REGIONAL DIFFERENCES IN COASTAL GEOGRAPHY AND THREATS FROM CLIMATE CHANGE

Short tag line (on graphic)	Extended description (clickable or on accompanying pdf)	References (with extended text)
Northeast		
Highly built-up coastal corridor concentrates population and supporting infrastructure.	Sixty-four million people are concentrated across the Northeast. The high-density urban coastal corridor from Washington, D.C. north to Boston is one of the most built-up environments in the world, and it comes with a huge network of supporting infrastructure. With a modest rise of 0.5 m (1.5 ft) in sea level, approximately $6 trillion worth of property could be exposed to coastal flooding in the Baltimore, Boston, New York, Philadelphia, and Providence metropolitan areas (Lenton et al. 2009). In New York City alone, this is an increase of 23% over the no-rise scenario (ibid.) New York City, Nassau County, and New York, New Jersey and Massachusetts are among the top ten cities, counties and states, respectively, in terms of the largest total populations living on land less than 4 ft above local high tide (Strauss et al. 2012).	Lenton, T., A. Footitt, and A. Dlugolecki (2009). *Major Tipping Points in the Earth's Climate System and Consequences for the Insurance Sector*. World Wide Fund for Nature, Gland, Switzerland and Allianz SE, Munich, Germany. Retrieved from: http://knowledge.allianz.com/climate_tipping_points_en.html. Strauss, B., C. Tebaldi and R. Ziemlinski (2012). *Surging Seas: Sea level rise, storms and global warming's threat to the US coast*. Climate Central. Retrieve from: http://sealevel.climatecentral.org/research/reports/surging-seas/
Storm surges from nor'easters and hurricanes can cause significant damage.	The northeast receives surges from northeasters (extratropical storms) and hurricanes (tropical storms). Both have caused significant damage historically, and Superstorm Sandy, followed by a nor'easter y in Fall 2012 is a particularly illustrative example. Northeasters typically cover larger areas and sometimes last over several tidal cycles, while hurricanes are relatively short-lived but typically greater in intensity (Kocin and Uccellini 1990; Dolan and Davis 1994). The wave run-up (movement of wave water up a slope or structure) on steeply sloping beaches and shorelines in New England contributes additionally to coastal flooding.	Kocin, P.J. and L.W. Uccellini (1990). *Snowstorms along the Northeastern Coast of the United States: 1955 to 1985*. Meteorological Monographs, vol. 22, no.44, American Meteorological Society, Boston, MA. Dolan, R. and R.E. Davis (1994). Coastal Storm Hazards. *Journal of Coastal Research*, Special Issue 12: 103-114.
The historical rate of relative sea-level rise varies across the region.	The historical rate of relative sea-level rise as reported by NOAA has varied from 1.76 (Seavey Island, ME) to 5.48 mm/yr (Ocean City, MD) (NOAA 2013; see also Kirshen et al. 2008). Subsidence and other local and regional processes contribute to differences	Calculated sea-level rise rates from NOAA: In mm/yr: http://tidesandcurrents.noaa.gov/sltrends/msltrendstable.htm.

	from the global rate of sea-level rise. Sallengeret al. (2012) reported a recent acceleration of regional sea-level rise rates. (See also Chapter 2: Climate Science)	In ft/century: http://tidesandcurrents.noaa.gov/sltrends/msltrendstablefc.htm Kirshen, P., C. Watson, E. Douglas, A. Gontz, J. Lee, and Y. Tian (2008). Coastal Flooding in the Northeastern USA under High and Low GHG Emission Scenarios, Mitigation and Adaptation Strategies for Global Change. *Mitigation and Adaptation Strategies for Global Change* 13 (5):437-451. Sallenger, A. H., K. S. Doran, and P. A. Howd (2012). Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Clim. Change* 2 (12):884-888.
Wetlands and estuaries are vulnerable to inundation from sea-level rise; buildings and infrastructure are most vulnerable to higher storm surges as sea-level rises.	The region's many wetlands and estuaries are vulnerable to inundation from sea-level rise. Buildings and infrastructure are most vulnerable to higher storm surges as sea-level rises but do show some vulnerability to sea-level rise alone (Neumann 2010). Coastal storms not only bring storm surges but also high winds and often heavy precipitation. Tebaldi et al. (2012) found that the recurrence intervals of 100-year storms under a sea-level rise equivalent to the NCA intermediate high scenario by 2050 decrease to similar storms occurring every 5 to 75 years depending on the specific location across the Northeast.	Neumann, J., D. Hudgens, J. Herter, and J. Martinich (2010). The economics of adaptation along developed coastlines. *Wiley Interdisciplinary Reviews: Climate Change* 2 (1):89–98. Tebaldi, C., Strauss, B.H. and C.E. Zervas (2012). Modelling sea-level rise impacts on storm surges along US coasts. *Environmental Research Letters*, 7, 014032 doi:10.1088/1748-9326/7/1/014032.
Mid-Atlantic		
Rates of local sea-level rise in the Chesapeake Bay are greater than the global average.	During the 20th century, the average rate of sea-level rise in the Chesapeake Bay was 3.5 mm per year, nearly double the long-term globally averaged rate (Zervas 2001). Relatively rapid land subsidence around Chesapeake Bay is well established (Davis and Mitrovica 1996). The Bay falls within a "hotspot" on the U.S. East Coast (between Cape Hatteras, NC and Boston, MA), where recent	Zervas, C.E. (2001). *Sea level variations of the United States, 1854-1999*. Silver Spring, MD: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service.

	rates of sea-level rise were 3-4 times higher than the global average, a potential early signal of local *acceleration* of sea-level rise due to the projected slowing of Atlantic currents (meridional overturning circulation) (Sallenger et al. 2012). Relative sea-level rise of 0.7 (within the projected NCA sea-level rise range) to 1.6 m (slightly higher than the NCA sea-level rise range) is projected for the Bay by 2100 (Pyke et al. 2008).	Davis, J.L. and Mitrovica, J.X. (1996). Glacial isostatic adjustment and the anomalous tide gauge record of eastern North America. *Nature,* 379: 331–333. Sallenger, A.H. Jr., Doran, K.S., and Howd, P.A. (2012). Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change* doi:10.1038/nclimate1597. Pyke, C., Najjar, R., Adams, M.B., Breitburg, D., Hershner, C., Kemp, M., Howarth, R., Mulholland, M., Sellner, K., and Wood, R. (2008). Climate Change and the Chesapeake Bay. US EPA Chesapeake Bay Program. Science and Advisory Committee White Paper. Annapolis, MD.
Sea-level rise and related flooding and erosion threaten coastal homes, infrastructure and commercial development, including ports.	Using block-level population and housing data from the 2010 US Census, Strauss et al. (2012a,b) estimated that more than 625,000 people currently live in nearly 347,000 homes within 3 ft. (1 m) of average local high tide along the Mid-Atlantic shoreline (including New York, New Jersey, Pennsylvania, Delaware, Maryland, the District of Columbia, Virginia and North Carolina). These numbers hint not only at the significant exposure of people and homes, but also of related infrastructure and economic activity to the impacts of coastal storms and sea-level rise. For example, Hampton Roads, Virginia, is a major port, ranking 9th in the United States in 2011 for the value of shipping through the port, with $58.8 billion in imports and exports (U.S. Census Bureau Trade Data Branch 2011). Ship construction and repair provided more than 20,000 jobs and $5.2 billion in output in 2002 (Hampton Roads Planning District Commission 2004; see also AAPA 2012). The mid-Atlantic region also supports the largest military port in the world (in Norfolk, VA).	Strauss, B., C. Tebaldi, and R. Ziemlinski (2012a). *Surging Seas: Sea level rise, storms and global warming's threat to the US coast*. State fact sheets. Climate Central. Retrieve from: http://sealevel.climatecentral.org/research/reports/surging-seas/ Benjamin, H. S., Z. Remik, L. W. Jeremy, and T. O. Jonathan (2012). Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. *Environmental Research Letters* 7 (1):014033. Retrieve from: http://iopscience.iop.org/1748-9326/7/1/014033/article. US Census Bureau Trade Data Branch (2011). Table: Top Ten US Seaport Districts in Dollar Value of goods handled. Retrieved from: South

