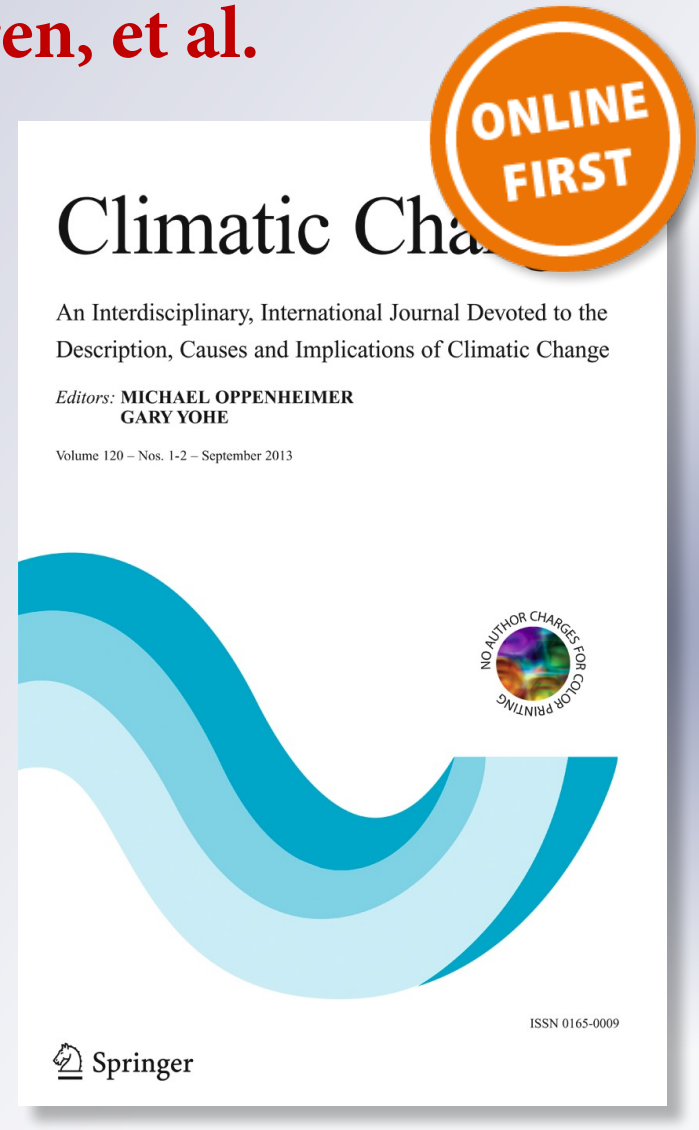
Climate change impacts on the water resources of American Indians and Alaska Natives in the U.S.

K. Cozzetto, K. Chief, K. Dittmer, M. Brubaker, R. Gough, K. Souza, F. Ettawageshik, S. Wotkyns, S. Opitz-Stapleton, S. Duren, et al.

Climatic Change
An Interdisciplinary, International Journal Devoted to the Description, Causes and Implications of Climatic Change

ISSN 0165-0009

Climatic Change
DOI 10.1007/s10584-013-0852-y



Springer

Climatic Change
DOI 10.1007/s10584-013-0852-y

Climate change impacts on the water resources of American Indians and Alaska Natives in the U.S.

K. Cozzetto · K. Chief · K. Dittmer · M. Brubaker · R. Gough · K. Souza · F. Ettawageshik · S. Wotkyns · S. Opitz-Stapleton · S. Duren · P. Chavan

Received: 26 November 2012 / Accepted: 16 July 2013

Abstract This paper provides an overview of climate change impacts on tribal water resources and the subsequent cascading effects on the livelihoods and cultures of American Indians and Alaska Natives living on tribal lands in the U.S. A hazards and vulnerability framework for understanding these impacts is first presented followed by context on the framework components, including climate, hydrologic, and ecosystem changes (i.e. hazards)

This article is part of a Special Issue on "Climate Change and Indigenous Peoples in the United States: Impacts, Experiences, and Actions" edited by Julie Koppel Maldonado, Rajul E. Pandya, and Benedict J. Colombi.

Electronic supplementary material The online version of this article (doi:10.1007/s10584-013-0852-y) contains supplementary material, which is available to authorized users.

K. Cozzetto (✉)
Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA
e-mail: kcozzetto@colorado.edu

K. Chief
Department of Soil, Water, and Environmental Sciences, University of Arizona, Tucson, AZ, USA

K. Dittmer
Columbia River Inter-Tribal Fish Commission, Portland, OR, USA

M. Brubaker
Alaska Native Tribal Health Consortium, Anchorage, AK, USA

R. Gough
Intertribal Council on Utility Policy, Rosebud, SD, USA

K. Souza
PRiMO, Indigenous Ecological Knowledge Circle, Honolulu, HI, USA

F. Ettawageshik
United Tribes of Michigan, Harbor Springs, MI, USA

S. Wotkyns
Institute for Tribal Environmental Professionals, Flagstaff, AZ, USA

S. Opitz-Stapleton
Staplets Consulting, Boulder, CO, USA

Published online: 30 August 2013

and tribe-specific vulnerability factors (socioeconomic, political, infrastructural, environmental, spiritual and cultural), which when combined with hazards lead to impacts. Next regional summaries of impacts around the U.S. are discussed. Although each tribal community experiences unique sets of impacts because of their individual history, culture, and geographic setting, many of the observed impacts are common among different groups and can be categorized as impacts on—1) water supply and management (including water sources and infrastructure), 2) aquatic species important for culture and subsistence, 3) ranching and agriculture particularly from climate extremes (e.g., droughts, floods), 4) tribal sovereignty and rights associated with water resources, fishing, hunting, and gathering, and 5) soil quality (e.g., from coastal and riverine erosion prompting tribal relocation or from drought-related land degradation). The paper finishes by highlighting potentially relevant research questions based on the five impact categories.

1 Introduction

Water is sacred. This is tradition. In contrast to the non-tribal utilitarian view of water, Native Americans revere water and water is life. It is integral to many Native American practices such as purification and blessing rituals and is used to acknowledge all relations and to establish connection to Mother Earth and Father Sky. Water is a holistic and integrating component connecting continents, humans, animals, and plants through a continuous cycle of liquid, solid, and vapor states. Without water, life would not exist as we know it. Water is the one thing we all need, all of us, all of life. As Native Americans, we honor and respect the tradition of water and must protect it always.

