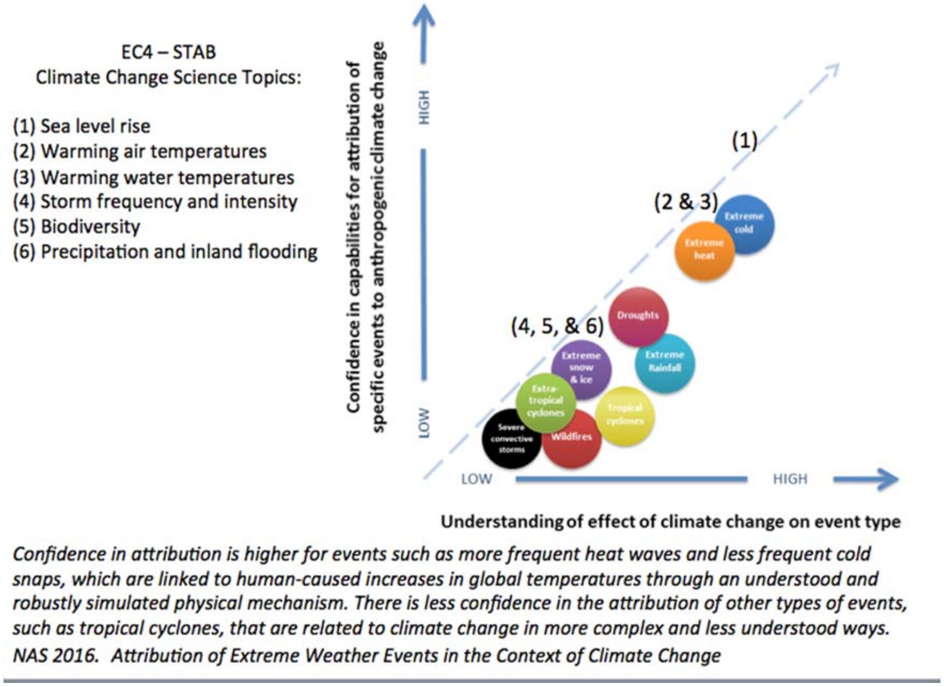
Current State of Climate Science in Rhode Island
A Report From the STAB to the EC4

The EC4 science and technical advisory board (STAB[1]) was charged to prepare a brief synopsis of the state of knowledge of the following manifestations of climate change in Rhode Island.

1. Sea level rise
2. Warming air temperatures
3. Warming water (marine and fresh) temperatures
4. Storm frequency and intensity
5. Biodiversity (changes in species and habitats)
6. Precipitation and inland flooding

For each theme, we were asked to prepare four PowerPoint slides: Slide 1- A concise description of the issue or impact; Slide 2- Hard data supporting the existence of the impact; Slide 3 - The top five to ten ramifications of this manifestation of climate change; and Slide 4: The best methods to assess vulnerability to this impact.



EC4 – STAB
Climate Change Science Topics:

(1) Sea level rise
(2) Warming air temperatures
(3) Warming water temperatures
(4) Storm frequency and intensity
(5) Biodiversity
(6) Precipitation and inland flooding

Confidence in attribution is higher for events such as more frequent heat waves and less frequent cold snaps, which are linked to human-caused increases in global temperatures through an understood and robustly simulated physical mechanism. There is less confidence in the attribution of other types of events, such as tropical cyclones, that are related to climate change in more complex and less understood ways. NAS 2016. Attribution of Extreme Weather Events in the Context of Climate Change

Figure 1. Levels of confidence in the scientific record for various manifestations of climate change. Taken from National Academy of Science Report. 2016. Attribution of Extreme Weather Events in the Context of Climate Change.

---

[1] *STAB members are: Peter August, URI (Chair); Todd Bianco, PUC; James Boyd, CRMC (Secretary); Kelly Knee, RPS/ASA; Jason Osenkowski, RI DEM; Ronald Pitt, RIC; Timmons Roberts, Brown Univ.; Carol Thornber, URI; Henry Walker, US EPA (Vice-chair)*

STAB members formed working teams to prepare the synopses which were then sent out to scientists in the region for peer review. The PowerPoint collection will be conveyed to the EC4 in May 2016. The major findings for each of the six themes are summarized here.

Our understanding of the effects of climate change, and attribution of changes associated with anthropogenic components of climate change varies in terms of the spatial scale of the effects, and temporal variability. Our understanding of how climate changes resulting from natural and anthropogenic factors affects extreme events (X axis in Figure 1) is greater than our ability to attribute extreme events to human-induced components of climate change (Y axis in Figure 1). There is greater confidence in larger scale patterns of sea level rise and air and water temperature increases. More local manifestations of climate change are less certain (Figure 1). The placement of the STAB climate change themes is based on our understanding of these systems.