	(http://www.cnic.navy.mil/norfolksta/). All of these assets are already and increasingly vulnerable to sea-level rise and storm surge (see also Figure 25.4, Panel (d).	Carolina State Ports Authority for calendar year 2011, http://www.port-of-charleston.com/About/statistics/dollarvalue.asp. Hampton Roads Planning District Commission (2004). The Hampton Roads Economy: Analysis and Strategies. Chesapeake, VA. Retrieved from http://www.hrpdc.org/Documents/Economics/Part%202%20Cluster%20Study.pdf American Association of Port Authorities (AAPA, 2012). Port Industry Statistics. Retrieved from: http://www.aapa-ports.org/industry/content.cfm?itemnumber=900andnavitemnumber=551
Chesapeake Bay ecosystems are already heavily degraded, making them more vulnerable to climate-related impacts.	Since the 1600s, land cover in the Chesapeake Bay has changed significantly, with 1.7 million acres of the Bay watershed land area developed between 1600 and 1950 and another 2.7 million acres of land developed between 1950 and 1980 (CBF 2012). As a result, the Bay has lost half of its forested shoreline, more than half of its wetlands, about 80 percent of underwater grasses, and more than 98 percent of the oysters (CBF 2012). Climate change can interact with (and potentially exacerbate) non-climatic stressors. Climate-related changes projected for the Chesapeake Bay ecosystem include: increased coastal flooding and submergence of estuarine wetlands, increased variability in salinity, increased harmful algal blooms, changes in nutrient loading, increased hypoxia, reduction in eelgrass, and changes in species interactions (Pyke et al. 2008; Najjar et al. 2010). More frequent inundation may alter species composition and favor the proliferation of invasive species, such as the wetland grass *Phragmites australis* (US EPA 2008, Najjar et al. 2010). Overall, future wetland change will be strongly influenced by changes in human land use, as development and shoreline hardening can inhibit wetland migration (Najjar et al. 2010).	Chesapeake Bay Foundation (CBF, 2012). Retrieved from: http://www.cbf.org/page.aspx?pid=433 Pyke, C., Najjar, R., Adams, M.B., Breitburg, D., Hershner, C., Kemp, M., Howarth, R., Mulholland, M., Sellner, K., and Wood, R. (2008). Climate Change and the Chesapeake Bay. US EPA Chesapeake Bay Program. Science and Advisory Committee White Paper. Annapolis, MD. Najjar, R., Pyke, C., Adams, M., Breitburg, D., Hershner, C., Kemp, M., Howarth, R., Mulholland, M., Paolisso, M., Secor, D., Sellner, K., Wardrop, D., and Wood, R. (2010). Potential Climate Change Impacts on the Chesapeake Bay. *Estuarine, Coastal and Shelf Science*. 86(1): 1-20.

		EPA (U.S. Environmental Protection Agency). (2008). Effects of Climate Change on Aquatic Invasive Species and Implications for Managementand Research, EPA/600/R-08/014. U.S. Environmental Protection Agency, Washington, D.C., 337 pp.
Southeast and Caribbean		
A large number of cities, critical infrastructure, and water supplies are at low elevations and exposed to sea-level rise, in some places moderated by land uplift.	Major cities, including New Orleans (with roughly half of its population living below sea level; Campanella 2010), Miami, Tampa, Charleston, Virginia Beach, are among those most at risk (Strauss et al. 2012). On a state-by-state comparison, Florida ranks second in terms of total land area below 3 ft (1 m) (behind Louisiana), but first nationwide in terms of housing units (894,339) and population (1,609,312) at risk in 2010 (Strauss et al. 2012).	Campanella, R., (2010) *Delta Urbanism: New Orleans*. American Planning Association, Chicago, Illinois. Strauss B., Ziemlinski R., Weiss J., and Overpeck J. T. (2012). Tidally-adjusted estimates of topographic vulnerability to sea-level rise and flooding for the contiguous United States. *Environ. Res. Lett.* 7 014033.
Ecosystems of the Southeast are vulnerable to loss from relative sea-level rise, especially tidal marshes and swamps.	Some tidal freshwater forests are already retreating while mangrove forests (adapted to coastal conditions) are expanding upslope (Doyle et al. 2010). The pace of sea-level rise will increase, further stressing coastal wetlands in the Southeast. This could lead to the level of loss that has occurred in coastal Louisiana for several decades (Couvillion et al. 2011). With tidal wetland loss, protection of coastal lands and people against storm surge will be compromised. In some southeastern coastal areas, changes in salinity and water levels due to sea-level rise can happen so fast that local vegetation cannot adapt quickly enough, and those areas become open water (Nichols et al. 2007). Fire, hurricanes, and other disturbances have similar effects, causing ecosystems to cross thresholds at which dramatic changes occur over short time frames (Burkett et al. 2005; Burkett 2008).	Doyle, TW, K.W. Krauss, W.H. Conner, and A.S. From (2010). Predicting the retreat and migration of tidal forests along the northern Gulf of Mexico under sea-level rise. *Forest Ecology and Management* 259: 770-777. Couvillion, B.R., Barras, J.A., Steyer, G.D., Sleavin, W., Fischer, M., Beck, H., Trahan, N., Griffin, B., and Heckman, D. (2011). Land area change in coastal Louisiana from 1932 to 2010: U.S. Geological Survey Scientific Investigations Map 3164, scale 1:265,000, 12 p. pamphlet. Nicholls, R.J., Wong, P.P., Burkett, V., Codignotto, J., Hay, J., McLean, R., Ragoonaden, S., and Woodroffe, C. (2007). Coastal Systems and Low-lying Areas. IN: M. L. Parry, O.F. Canziani, J.P Palutikof, P.J. van der Linden, and C.E. Janson (eds.), *Climate*

		Change Impacts, Adaptations and Vulnerability. Intergovernmental Panel on Climate Change, Working Group 2, Fourth Assessment Report. Cambridge University Press. London, UK, pp. 316-356. Burkett, V.R., Wilcox, D.A., Stottlemeyer, R., Barrow, W., Fagre, D., Baron, J., Price, J., Neilsen, J.L., Allen, C.D., Peterson, D.L., Ruggerone, G., and Doyle, T. (2005). Nonlinear dynamics in ecosystem response to climatic change: case studies and policy implications. *Ecological Complexity* 2: 357-394. Burkett, V. (2008). The Northern Gulf of Mexico Coast: Human development patterns, declining ecosystems, and escalating vulnerability to storms and sea-level rise. In: M.C. MacCracken, F. Moore, and J. C. Topping, (eds.), *Sudden and Disruptive Climate Change: Its Likelihood, Character and Significance*. Earthscan Publications, London, pp. 101-118.
Sea-level rise will affect coastal agriculture through increasing the higher storm surges, saltwater intrusion, and impacts on freshwater supplies.	Salt-water intrusion will reduce the availability of groundwater for irrigation thereby limiting crop production in some areas (Ritschard et al. 2002). Agricultural areas around Miami-Dade County with shallow groundwater tables are at risk of increasing inundation and future loss of cropland (Stanton and Ackerman 2007). Net water supply in the Southeast is expected to decline over the next several decades particularly in the western part of the region (Caldwell et al. 2012). Analysis of current and future water resources in the Caribbean shows many of the small islands would be exposed to severe water stress under all climate change scenarios (UNEP 2008).	Ritschard R., O'Brien J., Cruise J., Hatch U., Jones J., Shrikant J., McNulty S., Abt B., Murray B., and Cruise J. (2002) Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change - Southeast. Southeast Regional Assessment Team. See also: Southeast chapter of the 2013 NCA report. Stanton E. and Ackerman F. (2007). Florida and Climate Change: The Cost of Inaction. Tufts University.http://ase.tufts.edu/gdae/Pubs/rp/Flori