American Indians and Alaska Natives in the U.S. (AIAN) originate from diverse indigenous groups, each with a unique and rich tradition, culture, language, and history. Today there are 566 federally recognized tribes (supplemental Table S7) across 33 states and at least 34 state recognized tribes (Fig. 1). According to the 2010 Census, 5.22 million people are AIAN either fully or in part. While 78 % of AIAN live on non-tribal lands (cities and towns), this paper focuses on the over 1.14 million AIAN (22 %) living in tribal areas (supplemental Table S3).

This paper provides an overview of climate change impacts on tribal water resources (rivers, lakes, wetlands, springs, groundwater, permafrost, snowpack, glaciers, estuaries, oceans, and sea ice) and the subsequent cascading effects on AIAN livelihoods and cultures. We examine impacts in six regions: Alaska, Pacific Northwest, Southwest, Great Plains, Midwest, and East. Although Hawaii and unincorporated island territories were beyond the scope of this article, the impacts discussed for coastal areas are relevant for islands. First the paper presents a hazards and vulnerability framework to assist in understanding the severity and types of climate change impacts to tribal water resources. Then, context for the framework components is provided. Next, examples of regional impacts are summarized, and five categories of common impacts are identified. Finally, potentially relevant research questions based on the five impact categories are described. For more in depth discussion and additional examples for the various sections, we strongly encourage readers to make use of the extensive supplementary materials.

S. Duren
Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO, USA

P. Chavan
Alaska Native Tribal Health Consortium, Anchorage, AK, USA

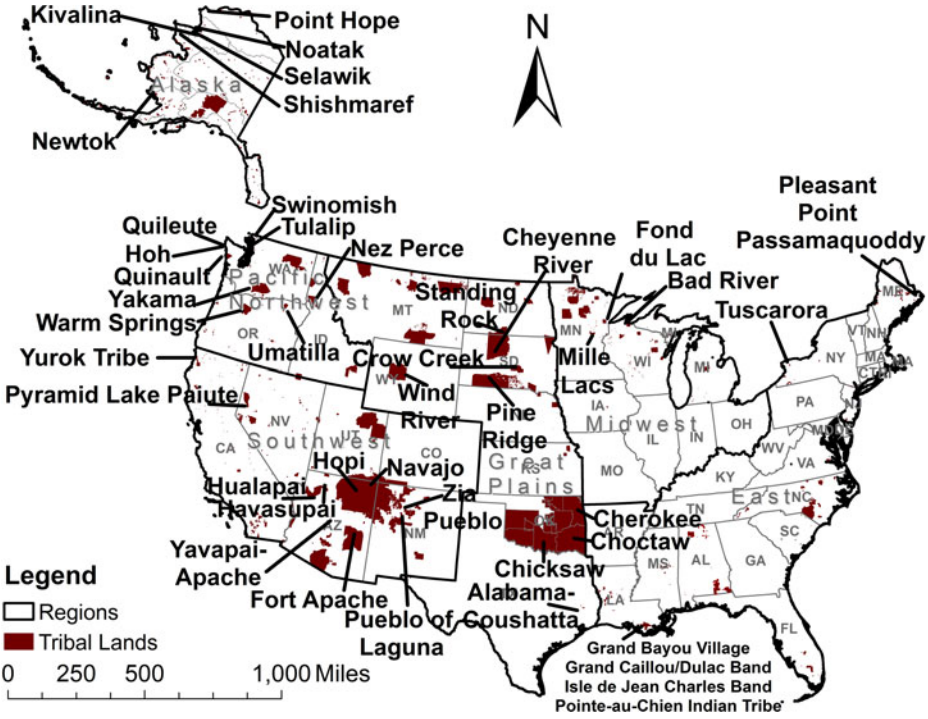


Fig. 1 Map showing the six regions and the locations of AIAN lands discussed. All *shaded areas* represent tribal lands. Source: U.S. Census Bureau

2 Framework for understanding impacts

The vulnerability of AIAN to climate change can be examined through a variety of frameworks. In this paper, we draw from hazards and disaster risk reduction research and describe vulnerability as the interconnectedness of factors constraining or enabling the ability of people to respond to hazards and exposing them to climate change and variability hazards (Fig. 2). Constraining or enabling factors contributing to vulnerability and/or adaptive capacity include socioeconomic, political, infrastructural, and environmental factors and spiritual and cultural values (Cutter et al. 2010; Füssel and Klein 2006). Whether or not an impact proves to be beneficial or detrimental depends on tribal vulnerability or adaptive capacity and the nature (severity and frequency) of the climate hazard. To summarize, vulnerability and adaptive capacity are functions of human and environmental factors and exposure to climate hazards. Impacts are functions of vulnerability and the nature of climate hazards.

3 Hazards and vulnerability context

Similar to other indigenous people around the world, AIAN residing on tribal lands in the U.S. often live in small, rural communities, under lower socioeconomic conditions, and are frequently politically marginalized (Nakashima et al. 2012; UN 2009). AIAN depend more on subsistence livelihoods and have deep spiritual and cultural connections with their waters and lands. This section describes the types of climate, hydrologic, and ecosystem changes