(1) Sea Level Rise (SLR)

Global sea level changes are sensitive to climate variation (Lambeck et al. 2002). Sea levels have risen over 9 inches in Rhode Island since 1930 as measured at the Newport tide gauge. The National Oceanic and Atmospheric Administration (NOAA) maintains two (2) long-term tide gauges in RI located at Providence and Newport. The historic rate of sea level rise (SLR) at the Newport tide gauge from 1930 to 2015 is presently 2.72 mm/year or more than an inch per decade. Carey et al. (2015) found that SLR at the Newport tide gauge from 1984-2011 was 4.1mm/year. This rate is similar to the mean annual rate of SLR for Newport of 4.8 mm/year for the period of 1999 to present as determined from the Permanent Service for Mean Sea Level at Newport (http://www.psmsl.org/data/obtaining/stations/351.php). However, caution is advisable when citing short-term data sets (less than 30 years) because of inherently large regression errors and the anomalous sea level increase of about 4 inches during 2009-2010 due to a slowdown in the Atlantic Meridional Overturning Circulation (Goddard et al. 2015). Nevertheless, at these present rates, sea levels will likely increase 1 inch between every 5 or 6 years in Rhode Island.

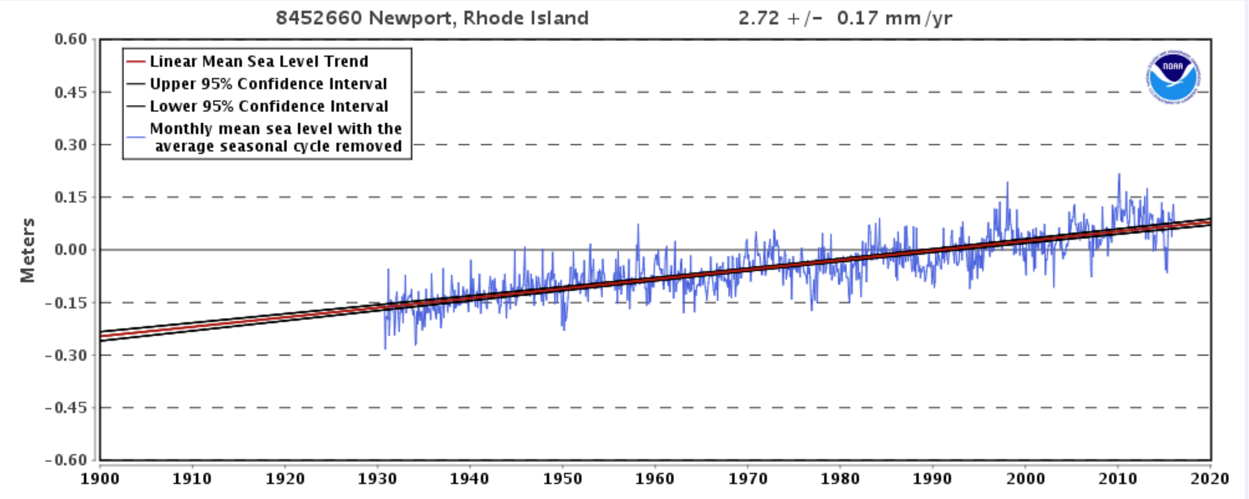


Figure 1.1 Mean sea level trend at Newport, RI tide gauge from 1930 to 2015

A recent analysis of global sea levels, correcting for spatial bias in the tide gauge records, calculates a rate of 1.2 mm/year from 1901-1990 (Hay et al. 2015), but along the U.S. East Coast the rate was 1.8 mm/year during the same period (Engelhart et al. 2009). Sea level rise is accelerating globally and in particular the North American Atlantic coastline north of Cape Hatteras, NC to the Canadian Maritime Provinces. Between 1950–1979 and 1980–2009, the SLR rate increase along this coastline was 3-4 times higher than the global average (Sallenger et al. 2012). Because of this factor, it is likely that this region, which includes Rhode Island, will see an additional 8 to 11+ inches above global average SLR by 2100.

The 20th century increase in the rate of global mean sea level rise is attributed to a combination of natural and anthropogenic radiative forcing (Church et al. 2013). Importantly, SLR has accelerated significantly to 3.3 mm/year since 1993 when analysis began with satellite altimetry http://sealevel.colorado.edu/). NOAA is projecting as much as 6.6 feet of SLR by the end of this century in Rhode Island. In the shorter-term, NOAA predicts upwards of 1 foot by 2035 and 1.9 feet by 2050. This has critical implications for RI, as approximately 6, 13 and 20 square miles of Rhode Island's coastal areas will be permanently flooded with 1, 3 and 5 feet of SLR, respectively, as quantified by Geographic Information System (GIS) analysis.