		daClimate.html Caldwell, P. V., Sun, G., McNulty, S. G., Cohen, E. C., and Moore Myers, J. A. (2012). Impacts of impervious cover, water withdrawals, and climate change on river flows in the Conterminous US. *Hydrol. Earth Syst. Sci. Discuss.* 9, 4263-4304, doi:10.5194/hessd-9-4263-2012. UNEP (2008). Climate Change in the Caribbean and the Challenge of Adaptation. United Nations Environment Programme, Regional Office for Latin America and the Caribbean.
The number of land-falling tropical storms may decline, reducing important rainfall.	The science of projecting hurricanes and tropical storms into the future is complex and still in flux. Most current literature expects the overall frequency of hurricanes to decrease, but more of the most extreme storms are possible. Because the most intense hurricanes have tighter structures the area affected might be smaller. Due to land development in the path of hurricanes and the possibility of more extreme events, the net effect is for more economic damage. Fewer low intensity land-falling tropical storms and hurricanes would decrease the important rainfall source for this region.	Mendelsohn, R., K. Emanuel, S. Chonabayashi, and L. Bakkensen (2012). The impact of climate change on global tropical cyclone damage. *Nature Climate Change* 2,205–209. See also: Southeast chapter of the 2013 NCA report.
The incidence of harmful algal blooms is expected to increase with climate change, as are health problems previously uncommon in the region.	The incidence of harmful algal blooms is expected to increase with climate change, as are health problems previously uncommon in the region as disease-carrying organisms spread into inland and coastal waters (Moore et al. 2008; Tester al. 2010; Hallegraeff 2010; Tirado et al. 2010; Weidner et al., 2007). Higher sea surface temperatures are associated, for example, with higher rates of ciguatera fish poisoning (Hales et al. 1999; Tester et al. 2010), one of the most common hazards from algal blooms in the region (Landsberg 2002). This disease is moving northward, following increasing sea surface temperatures (Villareal et al. 2006; Litaker et al. 2010). *Vibrio*, bacteria that grow in warm coastal waters and are	Moore, S.K., V.L. Trainer, N.J. Mantua, M.S. Parkder, E.A. Laws, L.C. Backer, and L.E. Fleming (2008). Impacts of Climate Variability and Future Climate Change on Harmful Algal Blooms and Human Health. *Environmental Health,* 7 (Suppl. 2): 4. Tester, P.A., R.L. Feldman, A.W. Nau, S.R. Kibler, and R.W. Litaker (2010). Ciguatera Fish Poisoning and Sea Surface Temperatures in the Caribbean Sea and the West Indies. *Toxicon*,

	present in Gulf Coast shellfish, can cause infections in humans. Infections are now frequently reported earlier and later by one month than traditionally observed (Martinez-Urtaza et al. 2009).	56(5): 698-710. Hallegraeff, G.M. (2010). Ocean Climate Change, Phytoplankton Community Responses, and Harmful Algal Blooms: a Formidable Predictive Challenge. *Journal of Phycology*, 46: 220-235. Tirado, M.C., R. Clarke, LA. Jaykus, A. McQuatters-Gollop, and J.M. Frank. (2010). Climate Change and Food Safety. *Food Research International* 1745-1765. Wiedner, C., J. Rücker, R. Brüggemann, and B. Nixdorf (2007). Climate Change Affects Timing and Size of Populations of an Invasive Cyanobacterium in Temperate Regions. *Oecologia* 152: 473–484. Hales, S. P. Weinstein and A. Woodward (1999). Ciguatera (Fish Poisoning), El Nino, and Pacific Sea Surface Temperatures. *Ecosystem Health*, 5(1):20-25. Lansberg, J.H. (2002). The Effects of Harmful Algal Blooms on Aquatic Organisms. *Reviews in Fisheries Science*, 10(2): 113-390. Villareal T.A., Moore C., Stribling P., Van Dolah F., Luber G., Wenck M.A. (2006). Ciguatera Fish Poisoning - Texas, 1998 and South Carolina, 2004. MMWR 55(34):935-37. Litaker, R.W., M.W. Vandersea, M.A. Faust, S.R. Kibler, A.W. Nau, W.C. Holland, M.

		Chinain, M.J. Holmes, and P.A. Tester (2010). Global Distribution of Ciguatera Causing Dinoflagellates in the Genus Gambierdiscus. *Toxicon*, 56(5): 711-730.
Gulf Coast		
Hurricanes, land subsidence, sea-level rise and erosion already pose great risks to Gulf Coast areas, placing homes, critical infrastructure and people at risk, and causing permanent land loss.	Coastal counties along the western Gulf, including those along the Texas coast, with a population of approximately 12 million and assets of about $2 trillion, already face significant losses, annually averaging $14 billion from hurricanes, subsidence, and sea-level rise. Future losses for the 2030 and 2050 timeframes respectively could reach $18-23 billion and $26-40 billion per year without adaptive actions. Implementing adaptations could reduce those losses significantly (Entergy 2010). Louisiana State Route 1, delivering critical oil and gas resources from Port Fourchon, is sinking and already floods during high tides and low-intensity storms (LADOT 2012; LA 2012 Master Plan, 2012). The Department of Homeland Security (2011) estimated that a 90-day shutdown of this road would cost the nation $7.8 billion.	Entergy (2010). *Building a Resilient Energy Gulf Coast*, Entergy*,* America's Energy Coast and America's Wetland Foundation. Retrieved from: www.entergy.com/gulfcoastadaptation Louisiana Department of Transportation and Development, LA 1 Project, www.la1project.com/ Louisiana's 2012 Coastal Master Plan, www.coastalmasterplan.louisiana.gov/2012-master-plan/final-master-plan/ Department of Homeland Security (2011). Louisiana Highway 1/Port Fourchon Study, July 15, 2011. National Infrastructure Simulation and Analysis Center Risk Development and Modeling Branch, Homeland Infrastructure Threat and Risk Analysis Center Office of Infrastructure Protection In Collaboration with The National Incident Management Systems and Advanced Technologies Institute at The University of Louisiana at Lafayette.
Coastal inland and water temperatures are expected to rise; coastal inland areas	Coastal inland temperatures are expected to rise, particularly in the western Gulf, as are coastal water temperatures. Coastal inland areas are expected to become drier, significantly more so under a higher emissions scenario than under a lower emissions scenario.	Ch. 2: Our Changing Climate Kunkel, K. E., P. D. Bromirski, H. E. Brooks, T. Cavazos, A. V. Douglas, D. R. Easterling, and et

are expected to become drier.		al. (2008). Observed changes in weather and climate extremes. *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North American, Hawaii, Caribbean, and U. S. Pacific Islands. Washington, D. C.: U. S. Climate Change Science Program and the Subcommittee on Global Change Research*, T. R. Karl, G. A. Meehl, C. D. Miller, S. J. Hassol, A. M. Waple, and, W. L. Murray (eds.). Ch. 19: Great Plains
There is still uncertainty about future frequency and intensity of Gulf of Mexico hurricanes but sea level rise will increase storm surges.	There is still considerable uncertainty about the future frequency and intensity of Gulf of Mexico hurricanes (Ch. 2: Our Changing Climate), but some of the highest rates of relative SLR (resulting from the combination of global sea-level rise and local land subsidence) will increase storm surges associated with tropical storms (Tebaldi et al. 2012; Parris et al. 2012, Ch.17: Southeast).	Ch. 2: Our Changing Climate Parris, A., P. Bromirski, V. Burkett, D. R. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss (2012). Global sea Level Rise Scenarios for the United States National Climate Assessment. NOAA. Tebaldi, C., Strauss, B.H., and C.E. Zervas (2012). Modelling sea-level rise impacts on storm surges along US coasts. *Environmental Research Letters*, 7, 014032 doi:10.1088/1748-9326/7/1/014032. Ch.17: Southeast
The Florida Keys, South Florida and coastal Louisiana are particularly vulnerable to additional sea-level	The Florida Keys, southern Florida and low-lying areas of coastal Louisiana are particularly vulnerable to additional sea-level rise. This is due to these areas being near sea level and having low topography, and/or because they are undergoing local subsidence (Ch.17: Southeast; Strauss et al. 2012). In addition, the Keys and southern Florida are underlain by porous limestone bedrock,	Ch. 17: Southeast Strauss, B. H., R. Ziemlinski, J. L. Weiss, and J. T. Overpeck (2012). Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States.