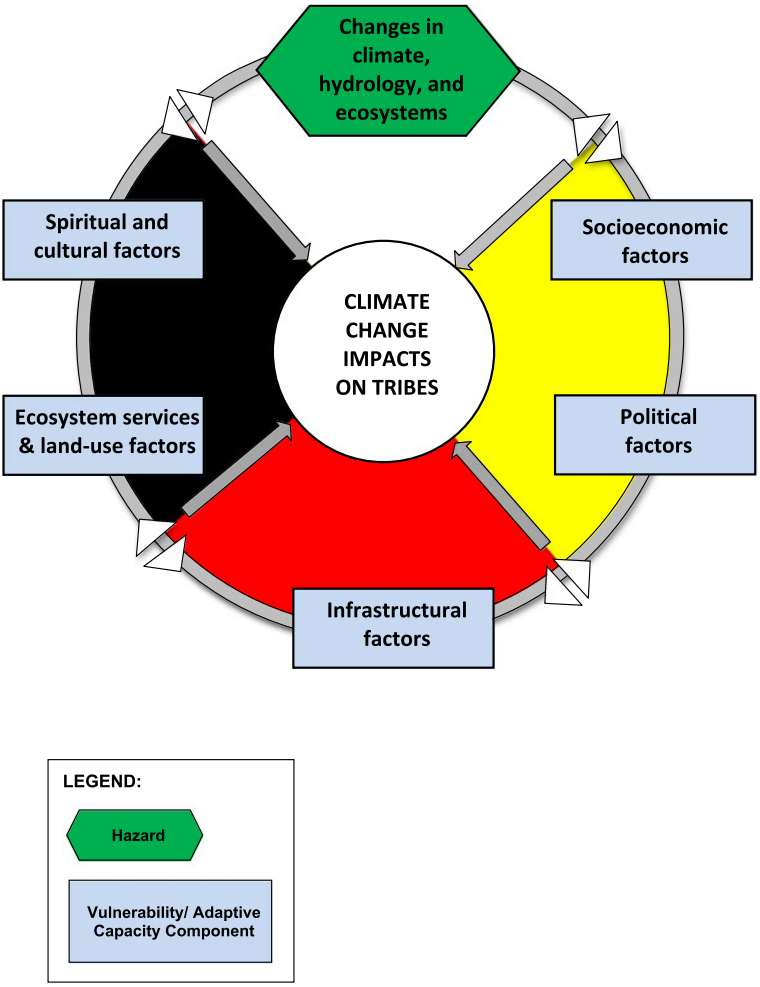


Fig. 2 Conceptual framework showing how climate change impacts are the outcome of vulnerability/adaptive capacity contexts and the nature (severity and frequency) of climate hazards

that constitute hazards experienced by tribes. It also describes sets of vulnerability/adaptive capacity factors that are common for many tribes, although, again, each tribe's situation is unique. Although we separate vulnerability factors into various categories for ease of conceptualization, these factors, as indicated in Fig. 2, will affect one another.

3.1 Climate, hydrologic, and ecosystem change hazards

Climate variability and change are currently resulting in or are likely to result in increased temperatures, changes to precipitation regimes, and increases in extreme events (CCSP 2008). These climatic changes are altering regional hydrology (i.e., quantity, quality, timing) in many ways such as permafrost thawing and earlier snowmelt (additional examples in supplemental Table S1). Changes in climatic and hydrologic parameters will lead to ecosystem changes. These can include habitat loss and altered nutrient cycling (Tillman and Siemann 2011). They

also include changes related directly to species, for instance, shifts in their geographic ranges and changes in population numbers (additional examples in supplemental Table S2). These types of changes constitute hazards to which AIAN are exposed. Ecosystem changes affect ecosystem services, as discussed below.

3.2 Socioeconomic factors

Factors such as community structure and rural–urban composition are recognized components of social vulnerability (Cutter et al. 2010). An examination of 2010 Census data for over 400 tribal lands (supplemental Table S3) shows that 69 % of AIAN communities have fewer than 2,000 people (AIAN and non-AIAN populations combined). Within these communities, 78 % of residents live in rural and 22 % in urban areas. These small, rural AIAN communities often have higher water supply costs because of greater transportation costs and smaller economies of scale (USEPA 2001). These higher costs are combined with economic conditions that are generally much lower than the U.S. average. The Census Bureau's 2006–2010 American Community Survey provides economic data for AIAN living in approximately 300 tribal areas. The average unemployment percentage (15 %) is nearly double the U.S. average (supplemental Table S3). The median household income is $33,379 or 36 % below the national average, and more than a quarter (29 %) of people live below the poverty level. A 2005 Bureau of Indian Affairs (BIA) report that uses different methods than the Census Bureau estimates higher unemployment (49 %) for AIAN living on or near tribal lands (supplemental Sec. 3.2). These economic conditions affect the management of tribal water resources (Sec. 3.4).

3.3 Political factors

Federally recognized tribes are domestic dependent nations with inherent rights of self-governance. Treaties, court decisions, and tribal legislation define this sovereignty and govern relationships between the tribes and outside entities (Houser et al. 2001). When tribes entered into treaties defining reservation lands, geographic boundaries became fixed for the first time in Native history. This restricted traditional migration practices, which were critical strategies for adapting to changing water resources and species movement (Gautam et al. 2013). Often, tribes were settled on remnants of their original land base or forcibly relocated to lands that were less valuable in terms of water resources and agricultural potential (Houser et al. 2001). Some tribes specifically reserved the rights to fish, hunt, and gather in customary areas off-reservation in treaties. However, these place-based rights may become geographically mismatched with species distributions as ranges shift in response to climate changes (Houser et al. 2001).

The foundational legal decision protecting tribal water resources is the 1908 *Winters* case [207 US 564 (1908)], which recognized that when tribes reserved reservation lands they also reserved the water rights necessary to fulfill the purpose of the reservation. Many of these "federal reserved rights" have yet to be adjudicated or exercised in full and many tribes are still in the process of negotiating with other stakeholders to quantify tribal water rights. Tribes who litigated and won water rights often did not receive infrastructure funding and subsequently are struggling to finance infrastructure to develop their water rights.

Off-reservation water use and pollution have direct impacts on tribal water resources yet tribes are often underrepresented in water resource management discussions and decision-making processes. Similarly, some international water commitments have not considered tribal rights (Houser et al. 2001). Climate change impacts on water quantity, quality, and timing add to legal and planning complexities and compound concern that Indian water

rights may be sacrificed under climate change resulting in unmet present and future human and environmental water demands.

3.4 Infrastructural factors

Water infrastructure pertains to physical structures (e.g., water supply and wastewater treatment plants, stormwater drainage systems, etc.) used to manage water for a variety of purposes (e.g., drinking, industrial, hydropower, agriculture, ranching). Changing climate, hydrologic, and ecologic regimes are creating conditions that tribal infrastructure may not be designed to accommodate, resulting, in cases, in the deterioration of physical structures and decreasing effectiveness (e.g., ability to treat water to a specified standard). This can lead to service disruptions with resulting economic and public health consequences.

Generally poorer economic conditions on tribal lands may mean that infrastructure is lacking, inadequate, or poorly maintained, increasing tribal vulnerability to flooding, drought, and waterborne diseases. Climate-related infrastructure damage can increase costs of providing water, which can quickly drain tribal financial reserves as funds are expended for emergency response (supplemental Sec. 3.4). Approximately 12 % of AIAN homes lack safe and adequate water supplies, and/or waste disposal facilities as compared to less than 1 % of the U.S. (IHS 2013). In some tribal areas, particularly in Alaska and the Navajo Nation, considerable portions of the population, 13 % and 25–40 % of households respectively, haul water (ITFAS 2008; NDWR 2003). Even without climate-related impacts, water haulers are more susceptible to waterborne diseases, especially if water is obtained from nonpotable sources (e.g., livestock wells) or if unsanitary hauling methods are used (ITFAS 2008).