Rhode Island is now well positioned to conduct state, municipal and private sector vulnerability analyses with new tools to assess the risk for sea level rise and coastal storm surge inundation with the development of STORMTOOLS by the University of Rhode Island on behalf of the Coastal Resources Management Council Shoreline Change Special Area Management Plan. In addition, within a year there will be a more robust monitoring system established for RI that will include more tide gauges, waves and current measurements and high-resolution monitoring of coastal erosion along the entire coast. This monitoring system will be designed to provide data directly into StormTools, making it an even more powerful analytical tool (http://www.beachsamp.org/resources/stormtools/).

References

Carey, J. C., S. B. Moran, R. P. Kelly, A. S. Kolker and R. W. Fulweiler. 2014. The declining role of organic matter in New England salt marshes. *Estuaries and Coasts* DOI: 10.1007/s12237-015-9971-1

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1137–1216, doi:10.1017/ CBO9781107415324.026.

Engelhart, S. E., B. P. Horton, B. C. Douglas, W. R. Peltier, and T. Tornqvist. 2009. Spatial variability of late Holocene and 20th century sea-level rise along the Atlantic coast of the United States. *Geology* DOI: 10.1130/G30360A.

Goddard, P. B., J. Yin, S. M. Griffies and S. Zhang. 2015. An extreme event of sea-level rise along the Northeast coast of North America in 2009–2010. *Nature Communications* DOI: 10.1038/ncomms7346

Hay, C. C., E. Morrow, R. E. Kopp, and J X. Mitrovica. 2015. Probalistic reanalysis of twentieth-century sea-level rise. *Nature Letters* DOI: 10.1038/nature14093.

Lambeck, K., T.M. Esat, and E.K. Potter. 2002. Links between climate and sea levels for the past three million years. *Nature* 419: 199-206.

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 Climate Change* DOI: 10.1038/NCLIMATE1597

NOAA sea level trends for Providence (8454000) and Newport (8452660). http://tidesandcurrents.noaa.gov/sltrends/sltrends.html

Permanent Service for Mean Sea Level for Newport. http://www.psmsl.org/data/obtaining/stations/351.php

STORMTOOLS (developed by URI Ocean Engineering for CRMC) map viewer to assess sea level rise and storm inundation - http://www.beachsamp.org/resources/stormtools/

University of Colorado Sea level Research Group 2016 Global Mean Sea Level Time Series http://sealevel.colorado.edu/

(2) Warming Air Temperatures

Carbon dioxide and other greenhouse gases are slowing the radiation of heat back into the atmosphere. This is slowly driving up temperatures, especially nighttime lows, as the blanket of greenhouse gases thickens (IPCC 2013). Current levels of CO_2 equivalents are just over 400 parts per million, above the pre-industrial level of about 280 ppm (in the year 1850 and before). It appears that the late 20^{th} and early 21^{st} centuries are likely the warmest period the Earth has seen in at least 1200 years (NOAA, 2008). The Paris Agreement set a target of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5° C above pre-industrial levels." Current global averages are around 1°C degree above pre-industrial levels, and rising (see Figure 2.1). Global temperature changes are less variable than for the contiguous US or RI where temperature rise and extremes are more apparent. A series of impacts are expected to be significantly worse at 2 degrees global mean temperature rise compared to 1.5 degrees (Schleussner et al. 2016). Much more research in this area is needed, but initial findings have raised debate about whether this threshold (1.5° C) better characterizes the level at which "dangerous" climate change is occurring.