rise and saltwater intrusion.	which also makes groundwater resources particularly vulnerable to saltwater intrusion.	*Environmental Research Letters*, **7,** 014033.
California		
Sea level has risen approximately 7 inches from 1900 to 2005, and is expected to rise at growing rates in this century.	Sea level along most of California's coast is already rising and the best science available suggests it will continue to rise at an increasing rate in the future (NRC 2012). At the Golden Gate tide gauge near San Francisco, for example, sea level has risen approximately 7 inches (18 cm) over the past century (1900-2005) (Cayan et al., 2012; NRC 2012); rates along other parts of the California coast vary with regional land movement (NRC 2012).	Cayan, D. R., M. Tyree, D. Pierce, and T. Das. (2012). Climate Change and Sea-Level Rise Scenarios for California Vulnerability and Adaptation Assessment. California Energy Commission. Publication number: CEC-500-2012-008. National Research Council (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.* Committee on Sea-Level Rise in California, Oregon, and Washington, Board on Earth Sciences and Resources and Ocean Studies Board, Division on Earth and Life Studies. Washington, DC: National Academies Press.
Higher temperatures, changes in precipitation, runoff and water supplies, and saltwater intrusion into coastal aquifers will result in negative impacts on coastal water resources.	Climate change will also result in higher air and water temperatures, changes in precipitation and runoff, and thus changes in water supplies and quality in coastal areas (Cayan et al. 2012; Bromirski et al. 2012). Regionally specific projections of these variables are available at cal-adapt.org.	Bromirski, P. D., D. R. Cayan, N. Graham, M. Tyree, and R. E. Flick (2012). Coastal Flooding- Potential Projections: 2000–2100. California Energy Commission. Publication number: CEC-500-2012-011. Cayan, D. R., M. Tyree, D. Pierce, and T. Das. (2012). Climate Change and Sea-Level Rise Scenarios for California Vulnerability and Adaptation Assessment. California Energy Commission. Publication number: CEC-500-2012-008.

Coastal storm surges are expected to be higher due to increases in sea level alone, and more intense persistent storm tracks (atmospheric river systems) will increase coastal flooding risks from inland runoff.	Bromirski et al. (2012) provide statewide averaged increases in extreme high tides/year using the B1 and A2 SLR scenarios. More extreme tides and storm surges will aggravate coastal flooding and erosion (Cayan et al. 2012; Bromirski et al. 2012). Currently rare storms (such as 100-year storms) are expected to occur annually by 2100 and in some locations possibly significantly sooner (Tebaldi et al. 2012), owing to sea level increases alone – not accounting for any changes in storm activity per se. Storm activity along the West Coast is – as in other extratropical areas – generally expected to move north, resulting in relatively fewer storms in southern California, and relatively more storms in northern parts of the state. Ralph and Dettinger (2011, 2012) and Dettinger et al. (2012) expect persistent storm tracks (atmospheric river systems) to become more intense, delivering more moisture to northern California. They significantly increase flood potential in coastal areas (and elsewhere) due to runoff from inland areas.	Bromirski, P. D., D. R. Cayan, N. Graham, M. Tyree, and R. E. Flick (2012). Coastal Flooding-Potential Projections: 2000–2100. California Energy Commission. Publication number: CEC-500-2012-011. Cayan, D. R., M. Tyree, D. Pierce, and T. Das. (2012). Climate Change and Sea-Level Rise Scenarios for California Vulnerability and Adaptation Assessment. California Energy Commission. Publication number: CEC-500-2012-008. Dettinger, M. (2011). Climate change, atmospheric rivers, and floods in California—A multimodel analysis of storm frequency and magnitude changes. *Journal of the American Water Resources Association (JAWRA)* 47(3): 514–523. Ralph, F.M. and Dettinger, M.D. (2011). Storms, floods and the science of atmospheric rivers. *Eos, Transactions of AGU*, 92(32), 265-266. Ralph, F.M. and Dettinger, M.D. (2012). Historical and national perspectives on extreme west coast precipitation associated with atmospheric rivers during December 2010. *Bulletin American Meteorological Society* 93, 783-790 Dettinger, M.D., Ralph, F.M., Hughes, M., Das, T., Neiman, P., Cox, D., Estes, G., Reynolds, D., Hartman, R., Cayan, D., and Jones, L. (2012). Design and quantification of an extreme winter

		storm scenario for emergency preparedness and planning exercises in California. *Natural Hazards*, 60, 1085-1111. Tebaldi, C., Strauss, B.H., and C.E. Zervas (2012). Modelling sea-level rise impacts on storm surges along US coasts. *Environmental Research Letters*, 7, 014032 doi:10.1088/1748-9326/7/1/014032
Expensive coastal development, critical infrastructure and valuable coastal wetlands are at growing risk from coastal erosion, temporary flooding and permanent inundation.	As a result of expected changes in sea level, storm surges and tidal flooding, coastal erosion, and impacts on wetlands – frequently hemmed in by development and thus unable to migrate inland – impacts on both natural and built human systems are expected to be extensive and costly (e.g., Ackerly et al. 2012; Biging et al. 2012; Caldwell et al. 2012; Cloern et al. 2012; Heberger et al. 2009; Sathaye et al. 2012; NRC 2012)	Ackerly, D., Rebecca A. Ryals, W. K. Cornwell, S. R. Loarie, S. Veloz, K. D. Higgason, W. L. Silver, and T. E. Dawson (2012). Potential Impacts of Climate Change on Biodiversity and Ecosystem Services in the San Francisco Bay Area. California Energy Commission. Publication number: CEC-500-2012-037. Biging, G., J. Radke, and J. H. Lee (2012). Vulnerability assessments of transportation infrastructure under potential inundation due to sea-level rise and extreme storm events in the San Francisco Bay Region. California Energy Commission. Publication number: CEC-500-2012-040. Caldwell, M., and E. Hartge (coordinating lead authors), L. Ewing, G. Griggs, R. Kelly, S. Moser, S. Newkirk, R. Smyth, and B. Woodson (lead authors) (2012). "Coastal Issues" (Chapter 9) In: Garfin et al., *Assessment of*

		Climate Change in the Southwest United States: A Technical Report Prepared for the U.S. National Climate Assessment. Washington, DC: Island Press. Cloern, J. E., N. Knowles, L. R. Brown, D. Cayan, M. D. Dettinger, T. L. Morgan, D. H. Schoellhamer, M. T. Stacey, M. van der Wegen, R. W. Wagner, and A. D. Jassby (2012). Projected evolution of California's San Francisco Bay-Delta-River System in a century of climate change. *PLoS ONE* 6 (9): e24465. Heberger, M., H. Cooley, E. Moore, P. Gleick, and P. Herrera. (2012). The Impacts of Sea-Level Rise on the San Francisco Bay. California Energy Commission. Publication number: CEC-500-2012-014. National Research Council (2012). *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.* Committee on Sea-Level Rise in California, Oregon, and Washington, Board on Earth Sciences and Resources and Ocean Studies Board, Division on Earth and Life Studies. Washington, DC: National Academies Press. Sathaye, J., L. Dale, P. Larsen, G. Fitts, K. Koy, S. Lewis, and A. Lucena (2012). Estimating Risk to California Energy Infrastructure from Projected Climate