3.5 Ecosystem services and land-use factors

People benefit from ecosystems in a variety of ways. These benefits are sometimes described as ecosystem services of which there are four commonly used categories: 1) provisioning (e.g., supply of food and water), 2) regulating (e.g., purification of wastewater discharged into a stream), 3) cultural services (e.g., supplying spiritual or recreational opportunities), and 4) supporting (e.g., photosynthesis, which supports food provisioning) (MEA 2005). Because climate changes can lead to ecosystem changes, climate changes affect ecosystem services. In addition, tribal ecosystem health and services are degrading because of depressed economic conditions, attempts to maintain traditional livelihoods on fixed, marginal lands (Sec. 3.3), urbanization, land-use changes, and invasive species (supplemental Box S6). One important ecosystem service for AIAN is provided by groundwater, which supplies 93 % of American Indian and 66 % of rural Alaska Native drinking water systems (USEPA 2001; ANTHC 2011). Others are provisioning of subsistence or supplemental foods and of spiritual and cultural services (see Sec. 3.6).

3.6 Spiritual and cultural factors

AIAN are intimately connected to the places in which they live through spiritual and cultural livelihoods and values. They are keepers of complex and extensive bodies of ecological and societal knowledge passed on through generations (UN 2009). They strongly associate cultural identities and traditional knowledge with their waters and lands and seek spiritual and religious inspiration from them. Particular locations such as mountains or springs are held sacred and certain waters may be used for ceremonial purposes. In addition, many tribes respect and hold sacred the individual role of species on Mother Earth and thus impacts on these species are of inherent concern to tribes. Traditional ecological knowledges (Wildcat this issue) contribute to

human cultural diversity and are a repository of long-term observations of environmental changes that have occurred and of adaptation strategies that have been effective in the past. This knowledge may be able to extend the environmental record in data sparse regions, improve monitoring design, and contribute to the future adaptive capacity of AIAN (supplemental Boxes S8 and S9).

4 Impacts

Climate change impacts to tribal water resources, livelihoods, and cultures are as diverse and unique as individual tribes and their cultures and geographic settings. However, based on our review, we have identified five categories of common impacts. These include impacts on: 1) water supply and management (including water sources and infrastructure), 2) aquatic species important for culture and subsistence, 3) ranching and agriculture particularly from climate extremes (e.g., droughts, floods), 4) tribal sovereignty and rights associated with water resources, fishing, hunting, and gathering, and 5) soil quality (e.g., from coastal and riverine erosion prompting tribal relocation or from drought-related land degradation). Several accompanying papers in this special issue expand on these themes, including the impacts of climate change on traditional foods (Lynn et al. 2013), a broader range of impacts for Alaska Natives (Cochran et al. 2013), and the relocation of tribal communities (Maldonado et al. 2013). As discussed below, observed impacts are predominantly detrimental. In addition to impacts, we have, in cases, also noted contributing vulnerability factors. For more information on impacts described and additional examples and references, we refer readers to the supplemental materials.

4.1 Alaska

Alaska, which is as large as one third of the continental U.S., is home to 227 federally recognized Alaska Native villages and communities (supplemental Table S7). Most of the villages are small and isolated, and many residents engage in traditional subsistence hunting (e.g., walruses, caribou), fishing (e.g., salmon), and gathering and are highly dependent on the state's rich water resources (ADFG 2010). Much of the water is frozen most of the year or locked up in glaciers or frozen ground. However, the Arctic including Arctic Alaska is experiencing some of the most profound warming in the world (IPCC 2007). In this section, we focus on impacts on Arctic Alaska Natives, most of whom live along the coast, and on water supply related impacts for the entire state. Key Arctic impacts include those on subsistence activities and coastal and riverine erosion. Key water supply impacts include those on source waters and related infrastructure.

Life for many Arctic Alaska Natives revolves around the hunting of sea mammals such as seals and whales, and sea ice plays an important role. Thinner ice and unusual cracks can create hazardous conditions leading to injuries and equipment loss (Mahoney et al. 2009). Timing shifts in sea ice freezing and thawing due to warming is altering hunting patterns. Permafrost thawing is making underground cellars used for storing food much less reliable (Brubaker et al. 2010). Storm surges exacerbated by delays in autumn sea ice development contribute to coastal erosion that is occurring to such a degree that some Native villages, such as Kivalina, are being forced to consider relocation at costs estimated in the hundreds of millions of dollars (Gray 2007). Permafrost thawing is contributing to riverine erosion with similar relocation concerns (Bowden et al. 2008).

Rural Alaska Native communities both in the Arctic and elsewhere in Alaska depend on groundwater (66 %), lakes and reservoirs (20 %), and rivers and creeks (14 %) for their water supply (ANTHC 2011). Little information is available on changes to Alaska Native

groundwater supplies, however, surface water sources and water supply infrastructure are being dramatically affected by climate changes (White et al. 2007). Algal blooms are increasing in lakes and rivers due to warmer temperatures, and in villages, like Point Hope, they are causing significant increases in treatment time and costs (Brubaker et al. 2010). Beavers, which can carry giardia, are occupying rivers in northern Alaska for the first time since the last ice age and are an example of shifting wildlife acting as vectors for waterborne diseases (Brubaker et al. 2012). As permafrost thaws in various areas of Alaska, the ground can absorb more water, and some lake water levels are decreasing or lakes are draining entirely, causing water supply problems (Rover et al. 2012). Erosion driven by permafrost thawing can cause high river turbidity levels, resulting in boil water notices and increased risk of waterborne disease (Brubaker et al. 2012). Extreme precipitation events can lead to flood-related contamination and high turbidity levels that can overwhelm water treatment systems (Brubaker et al. 2012). Subsidence due to permafrost thawing and erosion are causing widespread physical damage to water infrastructure, sometimes interrupting services for months (supplemental Sec. 4.1).

4.2 Pacific Northwest

The Pacific Northwest (PNW) is home to 42 federally recognized tribes (supplemental Table S7). The Cascade Mountains run north–south through the region, dividing it into a coastal zone west of the Cascades and a continental zone east of the mountains. The region has an October–March precipitation season. Much of the precipitation is stored in mountain snowpack and released during the April–July snowmelt period. PNW rivers host several salmon species, which are cultural keystones and important food and economic sources for many PNW tribes. Salmon are coldwater fish that start life in fresh, headwater streams as eggs. The juveniles are flushed to lower river estuaries to acclimate to saltwater, then migrate to the ocean for two to five years before returning upriver as adults to spawn and die (Crozier et al. 2008). Water supplies are important for tribal salmon hatcheries and reintroduction efforts (CRITFC 2013), riparian restoration, forestry, agriculture, small-scale hydropower, and municipal uses. Key climate change impacts include effects on salmon and shellfish, coastal erosion, and the exercise of treaty rights.