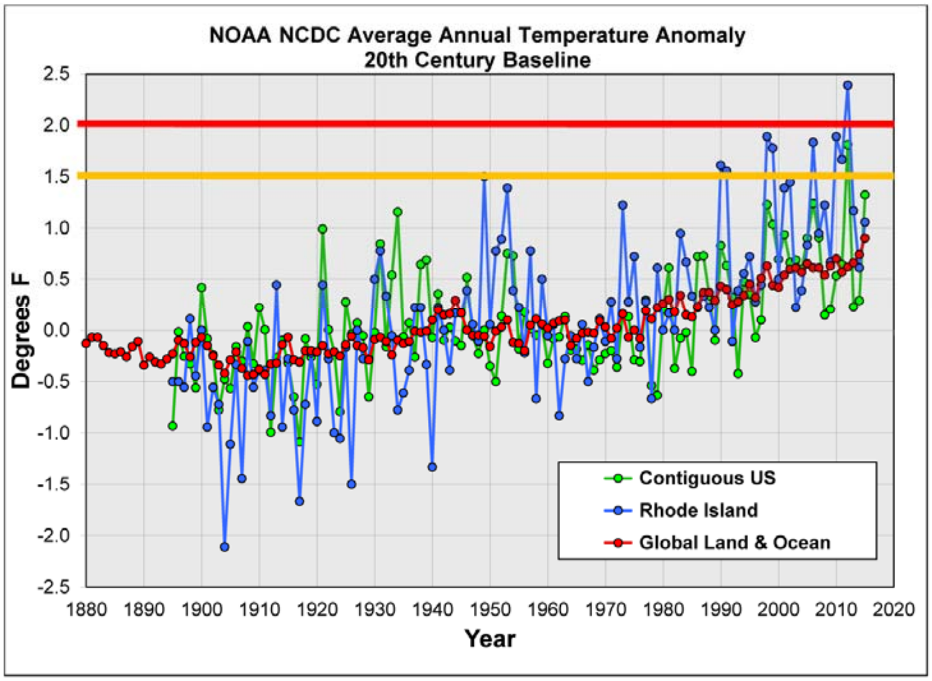


Figure 2.1 The Paris Agreement / goal: staying below 2 degrees C of warming (indicated by red horizontal line). Schleussner et al. (2016) report significant adverse effects can be anticipated with 1.5 degrees C of warming (indicated by orange horizontal line). Data downloaded from NOAA National Climate Data Center. The baseline temperature is the average from 1901 to 2000. The Y axis shows deviations (in degrees F) from this 20th century baseline.

Surface temperatures warm, especially as sunlight hits dark surfaces like asphalt and dark roofing. The Urban Heat Island Effect is marked in Rhode Island. Human health risks rise dramatically in RI with temperatures over 80 degrees F, based on records of emergency room admissions (Kingsley et al. 2015). This is due to asthma events and other heat-related cardio-respiratory problems worsened by ground-level ozone and smog, which are highly temperature sensitive (Kingsley et al 2015). Between 1950 and 2014 the number of days at TF Green Airport over 80 degrees has been increasing (Brown University, 2015).

RI Policy should prioritize vulnerable populations. To identify areas of vulnerable sub-populations, GIS mapping of demographic data to determine areas of expected high risk can be compared to registries and census data, as well as engagement with communities. The elderly, children, immigrants and the poor are most vulnerable, as was seen in Chicago 1995, Paris 2009, and Moscow 2013 heat waves. Rhode Island should engage the public to help identify cost effective and socially equitable solutions

Physical infrastructure is vulnerable, including roads due to increased frequency of freeze-thaw cycles. Electrical grids, power plants, and rail systems are also sensitive to heat as temperatures surpass 90 degrees F (GAO. 2014). Increased electrical demand for cooling, and lower performance in power generation and transmission increase risks of electrical grid failure at high temperatures. RI Policy should prioritize vulnerable sectors, in developing policies to reduce risks to water, waste water, and electric utilities, and engage utility operators like National Grid and ISO-New England (ISO New England, 2015) to help achieve efficient and equitable solutions.

References:

Brown University. 2015. Heat index study of TF Green Airport data. Online release at: https://news.brown.edu/articles/2015/09/temperature.

GAO. 2014. Climate Change: Energy infrastructure risks and adaptation efforts. GAO-14-74. http://www.gao.gov/assets/670/660558.pdf.

Intergovernmental Panel on Climate Change. 2013. The physical science basis. http://www.ipcc.ch/report/ar5/wg1/

ISO New England. 2015. Regional system plan. RSP15. www.iso-ne.com/static-assets/documents/2015/11/rsp15_final_110515.docx

Kingsley, S. L., M. N. Eliot, J. Gold, R. R. Vanderslice, and G. A. Wellenius. 2015. Current and projected heat-related morbidity and mortality in Rhode Island. *Environmental Health Perspectives* DOI:10.1289/ehp.1408826. http://ehp.niehs.nih.gov/1408826/)

NOAA. 2008. A paleo perspective on global warming: The “Medieval Warm Period”. https://www.ncdc.noaa.gov/paleo/globalwarming/medieval.html

Schleussner, C., T. K. Lissner, E. M. Fischer, J. Wohland, M. Perrette, A. Golly, J. Rogel, K. Childers, J. Schewe, K. Frieler, M. Mengel, W. Hare, and M. Schaeffer. 2016. Differential climate impacts for policy-relevant limits to global warming: the case of 1.5 C and 2 C. *Earth Syst. Dynam*. 7, 327–351. http://www.earth-syst-dynam.net/7/327/2016/esd-7-327-2016.pdf

(3) Warming Water (Marine and Fresh) Temperatures

The water in Narragansett Bay is getting warmer. Over the past 50 years, the surface temperature of the Bay has increased 1.4° to 1.6° C (2.5° to 2.9° F). Winter water temperatures in the Bay have increased even more, from 1.6° to 2.0° C (2.9° to 3.6° F) (Fulweiler et al. 2015). Ocean temperatures are increasing world-wide, but temperature increases in the northwestern Atlantic Ocean are expected to be 2-3 times larger than the global average (Saba et al. 2016).