		Change. California Energy Commission. Publication number: CEC-500-2012-057.
The San Francisco Bay and San Joaquin/Sacramento River Delta is particularly vulnerable to sea-level rise and changes in salinity, temperature and runoff; endangering one of the ecological "jewels" of the West Coast, growing development, and crucial water infrastructure.	The San Francisco Bay is the largest estuary on the US West Coast. The Bay and San Joaquin/Sacramento River Delta is an interconnected river network, estuary and coastal ocean, and thus is affected by multiple factors, underpinned by processes and changes that are atmospheric, oceanic and hydrologic in nature. The region is also heavily populated and contains critical infrastructure, including water conveyance, electrical transmission, and roads. It provides habitat for endemic species and for native fishes including Pacific salmon and steelhead trout, and has great social and economic significance as the source of runoff that provides drinking water to 25 million people and irrigation water to a million hectares of farmland, producing crops valued at $36 billion per year (Garfin et al. 2013; California Climate Change Center 2012; Cloern et al. 2011). Sea-level rise due to climate change will increase the risk of failure of levees that protect the islands in the Sacramento-San Joaquin Delta. Recent studies also indicate that the entire Delta area is subsiding which further reduces the protection afforded by the current levees (Brooks et al. 2012a,b). Water levels are going up with sea-level rise while the levees, and the Delta is experiencing a general long-term downward vertical movement. Catastrophic failure of multiple levees in the Delta would have far-reaching consequences to people, infrastructure and ecosystems. For example, a major levee failure in the Delta would impact the supply of water to central and southern California because the Delta is used as a principal conveyance facility in the transport of water from northern California to the more arid parts of the state. In addition, important energy facilities are located in the Delta, such as underground natural gas storage facilities, natural gas	Brooks, B.A., G. Bawden, D. Manjunath, C. Werner, N. Knowles, J. Foster, J. Dudas, and D.R. Cayan (2012a). Contemporaneous Subsidence and Levee Overtopping Potential, Sacramento-San Joaquin Delta, California. *San Francisco Estuary and Watershed Science.*10(1), 18pp. Brooks, B.A. and D. Manjunath (2012b). Twenty-First Century Levee Overtopping Projections from InSAR-Derived Subsidence Rates in the Sacramento-San Joaquin Delta, California: 2006–2010. California Energy Commission, School of Ocean and Earth Sciences and Technology, University of Hawaii. Lund, J., E. Hanak, W. Fleenor, R. Howitt, J. Mount, and P. Moyle (2007). Envisioning Futures for the Sacramento-San Joaquin Delta. Public Policy Institute of California, San Francisco. Retrieved from: http://www.ppic.org/main/publication.asp?i=671. Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy (eds.). *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*. A report by the Southwest Climate Alliance. (Washington, DC: Island Press, 2013). California Climate Change Center (2012). *Our Changing Climate 2012: Vulnerability and*

	pipelines, and electrical transmission lines (Lund et al. 2007).	*Adaptation to the Increasing Risks from Climate Change in California*. Retrieved from http://www.energy.ca.gov/2012publications/CEC-500-2012-007/CEC-500-2012-007.pdf. Cloern, J.E., N. Knowles, L.R. Brown, D. Cayan, M.D. Dettinger, T.L. Morgan, D.H. Schoellhamer, M.T. Stacey, M. van der Wegen, R.W. Wagner, and A.D. Jassby (2011). Projected Evolution of California's San Francisco Bay-Delta-River System in a Century of Climate Change. *PLoSOne* 6(9), doi:10.1371/journal.pone.0024465.
Pacific Northwest		
The substantial global sea-level rise is regionally moderated by the continuing uplift of land, with few exceptions, such as the Seattle area and central Oregon.	Along much of the Pacific Northwest coast, tectonic uplift reduces apparent sea-level rise below the global mean of 3mm/year (NRC 2012; Church and White 2011). Projected NW sea-level rise by 2100 is 0.1-1.4m relative to 2000, with a best estimate of around 63 cm (NRC 2012). This is lower than some other coastal areas around the US might experience, but still substantial, especially along highly developed shorelines. A major subduction-zone earthquake, expected within the next few hundred years, would immediately reverse centuries of uplift, increasing relative sea level a meter or more (Atwater and Yamaguchi, 1991).	National Research Council (2012). Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Church, J.A. and N.J. White (2011). Sea-level rise from the late 19th to the early 21st century, *Surveys in Geophysics*, 32, 585-602. Atwater, B.F. and D.K. Yamaguchi (1991). Sudden, probably coseismic submergence of Holocene trees and grass in coastal Washington State. *Geology*, 19, 706-709.
Commercial shellfish populations at risk from ocean acidification.	Ocean acidification threatens culturally and commercially significant marine species both directly, through changes in ocean chemistry on vulnerable organism (e.g., oysters and other calcifiers), as well as indirectly, through acidification-related changes in the marine food web (e.g., impacts on Pacific salmon that depend on shelled pteropods as a major food source) (Butorac et al. 2010; Ries 2009). NW coastal waters are among the most acidified worldwide, especially in spring and summer due to coastal upwelling (Butorac et al. 2010; Feely et al. 2008; NOAA	Butorac, D., S. Reeder, C. Krembs, J. Hennessey, S. Braley, and P. Pickett (2010). Ocean Acidification Paper for Ecology, Washington State Department of Ecology, White Paper. Ries, J.B. (2009). Marine calcifiers exhibit mixed responses to CO_2-induced ocean acidification. *Geology* 37(12): 1131-1134.

	coastal upwelling website; Hickey and Banas 2003) and local factors in estuarine waters (Butorac et al. 2010; Feely et al. 2010).	Feely, R.A., C. L. Sabine, J. M. Hernandez-Ayon, D. Ianson, and B. Hales (2008). Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf. *Science* 320(5882): 1490 – 1492. NOAA Northwest Fisheries Science Center, NOAA Fisheries Service, Coastal Upwelling website: (http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/db-coastal-upwelling-index.cfm) Hickey, B. and N. Banas (2003). Oceanography of the U.S. Pacific Northwest Coastal Ocean and Estuaries with Application to Coastal Ecology. *Estuaries* 26(4B): 1010-1031. Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy (2010). The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. *Estuarine, Coastal and Shelf Science* 88:442-449.
The region's relatively high economic dependence on commercial fisheries makes it sensitive to climate change impacts on marine species and ecosystems and related coastal ecosystems.	Changing coastal water temperatures and ecological conditions may alter the ranges, types and abundances of marine species (See for example, Hollowed et al. 2001; summary in Tillman and Siemann 2011). For example, during recent warm periods in the coastal ocean, subtropical and offshore marine species from zooplankton to top predators such as striped marlin, tuna, and yellowtail more common to the Baja area arrived (Pearcy 2002; Peterson and Schwing 2003). Warmer water in Puget Sound may contribute to a higher incidence of harmful algal blooms linked to neurotoxic shellfish poisoning (Feely et al. 2010; Huppert et al. 2009; Moore et al. 2008).	Hollowed, A.B., S.R. Hare, and W.S. Wooster (2001). Pacific Basin climate variability and patterns of Northeast Pacific marine fish production. *Progress in Oceanography* 49: 257-282. Tillmann, P. and Siemann (2011). *Climate Change Effects and Adaptation Approaches in Marine and Coastal Ecosystems of the North Pacific Landscape Conservation Cooperative Region,* National Wildlife Federation.

	See also Figure 25.4, Panel (d) on adaptation efforts in Washington State to ocean acidification.	Pearcy, W.G. (2002). Marine nekton off Oregon and the 1997-98 El Niño. *Prog. Oceanogr*. 54: 399-403. Peterson, W.T. and F.B. Schwing (2003). A new climate regime in northeast Pacific ecosystems. *Geophysical Research Letters* 30(17): 1896-1899, doi:10.1029/2003GL017528. Feely, R.A., S. Alin, J. Newton, C. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy, (2010). The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. *Estuarine, Coastal and Shelf Science* 88:442-449. Huppert, D.D., A. Moore, and K. Dyson (2009). Impacts of Climate Change on Coasts of Washington State, Chapter 8 in the Washington Climate Change Impacts Assessment, The Climate Impacts Group, University of Washington. Retrieved from: http://cses.washington.edu/db/pdf/wacciach8coasts651.pdf Moore, S.K., N.J. Mantua, J.A. Newton, M. Kawase, M.J. Warner, and J.P. Kellogg (2008). A descriptive analysis of temporal and spatial patterns of variability in Puget Sound oceanographic properties. *Estuarine, Coastal and Shelf Science* 80: 545-554.
Coastal storm surges are expected to be	Bromirski et al. (2012) provide statewide averaged increases in extreme high tides/year using the B1 and A2 SLR scenarios. More	Bromirski, P. D., D. R. Cayan, N. Graham, M. Tyree, and R. E. Flick (2012). Coastal Flooding-