Storm intensities during the early part of the wet season are increasing (CIG 2012) and can lead to increased flooding, habitat scouring, and washing away of buried salmon eggs. Warming air temperatures can shift snowmelt to earlier in the spring, which may lead to lower summer flows and unfavorably warm water temperatures (Dittmer 2013). Salmon may respond by migrating downstream earlier; however, this change may be mismatched with downstream conditions (Crozier et al. 2008). Warmer summer water temperatures are already affecting the migration of returning adult salmon. In summer 2003, for instance, salmon paused their upstream migration, remaining below the Bonneville Dam on the Columbia River for four weeks until temperatures cooled.

West of the Cascades, changes in coastal processes are also affecting tribes. In addition to salmon, the Swinomish (WA) rely on various shellfish as staples of food and culture. The tribe identified inundation from sea level rise and flooding from storm surges as major climate change threats to its estuaries, which provide critical habitat for shellfish and juvenile salmon (SITC 2010). Ocean acidification can disrupt the calcification process involved in shell development and affect the reproduction and growth of marine organisms (Ingram et al. 2012). Traditional foods like roots and berries are suffering from increased soil salinization due to sea-level rise (Papiez 2009). For the Quileute Nation and Hoh Tribe (WA), increased winter storms are coinciding with high tides at the Quileute and Hoh river

mouths to create high storm surges that are washing away tribal lands. The Quileute are considering relocation. The Hoh are relocating to National Park Service land (ITEP 2012). Species migration out of traditional areas seems to be increasing (Papiez 2009). Treaty-protected rights to hunt, fish, and gather are typically linked to reservation locations or customary areas on public lands. Tribes like the Tulalip (WA) are concerned that, as species move, their distributions may become mismatched with locations of access.

4.3 Southwest

In the Southwestern U.S. (SW) from California to Utah and Arizona live 170 federally recognized tribes (supplemental Table S7) with small and large land holdings set in ranching, agriculture, mining, tourism, and other economies. Key climate change impacts stem from drought and flooding that affect livestock, agriculture, water supply, water rights, soil quality, and aquatic species.

Increasing aridity and drought threaten SW tribal cultures, pushing them to use marginal resources. Most of the 21 Colorado Plateau tribes have experienced drought for more than a decade (Redsteer et al. 2012). In the SW, drought is expected to increase in frequency and severity in the future (supplemental Table S1). On Navajo and Hopi lands in Arizona, lack of moisture has extended sand dune growth and migration to a third of the reservations, covering housing, causing transportation problems, and contributing to loss of endangered native plants and grazing land (Redsteer et al. 2011, 2012). On the Navajo Reservation, 25–40 % of residents haul water for household use at costs 20 times more than for non-Navajo water users in surrounding areas while per capita income is less than half the U.S. average (NDWR 2003). According to one study, the average trip was 14 miles one way (ITFAS 2008). During drought, increased traveling distances to water bearing public systems and doubled water-hauling costs are common challenges (NDWR 2003).

In Arizona, the Hualapai Tribe depends on tourism, big-game hunting, cattle grazing, and forestry for revenue, and its economy was greatly impacted by a multiyear drought in the early 2000s (Knutson et al. 2006). The drought forced the tribe to sell approximately 500 of its cattle because of supplemental water and feed costs. Other impacts included more wildfires, road closures due to wildfire threat, increases in invasive species and wildlife disease, loss of wetlands, wind erosion and visibility problems, and increased operating expenses for a river rafting company (Knutson et al. 2006).

In Nevada, the Pyramid Lake Paiute Tribe is deeply connected to the unique ecosystem of Pyramid Lake, which is home to a native, endangered species called cui-ui, the tribe's primary cultural resource. Traditionally, Paiute people traveled to the lake for cui-ui spawning to gather and dry fish. Today, the tribal economy is centered on fishing and recreational activities at the lake. The lake's wetlands also provide reeds for basketry, which remains a symbol of native identity. In the future, drought, increased temperatures and reduced inflows will likely increase the lake's salinity leading to reduced biodiversity with dominance of warmer temperature and salt tolerant species (Gautam et al. 2013).

Extreme precipitation events have also affected SW tribes. The Havasupai Tribe in Arizona, for example, experienced several severe floods from 2008 to 2010 that damaged trails, campgrounds, and recreational areas in Havasu Canyon, greatly impacting tourism revenue (Wotkyns 2010). Over 20 southwestern tribes have reservation lands and associated water rights in the Colorado River watershed. Anticipated decreased flows due to climate change combined with rapid population growth are increasing the urgency of adjudicating and defining these rights (Cordalis and Suagee 2008).

4.4 Great Plains

The Great Plains extend from Montana to Texas with the Rocky Mountains marking the region's western edge. Historically, the Plains were predominantly grasslands and the range of vast bison herds. Today, 70 federally recognized tribes call the Great Plains their home (supplemental Table S7) and engage in subsistence and economic activities such as agriculture, ranching, tourism, energy extraction, and renewable energy production. Key climate change impacts include those on water supply, ranching, agriculture, and water for ceremonial uses stemming from climate extremes such as drought and flooding and from increased glacial melting and shifts in snowmelt timing.

In North Dakota, the Standing Rock Sioux Tribe depends on a sole intake pipe from the Missouri River at Fort Yates for its water supply. A 2003 drought caused water levels to drop so low that silt and sludge clogged the pipe. The tribe did not have water for several days and an Indian Health Service hospital had to temporarily shut down (Albrecht 2003). In 2011, Oklahoma and Texas experienced a historic drought and heat wave. Drought impacts noted by the tribes included difficulties producing enough food for sustenance and hay to feed cattle (Riley et al. 2012). The lack of hay combined with the drying of stock ponds forced farmers to sell their livestock prematurely and depressed markets resulted from the accelerated selloff. Low water levels contributed to fish die-offs and blooms of blue-green algae. Tribes relying on hydropower had difficulty meeting energy needs and drying soils shrinking and compacting around pipes caused water main breaks. Flowing water, crucial for many tribal ceremonies, was lacking. Drought can amplify wildfire and flooding risks by creating dry conditions that provide increased fuel for high intensity fires, which in turn create water repellent post-fire soils that lead to increased runoff and subsequent debris flows that decrease water storage capacity (NWF 2011; Moench and Fusaro 2012).

Flooding can cause various impacts as well. In February 2011, the Pine Ridge Reservation (SD) experienced unusually early flooding when statewide high temperatures reached 40–70 °F, causing premature snowmelt (Skadsen and Todey 2011). This, combined with ice jams and clogged culverts, resulted in flooding throughout much of the reservation, and emergency drinking water and supplies had to be delivered to stranded residents (ICTMN 2011). Tribes often have widely dispersed populations that can make emergency response to situations like this challenging.