Warming water temperatures in Narragansett Bay are causing many changes in ecosystem dynamics, fish, invertebrates, and plankton (Smith, Whitehouse, & Oviatt 2010). Winter and spring phytoplankton blooms rarely occur anymore due to more intensive grazing by zooplankton during the winter (Oviatt, Keller & Reed 2002) and this results in benthic (sea floor) organisms no longer receiving carbon and nutrients from the phytoplankton (Nixon et al. 2009).

Warming water temperatures are causing many changes in the marine fisheries of Rhode Island. Cold-water iconic fishery species (cod, winter flounder, hake, lobster) are moving north out of RI waters (e.g., Fogarty et al. 2007) and warm-water southern species are becoming more prevalent (scup, butterfish, squid) (Collie, Wood & Jeffries 2008). The fisheries of Narragansett Bay are changing from being dominated by bottom dwelling fish and invertebrates to being dominated by fish that occur throughout the water column (Gibson, RIDEM, 2016).

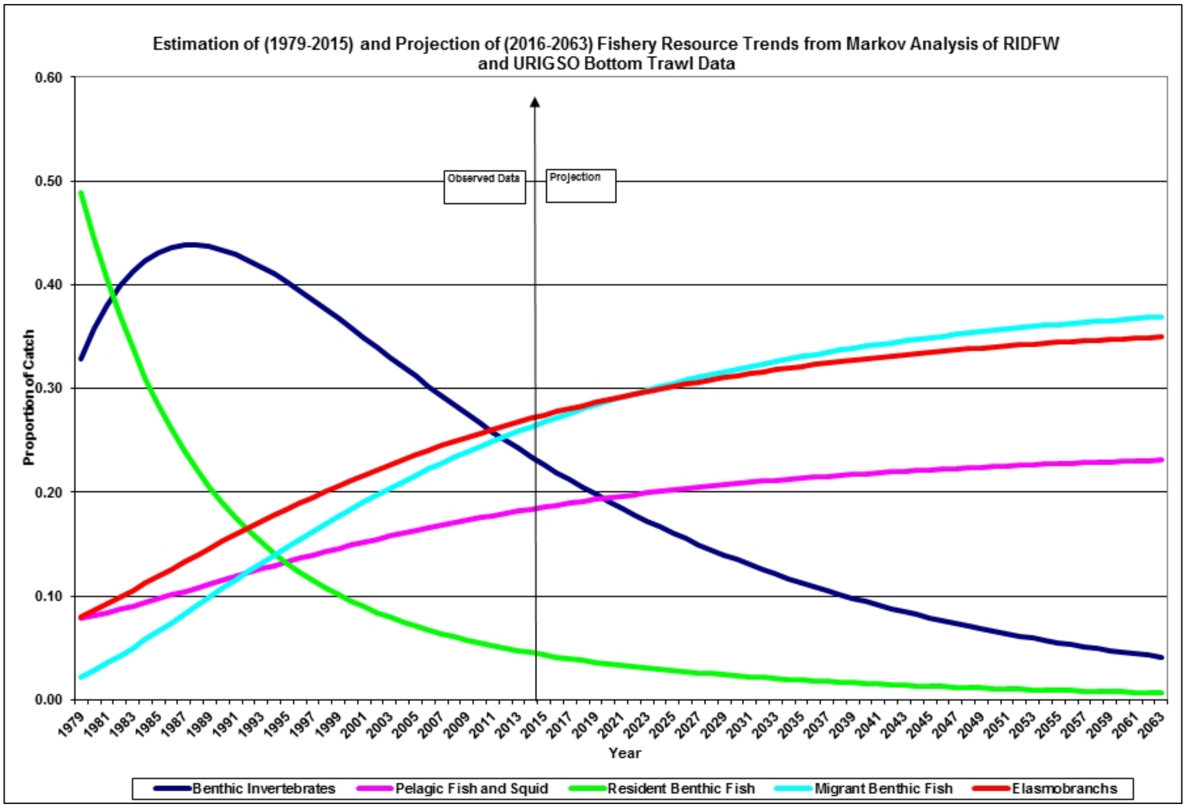


Figure 3.1 Changes in the dominant fisheries of Narragansett Bay. Prepared by Mark Gibson RIDEM.