higher due to increases in sea level alone, and more intense persistent storm tracks (atmospheric river systems) will increase coastal flooding risks from inland runoff.	extreme tides and storm surges will aggravate coastal flooding and erosion (Cayan et al. 2012; Bromirski et al. 2012). Currently rare storms (such as 100-year storms) are expected to occur annually by 2100 and in some locations possibly significantly sooner (Tebaldi et al. 2012), owing to sea level increases alone – not accounting for any changes in storm activity per se. Storm activity along the West Coast is – as in other extratropical areas – generally expected to move north, resulting in relatively fewer storms in southern California, and relatively more storms in northern parts of the state. Ralph and Dettinger (2011, 2012) and Dettinger et al. (2012) expect persistent storm tracks (atmospheric river systems) to become more intense, delivering more moisture to northern California. They significantly increase flood potential in coastal areas (and elsewhere) due to runoff from inland areas.	Potential Projections: 2000–2100. California Energy Commission. Publication number: CEC-500-2012-011. Cayan, D. R., M. Tyree, D. Pierce, and T. Das (2012). Climate Change and Sea-Level Rise Scenarios for California Vulnerability and Adaptation Assessment. California Energy Commission. Publication number: CEC-500-2012-008. Dettinger, M. (2011). Climate change, atmospheric rivers, and floods in California—A multimodel analysis of storm frequency and magnitude changes. *Journal of the American Water Resources Association (JAWRA)* 47(3): 514–523. Ralph, F.M. and Dettinger, M.D. (2011). Storms, floods and the science of atmospheric rivers. *Eos, Transactions of AGU*, 92(32), 265-266. Ralph, F.M. and Dettinger, M.D. (2012). Historical and national perspectives on extreme west coast precipitation associated with atmospheric rivers during December 2010. *Bulletin American Meteorological Society* 93, 783-790 Dettinger, M.D., Ralph, F.M., Hughes, M., Das, T., Neiman, P., Cox, D., Estes, G., Reynolds, D., Hartman, R., Cayan, D., and Jones, L. (2012). Design and quantification of an extreme winter storm scenario for emergency preparedness and planning exercises in California. *Natural*

		Hazards 60, 1085-1111. Tebaldi, C., Strauss, B.H., and C.E. Zervas (2012). Modelling sea-level rise impacts on storm surges along US coasts. *Environmental Research Letters*, 7, 014032 doi:10.1088/1748-9326/7/1/014032
Hawaiiand Pacific Islands		
Warmer and drier conditions will reduce fresh water supplies on many Pacific Islands, especially on low lying islands and atolls.	In Hawai'i mean precipitation, average stream discharge, and stream baseflow have been trending downward for nearly a century, especially in recent decades and with high ENSO and PDO-related variability (Marra et al. 2012; Bassiouni and Oki 2012; Frazier et al. 2011; Chu and Chen 2005; Diaz et al. 2005; Oki 2004). On most islands, increased temperatures coupled with decreased rainfall and increased drought will lead to an additional need for freshwater resources for drinking and crop irrigation (Döll 2002; Sivakumar and Hansen 2007). This is particularly important for locations in the tropics and subtropics, where observed data and model projections suggest that the average growing season temperatures will exceed the most extreme seasonal temperatures recorded from 1900 to 2006 (Battisti and Naylor 2009) by the end of the 21st century. Low-lying islands will be particularly vulnerable due to their low elevation, small land mass, geographic isolation, limited potable water sources and agricultural resources (Barnett and Adger 2003). The situation will also be exacerbated by the increased incidence of intrusion of saltwater from the ocean during storms as the mean sea-level rises over time.	Marra, J.J., Keener, V.W., Finucane, M.L., Spooner, D., Smith, M.H. (eds.) (2012). Climate Change and Pacific Islands: Indicators and Impacts. Report for The 2012 Pacific Islands Regional Climate Assessment (PIRCA). Honolulu, Hawai'i, USA. Oki, D. S. (2004). Trends in streamflow characteristics at long-term gaging stations, Hawai'i (Scientific Investigations Report No. 2004-5080). United States Geological Survey. Chu, P.-S. and Chen, H. (2005). Interannual and interdecadal rainfall variations in the Hawaiian Islands. *Journal of Climate* 18(22): 4796–4813. Diaz, H.F., Chu, P. S., and Eischeid, J. K. (2005). Rainfall changes in Hawai'i during the last century. Presented at the 16th Conference on Climate Variability and Change, San Diego, American Meteorological Society. Frazier, A.G., Diaz, H.F., and Giambelluca, T.W. (2011). Rainfall in Hawai'i: Spatial and temporal changes since 1920. American Geophysical Union Fall Meeting, San Francisco, December 2011.

		Bassiouni, M. and Oki, D. S. (2012). Trends and shifts in streamflow in Hawai'i, 1913-2008, Hydrological Processes, online first, May 1, 2012 at http://onlinelibrary.wiley.com/doi/10.1002/hyp.9298/abstract Döll, P. (2002). Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic Change, 54*, 269–293. Sivakumar, M. V. K. and Hansen, J. (eds.). (2007). *Climate prediction and agriculture: Advances and challenges*. Springer. Battisti, D. S. and Naylor, R. L. (2009). Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 323(5911), 240. Barnett, J. and Adger, W. N. (2003). Climate dangers and atoll countries. *Climatic Change* 61(3), 321-337.
Sea-level rise will continue at accelerating rates, exacerbating coastal erosion, damaging infrastructure and agriculture, reducing critical habitat, and threatening shallow coral reef systems.	Sea level in the Western North Pacific has risen dramatically starting in the 1990s. This regional change appears to be largely wind-driven; however, the underlying cause is yet to be determined (PIRCA 2012). In general, recent regional sea level trends in the western tropical Pacific may be higher (Becker et al. 2012; Timmerman et al. 2010; Merrifield 2011) than the global mean trend, due in part to the changing wind patterns associated with natural climate variability such as ENSO or the PDO (Feng et al. 2004; Di Lorenzo et al. 2010; Feng et al. 2010; Merrifield 2011; Merrifield 2012; Meyssignac et al. 2012).	Becker, M., B. Meyssignac, W. Llovel, A. Cazenave, and T. Delcroix (2012). Sea level variations at Tropical Pacific Islands during 1950-2009. *Global and Planetary Change* 80/81, 85-98. Timmermann, A., S. McGregor, and F. Jin (2010). Wind effects on past and future regional sea level trends in the Southern Indo-Pacific. *J. Climate* 23: 4429-4437.

	Over the next century, sea level in the Pacific is expected to rise with the projected increase in global mean sea level, with regional variations associated with ocean circulation changes and the Earth's response to predicted mass changes (e.g., land ice melt, continental water storage) (Stammer et al. 2012). On low islands, critical public facilities and infrastructure, as well as private commercial and residential property, are especially vulnerable to rising sea levels. Agricultural activity will also be affected, as sea-level rise decreases the land area available for farming (Easterling et al. 2007), and episodic flooding increases the salinity of groundwater resources. Impacts to the built environment on low-lying portions of high islands, where nearly all airports are located and where each island's road network is sited, will be much the same as those experienced on low islands (Walker and Barrie 2006). Islands with more developed built infrastructure will experience more economic impacts from tourism loss. In Hawai'i, for example, where tourism comprises 26% of the state's economy, damage to tourism infrastructure, including the loss of Waikīkī Beach, could lead to an annual loss of $2 billion in visitor expenditures (Waikīkī Improvement Association 2008).	Merrifield, M. A. (2011). A shift in western tropical Pacific sea level trends during the 1990s. *J. Clim*. 24: 4126-4138, doi:10.1175/2011JCLI3932.1 Feng, M., Y. Li, and G. Meyers (2004). Multidecadal variations of Fremantle sea level: Footprint of climate variability in the tropical Pacific. *Geophys. Res. Lett.*, *31*, L16302, doi:10.1029/2004GL019947. Di Lorenzo, E., Cobb, K. M., Furtado, J. C., Schneider, N., Anderson, B. T., Bracco, A., Alexander, M. A., et al. (2010). Central Pacific El Niño and decadal climate change in the North Pacific Ocean. *Nature Geoscience* 3(11): 762–765. doi:10.1038/ngeo984 Feng, M., McPhaden, M. J., and Lee, T. (2010). Decadal variability of the Pacific subtropical cells and their influence on the southeast Indian Ocean. *Geophysical Research Letters*, 37, 6 PP. doi:201010.1029/2010GL042796. Merrifield, M. A. and Maltrud, M. E. (2011). Regional sea level trends due to a Pacific trade wind intensification. *Geophysical Research Letters* 38(21). doi:10.1029/2011GL049576 Merrifield, M. A., P. R. Thompson, and M. Lander (2012). Multidecadal sea level anomalies and trends in the western tropical Pacific. *Geophys. Res. Lett.*, 39: L13602, doi:10.1029/2012GL052032.