Residents of the Wind River Reservation (WY) depend on Rocky Mountain snowmelt for irrigation water, and during times of earlier snowmelt concerns about water for late season agricultural irrigation arise. In addition, flooding from the dramatic glacial retreat in the Wind River Mountain range is causing silt build up in irrigation ditches (NWF 2011). In some Rocky Mountain areas, dust from anthropogenically-disturbed soils may contribute to earlier snowmelt (Painter et al. 2010) and exacerbate impacts from warming temperatures.

4.5 Midwest

The Midwest (MW) is the location of the five lakes comprising the Great Lakes that together form Earth's largest surface freshwater system. Thirty federally recognized tribes live in MW states and depend on this resource (supplemental Table S7). Ceremonies honoring the waters as the life-blood of Mother Earth are held throughout the region. MW tribes depend on the waters for subsistence and commercial fishing and for water-based plant materials for traditional crafts and artwork (Tribal and First Nations Great Lakes Water Accord 2004). Additionally, most MW tribes now operate gaming facilities and other tourism enterprises that rely heavily upon water for aesthetic and recreational uses (Tribal Gaming in the States 2007).

Many MW tribes consider climate change adaptation to be one of the most important long-range environmental issues for tribal nations. Michigan tribes, for instance, have worked with the state to negotiate and sign the May 12, 2004 Intergovernmental Accord between the Federally Recognized Indian Tribes in Michigan and the Governor of the State of Michigan Concerning Protection of Shared Water Resources and the June 11, 2009 Intergovernmental Accord between the Tribal Leaders of the Federally Recognized Indian Tribes in Michigan and the Governor of Michigan to Address the Crucial Issue of Climate Change. Biannual meetings are held between the state and tribes to discuss shared responsibilities and potential cooperative efforts.

Impacts on MW tribes are diverse. Key impacts are related to flora and fauna important for diet, acknowledging clan responsibilities, social and mental health, and the exercise of treaty rights. Traditional healers in the region, for instance, have noted that lack of moisture and unreliable springtime temperatures have caused significant wild and cultivated crop losses (traditional healers, personal communication; CIAB 2012).

Wild rice (manoomin) is a sacred food of great importance to the Ojibwe of the Great Lakes area and may be detrimentally affected by climate change. In the Ojibwe Migration Story, The Great Mystery foretold the coming of the light-skinned race and instructed the Ojibwe to journey westward until they found "the food that grows on water." Since the 1900s, the loss of wild rice acreage to mining, dams, and other activities has been substantial (FDLNR 2013). Warmer temperatures could cause further losses by reducing seed dormancy, favoring invasive, outcompeting plants, and being conducive to brown spot disease (MDNR 2008). Water levels also influence rice survival. Extremely low Lake Superior levels in 2007 forced the Bad River Band of the Lake Superior Tribe of Chippewa (WI) to cancel its annual wild rice harvest due to dramatic crop reductions (UW Sea Grant 2007). A 2012 flood led to near total wild rice crop failure on the Fond du Lac Reservation (T. Howes 2013, personal communication).

Tribes in the Great Lakes area rely on treaty fishing, hunting, and gathering rights. The exercise of these rights requires considerable attention to environmental issues, including climate changes that affect species and habitats. These rights have been the subject of several court cases, which have resulted in decisions upholding tribal rights.

4.6 East

The eastern U.S. extends from Maine to Florida and Louisiana. Twenty-seven federally recognized tribes live in the region (supplemental Table S7). Tribal members rely on natural resources to provide them with food and spiritual sustenance. Many tribal members engage in fishing (e.g., lobsters, shrimp), hunting (e.g., moose), and gathering (e.g., blueberries, medicinal plants) and rely on diverse water resources including riverine, estuarine, and oceanic ones. Key climate change impacts include those on aquatic species of cultural and livelihood importance and coastal erosion.

Riverine tribal communities may be exposed to higher incidences of flooding as a result of increased snowfall and rapid snowmelt (Horton et al. submitted). Fishery habitat may also be affected by flooding, as high river flows can potentially scour fish habitat and nesting sites, increasing fish mortality.

Coastal tribes obtain sustenance and employment from shellfish harvesting and fishing. Similar to the PNW, ocean acidification may affect the ability of shellfish to process calcium and magnesium carbonate and impact shell development (Ingram et al. 2012). Tribes in coastal Louisiana have identified land loss, which is leading to concerns about relocation, and saltwater intrusion, which is affecting the ability of tribal members to farm, as major issues (Louisiana Workshop 2012). These changes stem from a complex combination of human and environmental causes to which climate change may be contributing. Factors in

one or both issues include canal construction associated with oil extraction; subsidence; levee systems leading to decreased sediment deposition; storms; and erosion (Bethel et al. 2011). Rising sea levels can also contribute to inundation leading to land loss and saltwater intrusion (Nicholls and Cazenave 2010). The Gulf of Mexico along the Louisiana/Texas coast is the location of one of the world's largest zones of coastal hypoxia, which is a concern for tribes. Climate changes could exacerbate/lessen hypoxia by, for example, increasing/decreasing river discharges and associated nutrient delivery into coastal areas, however, other factors like rising populations will likely lead to increased nutrient loads (Rabalais et al. 2009; supplemental Sec. 4.6).

The fishing/shellfish livelihoods of both riverine and coastal tribes may be affected by warming water temperatures, which can result in lower oxygen levels and greater susceptibility to parasites and disease that can stunt growth and increase juvenile mortality (Frumhoff et al.

Table 1 Examples of potentially significant research questions based on the five impacts categories