Besides warming, our marine waters are becoming more acidic due to increasing CO_2. This may cause severe impacts to shellfish, especially in their larval life stages (Talmage & Gobler 2010). A current carbonate chemistry baseline in Narragansett Bay (Wallace et al. 2014) can be used as in monitoring variability and trends in estuarine pH in future years.

Water temperatures in our freshwater ecosystems are warming. This will have a negative impact on species of fish that prefer cold water rivers and streams, especially in the summertime. In 2013, water temperatures in the Wood River exceeded the preferred temperature (<20° C) for native Brook Trout (*Salvelinus fontinalis)* for one full month.

Environmental monitoring allows us to measure long-term changes in our ecosystems. It is imperative that we continue, and expand, the monitoring of fish, shellfish, invertebrates, plankton, and water conditions in Narragansett Bay and our offshore waters. Similarly, we need to continue and expand monitoring of freshwater quality and the fauna of our rivers, streams, and ponds.

References

Collie, J.S., A.D. Wood, and H. P. Jeffries, 2008. Long-term shifts in the species composition of a coastal fish community. *Canadian Journal of Fisheries and Aquatic Sciences 65*: 1352-1365.

Fogarty, M., L. Incze, R. Wahle, D. Mountain, A. Robinson, A. Pershing, K. Hayhoe, A. Richards, and J. Manning, 2007. Potential climate change impacts on marine resources of the Northeastern United States. *Report to Union of Concerned Scientists*.

Fulweiler, R.W., A.J. Oczkowski, K.M. Miller, C.A. Oviatt, M.E.Q. Pilson, 2015. Whole truths vs. half truths - And a search for clarity in long term water temperature records. *Estuarine, Coastal, and Shelf Science* 157: A1-A6.

Gibson, M. 2016. Estimation of (1979 to 2015) and projection of (2016 to 2063) fishery resource trends from Markov analysis of RIFFW and URI GSO bottom-trawl data. Unpublished.

Nixon, S.W., R.W. Fulweiler, B.A. Buckley, S.L. Granger, B.L. Nowicki, and K.M. Henry, 2009. The impact of changing climate on phenology, productivity, and benthic–pelagic coupling in Narragansett Bay. *Estuarine, Coastal and Shelf Science 82*: 1-18.

Oviatt, C., A. Keller, and L. Reed, 2002. Annual primary production in Narragansett Bay with no bay-wide winter–spring phytoplankton bloom. *Estuarine, Coastal and Shelf Science 54*: 1013-1026.

Saba, V.S., S.M. Griffies, W.G. Anderson, M. Winton, M.A. Alexander, T.L. Delworth, J.A. Hare, M.J. Harrison, A. Rosati, G.A. Vecchi, and R. Zhang, 2016. Enhanced warming of the Northwest Atlantic Ocean under climate change. *Journal of Geophysical Research: Oceans*.

Smith, L.M., S. Whitehouse, and C.A. Oviatt, 2010. Impacts of climate change on Narragansett Bay. *Northeastern Naturalist*, *17*: 77-90.

Talmage, S.C. and C.J Gobler, 2010. Effects of past, present, and future ocean carbon dioxide concentrations on the growth and survival of larval shellfish. *Proceedings of the National Academy of Sciences*, *107*: 17246-17251.

Wallace, R.B. H. Baumann, J.S. Grear, R.C Aller, and C.J. Gobler. 2014. Coastal ocean acidification: The other eutrophication problem. *Estuarine, Coastal and Shelf Science* 148: 1-13.

(4) Storm Frequency and Intensity

Records of tropical cyclones impacting the U.S. are too short to assess long term trends (Emanual 2006, Reed et al. 2015). While it is premature to conclude that climate change has had an impact on Atlantic hurricane activity, as yet undetectable changes may be still be occurring (GFDL 2015).

The physics driving the global climate are complicated thus it is hard to be certain how climate change will influence the intensity, frequency, and geographical distribution of hurricanes. Some effects of climate change, like rising sea surface temperatures, are thought to favor hurricane development and intensification. Other meteorological effects (such as increasing upper troposphere temperature and vertical wind shear) of climate change are believed to be unfavorable for hurricane formation (GFDL 2015).