		Meyssignac, B., Y. Salas, D. Melia, W. Llovel, and A. Cazenave (2012). Spatial trend patterns in observed sea level: Internal variability or anthropogenic signature? *Climate of the Past* 8, 787-802. Stammer, D., A. Cazenave, R. M. Ponte, and M. E. Tamisiea (2012). Contemporary regional sea level changes. *Ann. Rev. of Marine Sciences*, vol.5, published online; expected in press in January 2013. Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., et al. (2007). Food, fibre, and forest products. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. Van der Linden, and C. E. Hanson (eds.). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Walker, I.J. and J.V. Barrie (2006). Geomorphology and sea-level rise on one of Canada's most 'sensitive' coasts: Northeast Graham Island, British Columbia. *J. Coastal Res.*, SI 39: 220-226. Waikīkī Improvement Association (2008). *Economic impact analysis of the potential erosion of Waikīkī Beach*. Honolulu, HI. Marra, J.J., Keener, V.W., Finucane, M.L., Spooner, D., and Smith, M.H. (eds.) (2012).

		Climate Change and Pacific Islands: Indicators and Impacts. Report for The 2012 Pacific Islands Regional Climate Assessment (PIRCA). Honolulu, Hawaiʻi, USA.
Extreme water levels occur when high tides combine with interannual and interdecadal sea level variations (such as ENSO, PDO, mesoscale eddy events) and storm surge.	The high interannual and interdecadal variability of the climate in the Pacific Islands region (e.g., ENSO, PDO) makes it difficult to discern long-term trends, and how ENSO will change with climate change remains uncertain (Marra et al. 2012). But highest wave heights and tides are experienced during tidal extremes, coastal storms and La Niña events.	Marra, J.J., Keener, V.W., Finucane, M.L., Spooner, D., and Smith, M.H. (eds.) (2012). Climate Change and Pacific Islands: Indicators and Impacts. Report for The 2012 Pacific Islands Regional Climate Assessment (PIRCA). Honolulu, Hawaiʻi, USA.
Coral reef changes pose threats to communities, cultures, and ecosystems.	Coral reefs are at risk from climate change, due to both warming temperatures (which can lead to coral bleaching) and ocean acidification (Hoegh-Guldberg et al. 2007). Aragonite, the biologically important mineral that is critical to reef-building coral, is projected to decrease as a result of ocean acidification with the annual maximum aragonite saturation state dropping below 3.5 (marginal for coral growth) by 2035 to 2060 around the Pacific with continuing decline thereafter (Langdon and Atkinson 2005). Coral reefs in Hawaiʻi provide an estimated $385 million in goods and services annually (Cesar and von Beukering 2004). Loss of corals and high relief-habitat would result in a 20 to 50% decline in reef fishes (Pratchett et al. 2011).	Langdon, C. and Atkinson, M. J. (2005). Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment. *Journal of Geophysical Research* 110(C9). doi:10.1029/2004JC002576. Cesar, H. S. J. and von Beukering, P. J. H. (2004). Economic valuation of coral reefs of Hawaii. *Pacific Science* 58(2), 231-242. Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, B.H., Dubi, A., and Hatziolos, M.E. (2007). Coral reefs under rapid climate change and ocean acidification. *Science* 318: 1737-1742. Pratchett, M.S. P. L. Munday, N, A. J Graham et al. (2011). Vulnerability of coastal fisheries in

		the tropical Pacific to climate change. In: J. D. Bell, J. E Johnson, and A. J. Hobday (eds.) *Vulnerability of tropical Pacific fisheries and aquaculture to climate change*. Secretariat of the Pacific Community, Noumea, New Caledonia.
Alaska		
Summer sea ice is receding rapidly, altering marine ecosystems, allowing for greater ship access and offshore development and making Native communities highly susceptible to coastal erosion.	Arctic sea ice extent has declined substantially, especially in late summer, when there is now 40 percent less sea ice than at the beginning of the satellite record in 1979 (Stroeve et al. 2011). With the late-summer ice edge located further north than it used to be, storms produce larger waves and more coastal erosion (Markon et al. 2012). At the same time, coastal bluffs that were "cemented" by permafrost are beginning to thaw in response to warmer air and ocean waters and are therefore more vulnerable to erosion (Overeem et al. 2011). Standard defensive adaptation strategies to protect many of the Native coastal communities from erosion, such as through the use of rock walls, sandbags, and rip-rap, have been largely unsuccessful (State of Alaska 2011b; see also Figure 25.4, Panel (d)).	Stroeve, J.C., Serreze, M.C., Holland, M.M., Kay, J.E., Maslanik, J., and Barrett, A.P. (2011) The Arctic's rapidly shrinking sea ice cover - a research synthesis. *Climatic Change*, doi: 10.1007/s10584-011-0101-1. Markon, C.J., Trainor, S., and Chapin, F.S., III, (eds.) (2012). The United States National Climate Assessment – Alaska Technical Regional Report: in press. Overeem, I., Anderson, R.S., Wobus, C.W., Clow, G.D., Urban, F.E., and Matell, N. (2011). Sea ice loss enhances wave action at the Arctic coast. *Geophysical Research Letters*.38, L17503, doi:10.1029/2011GL04681. State of Alaska (2011). Adaptation Advisory Group of the Governor's Sub-Cabinet on Climate Change: State of Alaska – Adaptation Advisory Group webpage, retrieved from: http://www.climatechange.alaska.gov/aag/aag.htm (accessed May 15, 2012).
Ice loss from melting Alaskan and Canadian glaciers currently contributes almost as much to sea-level rise currently as does	Alaska is home to some of the largest glaciers and fastest loss of glacier ice on Earth (Larsen et al. 2007, Berthier et al. 2010), primarily as a result of rising temperatures (e.g., Oerlemans 2005, Arendt et al. 2002). Glaciers in Alaska and neighboring British Columbia, Canada currently contribute nearly as much surplus fresh water to the oceans as does the Greenland Ice Sheet—about	Larsen, C. F., Motyka, R.J., Arendt, A., Echelmeyer, K.A., and Geissler, P.E. (2007). Glacier changes in southeast Alaska and northwest British Columbia and contribution to sea-level rise. *Journal of Geophysical Research* 112, F1:1-11. doi:10.1029/2006JF000586.

melting of the Greenland Ice Sheet.	40-70 Gt per year (Pritchard et al. 2010, Kaser et al. 2006, Jacob et al. 2012), comparable to 10% of the annual discharge of the Mississippi River (Dai et al. 2009). This decline in ice volume is predicted to be one of the largest contributors to global sea-level rise during this century (Radic and Hock 2011).	Berthier, E., Schiefer, E., Clarke, G. K.C., Menounos, B., and Rémy, F. (2010). Contribution of Alaskan glaciers to sea-level rise derived from satellite imagery. *Nature Geoscience* 3(2): 92-95, doi:10.1038/ngeo737. Pritchard, H.D., Luthcke, S.B., and Fleming, A.H. (2010). Understanding ice-sheet mass balance – progress in satellite altimetry and gravimetry. *Journal of Glaciology* 56(200):1151-1161. Kaser, G., Cogley, J.G., Dyurgerov, M.B., and Meier, M. (2006). Mass balance of glaciers and ice caps - consensus estimates for 1961-2004. *Geophysical Research Letters* 33(19), L19501. Jacob, T., Wahr, J., Pfeffer, W.T. and Swenson, S. (2012). Recent contributions of glaciers and ice caps to sea-level rise. *Nature*, 482: 514-518,doi:10.1038/nature10847. Dai, A., Qian, T., Trenberth, K.E., and Milliman, J.D. (2009). Changes in continental freshwater discharge from 1948 to 2004. *Journal of Climate* 22: 2773-2792. Radic, V., and Hock, R. (2011). Regionally differentiated contribution of mountain glacier and ice caps to future sea-level rise. *Nature Geoscience*, 4(2):91-94, doi:10.1038/ngeo1052.
Current and projected increases in Alaska's ocean temperatures	Ocean acidification, rising ocean temperatures, declining sea ice, and other environmental changes interact to affect the location and abundance of marine fish, including those that are commercially	Gaines, S.D., Gaylord, B., and Largier, J.L., (2003). Avoiding current oversights in marine reserve design. *Ecological Applications*.13(1):