1) Impacts on water supply and management (including water sources and infrastructure)
   - How will climate change and other vulnerability factors such as population growth and land use changes affect the quantity and quality of AIAN surface and groundwater?
   - Given the importance of groundwater for AIAN drinking water systems, how can groundwater-surface water systems be collaboratively and conjunctively managed to maintain the viability and quality of AIAN aquifers?
   - What are the most effective ways (in terms of decreasing health risks, time, costs) for addressing water supply deficiencies in Indian Country, while taking climate change into account?
   - How can AIAN water supply infrastructure be better adapted to the climate changes occurring (e.g. drought, permafrost melting, algal blooms)?
2) Impacts on aquatic species important for culture and subsistence
   - Which species are particularly important to tribes for culture and subsistence (acknowledging that for many tribes all species are inherently important)?
   - How are and will climate changes and other vulnerability factors (e.g., habitat fragmentation) affect the geographic ranges and populations of such species?
   - What partnerships are needed and what strategies can help promote species resilience and transition?
3) Impacts on ranching and agriculture particularly from climate extremes (e.g., droughts, floods)
   - How can AIAN ranching and agriculture be made more resilient to climate extremes such as drought and flooding?
4) Impacts on tribal sovereignty and rights associated with water resources, fishing, hunting, and gathering
   - What are the potential impacts of climate change on tribal water rights (both in terms of quantity and quality) and off-reservation rights to fish, hunt, and gather?
   - How can climate change considerations be incorporated into AIAN water rights negotiations?
   - What types of legal and governmental processes can be put into place to allow tribes to renegotiate off-reservation rights to fish, hunt, and gather if species migrate to new areas?
5) Impacts on soil quality (e.g. coastal and riverine erosion prompting tribal relocation and drought-related land degradation)
   - Which tribes have a higher risk of losing their lands due to climate-related changes (e.g., coastal inundation, melting permafrost, coastal and riverine erosion) and to other vulnerability factors (e.g., levee systems leading to decreased sediment deposition and land buildup, unsustainable resource extraction) or have a higher risk of lands becoming unusable due to factors such as drought-related soil degradation and sand dune formation and migration?
   - What strategies can be put into place to decrease land loss or restore degraded lands?
   - What types of governmental processes (tribal and federal) can be put into place to assist tribes with identifying lands and funds for relocation if that becomes a necessity?
   - How can sites and/or practices that may be lost be documented most effectively?

2007). Although warming in the Northeast's colder water, particularly in the eastern Gulf of Maine, could boost lobster productivity, warmer waters may also be more hospitable for a bacterial condition known as lobster shell disease that grotesquely scars lobster shells making them less lucrative for sale (Frumhoff et al. 2007) impacting northeastern coastal tribes like the Pleasant Point Passamaquoddy in Maine who harvest lobster. Tribal communities often consume higher amounts of fish and shellfish than the average population increasing their exposure to methylmercury accumulated in seafood. One study found that warming oceans may facilitate the methylation of mercury and its uptake by fish (Booth and Zeller 2005).

5 Concluding thoughts

From the discussion above, it is evident that tribes have an urgent need to prepare for and respond to climate change impacts and that tribes as well as non-tribal entities supporting such efforts need to do so in a way that considers cultural values. In addressing these issues, it is important to take into account not only climate hazards but also socioeconomic, political, and other factors (Fig. 2) that contribute both to a community's vulnerability and adaptive capacity. In the supplemental section, we have provided an extensive table (Table S6) with general categories of actions that could increase the adaptive capacity of tribes, how they relate to contributing hazard and vulnerability factors, and examples of such actions currently taking place.

More specifically, Native American tribes need relevant and culturally appropriate (supplemental Sec. 5) monitoring, assessment, and research on their waters and lands and to develop or be included in the development of contingency, management, and mitigation plans. Tribes also greatly need actual implementation of projects. Although climate change preparedness can take place as a stand-alone effort, climate change considerations can be included as part of planning and implementation that is already occurring (supplemental Table S4).

Tribes or intertribal organizations must decide what constitutes relevant work. In Table 1, we propose research questions that might be significant for tribes based on the five impact categories. These include examples of science, policy, and social science questions related both to further identifying impacts and contributing climate and vulnerability factors and to identifying adaptation strategies.

To the benefit of adaptation processes, traditional ecological knowledges (TEKs) (Wildcat this issue) should be incorporated at all stages in a way that respects individual and tribal sovereignty over these TEKs. Capacity building in the form of training, employment, and education opportunities will enhance tribes' abilities to conduct their own assessments and implementation. Many tribes have unquantified and/or undeveloped water rights, which makes planning for tribes and others in a region more challenging (Collins et al. 2010). It is thus imperative that tribes adjudicate and solidify their water rights and that water management polices be designed to consider climate change scenarios while also considering tribal rights. Many tribes have a great need for monitoring to help identify the environmental changes that are occurring and to assess the effectiveness of adaptation strategies (Collins et al. 2010). Because tribes are stretched thin in addressing current problems, much less preparing for future climate change impacts, funding strategies to assist with all stages of climate change preparedness are critical. In the aforementioned undertakings, tribes can take advantage of partnerships with government entities, nonprofit organizations, universities, tribal colleges, and one another (supplemental Table S5). For in the end, like raindrops forming an ocean, we are all family, in relationship, and deeply connected.

Acknowledgments The authors would like to thank the following people for their valuable assistance with the manuscript preparation: D. Heom, J. Deems, J. Nania, J. Maldonado, M. Stover, N. Crowe, R. Pandya, T. Howes, and two anonymous reviewers.

References

Alaska Department of Fish and Game (ADFG) (2010) Subsistence in Alaska: a year 2010 update. Anchorage, Alaska

Alaska Native Tribal Health Consortium (ANTHC), Center for Climate and Health (2011) Alaska community source water inventory

Albrecht M (2003) Progress made, but Fort Yates still dry. The Bismarck Tribune. Nov. 25, 2003

Bethel MB, Brien LF et al (2011) Blending geospatial technology and traditional ecological knowledge to enhance restoration decision-support processes in Coastal Louisiana. J Coast Res 27(3):555–571

Booth S, Zeller D (2005) Mercury, food webs, and marine mammals: implications of diet and climate change for human health. Environ Heal Perspect 113(5):521–526

Bowden WB, Gooseff MN et al (2008) Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska. J Geophys Res Biogeosci 113(G2)

Brubaker M, Berner J et al (2010) Climate change in point hope Alaska, strategies for community health. ANTHC Center for Climate and Health

Brubaker M, Berner J et al (2012) Climate change in Selawik, Alaska, strategies for community health. ANTHC Center for Climate and Health

Bureau of Indian Affairs (BIA) (2005) 2005 American Indian population and labor force report. Washington, DC

CCSP (2008) Weather and climate extremes in a changing climate. Regions of focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research

Cherry Industry Administrative Board (CIAB) (2012) The crop failure of 2012. In CIAB Newsletter

Climate Impacts Group, University of Washington (CIG) (2012) About Pacific Northwest Climate. http://cses.washington.edu/cig/pnwc/pnwc.shtml

Cochran P, Huntington OH et al (2013) Indigenous frameworks for observing and responding to climate change in Alaska. doi:10.1007/s10584-013-0735-2

Collins G, Redsteer M et al (2010) Climate change, drought and early warning on Western Native Lands workshop report. National Integrated Drought Information System

Cordalis D, Suagee DB (2008) The effects of climate change on American Indian and Alaska native tribes. Nat Resour Environ 22(3):45–49