Because neither the observational record nor the governing physics provide a clear indication of how climate change will impact hurricane activity, modeling studies are used to predict the potential impacts. These studies predict a global increase in the intensity of (GFDL 2015), a pole-ward migration in the latitude at which storms reach maximum intensity (Kossin et al. 2013), and increases in tropical rainfall rates (GFDL 2015, IPCC 2012). In the Atlantic basin modeling studies predict a substantial reduction in the number of tropical storms and hurricanes (GFDL 2015, Knutson et al. 2008, 2013), the frequency of intense storms (Category 4 and 5) is likely to increase and possible double by the end of the 21st century (GFDL 2015, Bender et al. 2010, IPCC 2013) (Figure 4.1)

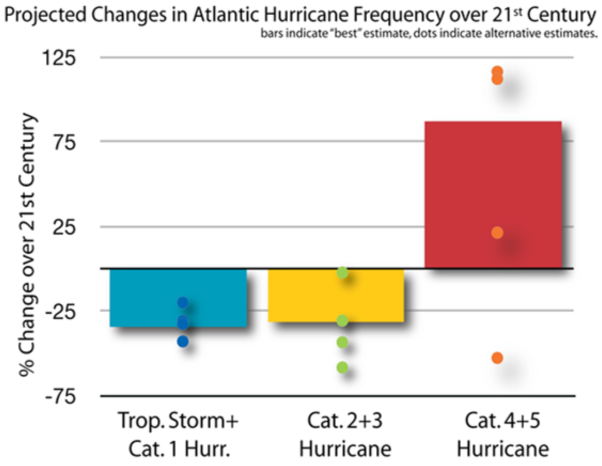


Figure 4.1: Projected Changes in Atlantic Hurricane Frequency over the 21st century.

While not as much research has been conducted on extra-tropical storms, for the U.S. East Coast an increase in both frequency and intensity is expected (IPCC 2013).

The predicted changes in storm activity could change the frequency and intensity of associated storm surges, high winds, and precipitation events, causing serious implications for both coastal and inland communities and infrastructure systems. Important studies on the impacts to water and wastewater infrastructure have already been commissioned by the state. Additional research on impacts to transportation, businesses and homes, and public health should be considered.

References

Bender, M. A., T. R. Knutson, R. E. Tuleya, J. J. Sirutis, G. A. Vecchi, S. T. Garner and I. M. Held. 2010. Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes. *Science* 22 JAN 2010: 454-458

Emanuel, K. 2006. Anthropogenic Effects on Tropical Cyclone Activity, http://eaps4.mit.edu/faculty/Emanuel/publications/position_paper. Accessed on 30 December, 2015.

GFDL (NOAA Geophysical Fluid Dynamics Laboratory). 2015. Global Warming and Hurricanes, http://www.gfdl.noaa.gov/global-warming-and-hurricanes. Accessed on 30 December, 2015.

Intergovernmental Panel on Climate Change. 2012. Summary for Policymakers. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

Intergovernmental Panel on Climate Change. 2013. Christensen, J.H., K. K Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou, 2013. Climate Phenomena and their Relevance for Future Regional Climate Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Knutson, T. R., J. J. Sirutis, S. T. Garner, G. A. Vecchi, and I. M. Held. 2008. Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions. *Nature* Published online: 18 May 2008; doi:10.1038/ngeo202.

Knutson, T. R., J. J. Sirutis, G. A. Vecchi, S. T. Garner, M. Zhao, H. Kim, M. A. Bender, R. E. Tuleya, I. M. Held, and G. Villarini. 2013. Dynamical downscaling projections of 21st century Atlantic hurricane activity: CMIP3 and CMIP5 model-based scenario. *Journal of Climate* 26(17), DOI:10.1175/JCLI-D-12-00539.1.

Kossin, J. P., K. Emanuel, and G. A. Vecchi. 2014. The poleward migration of the location of tropical cyclone maximum intensity, *Nature* 509, 349–352.

Reed, AJ, M. E. Mann, K. A. Emanuel, N. Lin, B. P. Horton, A. C. Kemp, and J. P. Donnelly. 2015. Increased threat of tropical cyclones and coastal flooding to New York City during the anthropogenic era. *Proc Natl Acad Sci* 112:12610-5.

(5) Biodiversity

Climate change is altering the ecology and distribution of plants and animals in Rhode Island. These changes occur in three primary ways: (1) shifts in the use of space and geographic distributions; (2) changes in the timing of fruiting, flowering and leaf-out in plants, and timing of migration and reproduction in animals; and (3) changes in the behavior, ecology, and physiology of individual species (Bellard et al. 2012).

In southern New England, spring is arriving sooner and plants are flowering earlier (one week earlier now when compared to the 1850's; Miller-Rushing and Primack 2008). For every degree of temperature rise in the spring and winter, plants flower 3.3 days earlier. For woody plants, leaf-out is occurring 18 days earlier now than in the 1850's (Polgar and Primack 2011). Changes in the timing of leaf-out, flowering, and fruiting in plants can be very disruptive to plant pollinators and seed dispersers.