and changes in ocean chemistry are expected to alter the distribution and productivity of Alaska's marine fisheries.	important, those used as food by other species, and those used for subsistence (Gaines et al. 2003; Pörtner and Knust 2007; Pauly 2010, Sumaila et al. 2011; Doney et al. 2009; Allison et al. 2011; Cooley and Doney 2009). These conditions have allowed some near-surface fish species such as salmon to expand their range northward along the Alaskan coast (Moore and Huntington 2008; Grebmeier et al. 2010; Grebmeier 2012). Models project that continued ocean warming would reduce the abundance of pollock, the most commercially valuable fish stock in the Bering Sea, by 32–58% (Mueter et al. 2011). These changes present a challenge to fisheries managers and fisheries-dependent economies.	S32-S46. Pörtner, H.O., and Knus, R. (2007). Climate change affects marine fishes through the oxygen limitation of thermal tolerance. *Science*, 315:95-97. Pauly, D.(2010). Gasping fish and panting squids – Oxygen, temperature and the growth of water-breathing animals: Kinne, O., ed., Excellence in Ecology Series, International Ecology Institute. Sumaila, U.R., Cheung, W.W.L., Lam, V.W.Y., Pauly D., and Herrick, S. (2011). Climate change impacts on the biophysics and economics of world fisheries. *Nature Climate Change*1:449-456, doi:10.1038/nclimate1301 Doney, S.C., Fabry, V.J., Feely, R.A. and Kleypas, J.A. (2009). Ocean acidification - the other CO_2 problem. *Annual Review of Marine Science* 1:169–92. Allison, E.H., Badjeck, M.-C., and Meinhold, K., (2011). The implications of global climate change for molluscan aquaculture, in shellfish aquaculture and the environment: Shumway, E.S., ed., Wiley-Blackwell, Oxford, UK, doi: 10.1002/9780470960967.ch17. Cooley, S.R. and Doney, S.C. (2009). Anticipating ocean acidification's economic consequences for commercial fisheries. *Environmental Research Letters* 4: 024007, 8pp., doi:10.1088/1748-9326/4/2/024007.

		Moore, S. E. and Huntington, H. P. (2008). Arctic marine mammals and climate change - impacts and resilience. *Ecological Applications* 18(S2):157–165. Grebmeier, J.M, Moore, S.E., Overland, J.E., Frey, K.E., and Gradinger, R. (2010). Biological Response to Recent Pacific Arctic Sea Ice Retreats. *Eos, Transactions, American Geophysical Union* 91(18):161-163. Grebmeier, J.M., Priscu, J.C., D'Arrigo, R., Ducklow, H.W., Fleener, C., Frey, K.E., and Rosa, C. (2011). Frontiers in understanding climate change and polar ecosystems – Summary of a workshop. National Academy Press, Washington, DC, 78pp. Mueter, F. J., Bond, N. A., Ianelli, J. N., and Hollowed, A. B. (2011). Expected declines in recruitment of walleye pollock (Theragrachalcogramma) in the eastern Bering Sea under future climate change. *ICES Journal of Marine Science* 68: 1284–1296.
Great Lakes		
Higher temperatures and longer growing seasons in the Great Lakes region favor production of blue-green and toxic algae that can harm fish, water quality, habitat, and aesthetics.	Higher temperatures and lengthened growing seasons in the Great Lakes region favor production of blue-green and toxic algae that can harm fish, water quality, habitat, and aesthetics (Reutter et al., 2012; Mackey, 2012; Ficke et al., 2007). This may potentially heighten the impact of invasive species already present (Bronte et al., 2003; Rahel et al., 2008).	Reutter, J.M., et al. (2011). *Lake Erie nutrient loading and harmful algal blooms: Research findings and management implications. Final report of the Lake Erie Millennium Network synthesis team*. Ohio Sea Grant College Program: Columbus, OH. Mackey, S., (2012). "Great Lakes nearshore and coastal systems". In :*Midwest technical input*

		report: Prepared for the US National Climate Assessment, J. Winkler, J. Andresen, and J. Hatfield, (eds.). Available from: http://glisa.umich.edu/resources/nca. Ficke, A.D., C.A. Myrick, and L.J. Hansen (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries* 17(4): 581-613. Bronte, C.R., M.P. Ebener, D.R. Schreiner, D.S. DeVault, M.M. Petzold, D.A. Jensen, C. Richards, and S.J. Lozano (2003). Fish community change in Lake Superior, 1970–2000. *Canadian Journal of Fisheries and Aquatic Sciences* 60(12): 1552-1574. Rahel, F.J., B. Bierwagen, and Y. Taniguchi (2008). Managing Aquatic Species of Conservation Concern in the Face of Climate Change and Invasive Species. *Conservation Biology* 22(3): 551-561.
Increased winter air temperatures will lead to decreased Great Lakes ice cover, making shorelines more susceptible to erosion and flooding.	Increased winter air temperatures led to decreased Great Lakes ice cover which coupled with more frequent and intense storms, leaves shores vulnerable to erosion and flooding and could harm property and fish habitat (Mackey, 2012; Ferris, 2009; Wuebbles et al., 2010). However, reduced ice cover also has the potential to lengthen the shipping season (Millerd 2010). The navigation season has increased by an average of 8 days since 1994, and the Welland Canal in the St. Lawrence River remained open nearly two weeks longer. Increased shipping days benefit commerce but could also increase shoreline scouring and bring in more invasive species (Millerd 2010; Hellman et al. 2008; Smith et al. 2012).	Mackey, S. (2012). *Great Lakes nearshore and coastal systems*, in *Midwest technical input report: Prepared for the US National Climate Assessment*, J. Winkler, J. Andresen, and J. Hatfield (eds.). Available from: http://glisa.umich.edu/resources/nca. Ferris, G. (2009). *State of the Great Lakes 2009. Climate change: Ice duration on the Great Lakes*. State of the Lakes Ecosystem Conference. Wuebbles, D.J., K. Hayhoe, and J. Parzen (2010). Introduction: Assessing the effects of

		climate change on Chicago and the Great Lakes. *Journal of Great Lakes Research* 36(Supplement 2): 1-6. Millerd, F. (2010). The potential impact of climate change on Great Lakes international shipping. *Climatic Change* 104(3-4): 629-652. Hellmann, J.J., J.E. Byers, B.G. Bierwagen, and J.S. Dukes (2008). Five Potential Consequences of Climate Change for Invasive Species.*Conservation Biology* 22(3): 534-543. Smith, A.L., N. Hewitt, N. Klenk, D.R. Bazely, N. Yan, S. Wood, I. Henriques, J.I. MacLellan, and C. Lipsig-Mummé (2012). Effects of climate change on the distribution of invasive alien species in Canada: a knowledge synthesis of range change projections in a warming world.*Environmental Reviews* 20(1): 1-16.
Current projections of lake level changes are uncertain.	New model projections indicate only a slight decrease or even a rise in levels of the Great Lakes (Angel and Kunkel 2010), in contrast to earlier models that had overstressed water loss due to evaporation and had therefore projected lower levels (Milly and Dunne 2011; Lofgren et al. 2011; UGLSB 2012).	Angel, J.R. and K.E. Kunkel (2010). The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron. *Journal of Great Lakes Research* 36: 51-58. Milly, P.C.D. and K.A. Dunne (2011). On the Hydrologic Adjustment of Climate-Model Projections: The Potential Pitfall of Potential Evapotranspiration. *Earth Interactions* 15(1): 1-14. Lofgren, B.M., T.S. Hunter, and J. Wilbarger (2011). Effects of using air temperature as a proxy for potential evapotranspiration in climate

		change scenarios of Great Lakes basin hydrology. *Journal of Great Lakes Research* 37(4): 744-752. UGLSB (2012). *Lake Superior regulation: Addressing uncertainty in upper Great Lakes water levels. Final report to the International Joint Commission: Summary of findings and recommendations*. International Upper Great Lakes Study Board: Ottawa and Washington