Columbia River Inter-Tribal Fish Commission (CRITFC) (2013) Salmon restoration projects. http://www.critfc.org/fish-and-watersheds/fish-and-habitat-restoration/restoration-projects/search-results

Crozier LG, Hendry AP et al (2008) Potential responses to climate change in organisms with complex life histories: evolution and plasticity in Pacific salmon. Evol Appl 252–270

Cutter SL, Burton CG, Emrich CT (2010) Disaster resilience indicators for benchmarking baseline conditions. Journal of Homeland Security and Emergency Management 7(1):1–24

Dittmer K (2013) Changing streamflow on Columbia basin tribal lands-climate change and salmon. doi:10.1007/s10584-013-0745-0

Fond du Lac Natural Resources Program (FDLNR) (2013) http://www.fdlrez.com/newnr/natres/wildrice.htm

Frumhoff PC, McCarthy JJ et al (2007) Confronting climate change in the U.S. Northeast: science, impacts, and solutions. Union of Concerned Scientists, Cambridge

Füssel HK, Klein RJT (2006) Climate change vulnerability assessments: an evolution of conceptual thinking. Clim Chang 75:301–329

Gautam M, Chief K, Smith Jr WF (2013) Climate change in Arid Lands and Native American socioeconomic vulnerability: the case of the Pyramid Lake Paiute Tribe. doi:10.1007/s10584-013-0737-0

Gray G (2007) Alaska villages face increased hazards from climate change. Coastal Zone Conference Proceedings, Portland

Horton R, Solecki W, Rosenzweig C (eds) (submitted) Climate change in the Northeast: a source handbook. Draft Technical Input Report for the US National Climate Assessment

Houser S, Teller V et al (2001) Chapter 12—Potential consequences of climate variability and change for native peoples and homelands. In: National Assessment Synthesis Team (ed) Climate change impacts on the United States: the potential consequences of climate variability and change. Cambridge University Press, Cambridge

Indian Country Today Media Network (ICTMN) (2011) Flood of help to stranded Pine Ridge residents. February 20, 2011
Indian Health Service (IHS) (2013) Safe water and waste disposal facilities fact sheet. Rockville, MD
Infrastructure Task Force Access Subgroup (ITFAS) (2008) Meeting the access goal: strategies for increasing access to safe drinking water and wastewater treatment to American Indian and Alaska native homes. Washington, DC
Ingram KT, Dow K, Carter L (2012) Southeast region technical report for the US National Climate Assessment.
Institute for Tribal Environmental Professionals (ITEP) (2012) Tribal climate change profile: first stewards symposium
IPCC (2007) Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, United Kingdom
Knutson C, Svoboda M, Hayes M (2006) Analyzing tribal drought management: a case study of the Hualapai Tribe. Natural Hazards Quick Response Report, No. 183
Louisiana Workshop (2012) Stories of change: Coastal Louisiana Tribal Communities' experiences of a transforming environment. Input to the National Climate Assessment
Lynn K, Daigle J et al (2013) The impacts of climate change on tribal traditional foods. doi:10.1007/s10584-013-0736-1
Mahoney A, Gearheard S, Oshima T, Qillaq T (2009) Sea ice thickness from a community-based observing network. Bull Am Meteorol Soc 90:370–377
Maldonado JK, Shearer C et al (2013) The impact of climate change on tribal communities in the U.S.: displacement, relocation, and human rights. doi:10.1007/s10584-013-0746-z
Millenium Ecosystem Assessment (MEA) (2005) Ecosystems and human well-being: synthesis. Island Press, Washington
Minnesota Department of Natural Resources (MDNR) (2008) Natural Wild Rice in Minnesota.
Moench R, Fusaro J (2012) Soil erosion control after wildfire. Colorado State University Extension
Nakashima DJ, McLean KG et al (2012) Weathering uncertainty: traditional knowledge for climate change assessment and adaptation. UNESCO, Paris
National Wildlife Federation (NWF) (2011) Facing the storm—Indian Tribes, climate-induced weather extremes, and the future for Indian Country
Navajo Department of Water Resources (NDWR) (2003) Navajo nation drought contingency plan. Fort Defiance, AZ
Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. Science 328(5985):1517–1520
Painter TH, Deems JS et al (2010) Response of Colorado River runoff to dust radiative forcing in snow. Proc Natl Acad Sci U S A 107:17125–17130
Papiez C (2009) Climate change implications for the Quileute and Hoh Tribes of Washington: A multidisciplinary approach to assessing climatic disruptions to coastal indigenous communities. M.S. Thesis published by Evergreen State College
Rabalais NN, Turner RE et al (2009) Global change and eutrophication of coastal waters. ICES J Mar Sci 66:1528–1537
Redsteer M. Hiza, Bogle RC, Vogel JM (2011) Monitoring and analysis of sand dune movement and growth on the Navajo Nation, Southwestern United States. U.S. Geological Survey Fact Sheet 2011–3085
Redsteer M. Hiza, Bemis K et al (2012) Unique challenges facing Southwestern tribes: impacts, adaptation, and mitigation. Chapter 17 in Assessment of Climate Change in the Southwest United States: a Technical Report Prepared for the U.S. National Climate Assessment
Riley R, Blanchard P et al (2012) Oklahoma inter-tribal meeting on climate variability and change—December 12, 2011 meeting summary report. National Weather Center, Norman
Rover J, Ji L et al (2012) Establishing water body areal extent trends in interior Alaska from multi-temporal Landsat data. Remote Sens Lett 3(7):595–604
Skadsen N, Todey D (2011) South Dakota climate summary—February 2011. South Dakota State University
Swinomish Indian Tribal Community (SITC) (2010) Swinomish climate adaptation action plan. La Conner, WA
Tillman P, Siemann D (2011) Climate change effects and adaptation approaches in freshwater aquatic and riparian ecosystems in the North Pacific landscape conservation cooperative region. National Wildlife Federation
Tribal and First Nations Great Lakes Water Accord (2004)
Tribal Gaming in the States (2007)
United Nations (UN) Secretariat of the Permanent Forum on Indigenous Issues (2009) State of the world's indigenous people. UN, New York.

U.S. Environmental Protection Agency (USEPA) (2001) Drinking water infrastructure needs survey: American Indian and Alaska native village water systems survey. USEPA, Washington

University of Wisconsin Sea Grant (UW Sea Grant) (2007) Unknowns on our coast.

White DM, Gerlach SC et al (2007) Food and water security in a changing arctic climate. Environ Res Lett 2(4):045018

Wotkyns S (2010) Tribal climate change efforts in Arizona and new Mexico. Institute for Tribal Environmental Professionals, Flagstaff