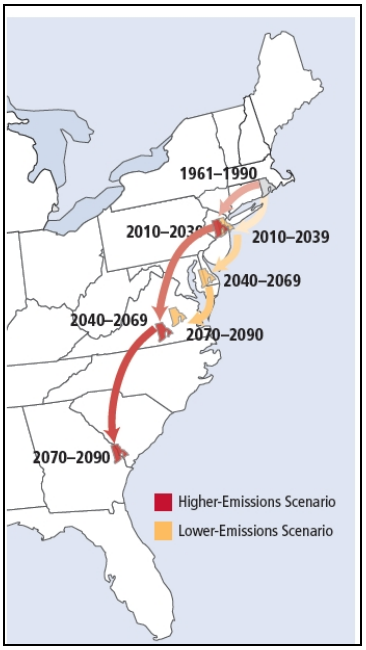


Figure 5.1 Changing climate of RI. From Frumhoff et al. 2007

Changes in the timing of annual cycles has been observed in Rhode Island birds. Based on a 45-year near-continuous record of monitoring fall migration times for passerine birds in Kingston, RI, Smith and Paton (2011) found a 3.0 days/decade delay in the departure time of 14 species of migratory birds.

Sea level rise will cause changes in coastal habitats that are important for biodiversity. For example, salt marshes in Rhode Island, critical habitat for fish and shellfish, will either drown or migrate landward. In Rhode Island, the rate at which salt marshes increase in elevation through the deposition of organic matter is less than the current rate of seal level rise (Carey et al. 2015).

Warming sea water temperatures are resulting in shifts of the timing of ecologically significant events in Narragansett Bay (Oviatt 2004), such as the winter/spring phytoplankton bloom (Smith et al. 2010). The fish species occurring in Narragansett Bay are changing as waters warm. Bottom-dwelling fish that prefer cold water such as winter flounder are less common and fish that swim in the water column and prefer warmer water, for example butterfish and scup, are becoming more common (Collie et al. 2008).

Increased levels of CO2 and subsequent ocean acidification (Doney et al. 2009), will have both direct and indirect impacts. For example, shell formation and shell growth of mollusks will be negatively impacted by ocean acidification (Talmage & Gobler 2009).

Changes in the abundance and annual cycle of animals is expected to have profound effects on public health. Cyanobacteria blooms, a toxic algae, in aquatic systems are expected to increase as well as the prevalence of vector-borne diseases of humans that are transmitted by ticks and mosquitoes.

Changes in climate and subsequent impacts on biodiversity will manifest itself differently between species. It is expected that some species will be able to adapt well while others may become extirpated because of they lack the evolutionary ability to adapt at the rate of change to the predicted conditions. Furthermore, it is unclear how shifts of species distributions will impact the relationships of flora and fauna (that may remain) this will undoubtedly impact food webs within ecosystems.

It is imperative that we systematically monitor changes in biodiversity, especially 1) sentinel habitats such as salt marshes and rare habitats at the fringe of tidal and freshwater systems, 2) the occurrence of harmful algae or animal vectors of human diseases, and 3) continue long-term assessment of fish in Narragansett Bay and changes in the species abundance and timing of avian migrants at the Block Island and Kingston bird banding stations.

References

Bellard, C., C. Bertelsmeier, P. Leadley, W. Thuiller, and F. Courchamp, 2012. Impacts of climate change on the future of biodiversity. *Ecology letters* 15:365-377.

Carey, J.C., S.B. Moran, R.P. Kelly, A.S. Kolker, and R.W. Fulweiler. 2015. The declining role of organic matter in New England salt marshes. *Estuaries and Coasts* 1-14.

Collie, J.S., A.D. Wood, and H.P. Jefferies. 2008. Long-term shifts in the species composition of a coastal fish community. *Canadian Journal of Fisheries and Aquatic Science* 65:1352-1365.

Doney, S. C., V.J. Fabry, R.A. Feely, and J.A. Kleypas, 2009. Ocean acidification: the other CO2 problem. *Marine Science* 1:169-192.

Frumhoff, P.C., J. J. McCarthy, J. M. Melillo, S. C. Moser, and D. J. Wuebbles. 2007. Confronting climate change in the US Northeast. A report of the northeast climate impacts assessment. Union of Concerned Scientists, Cambridge, Massachusetts.

Miller-Rushing, A.J. and R. B. Primack, 2008. Global warming and flowering times in Thoreau's Concord: a community perspective. *Ecology* 89:332-341.

Oviatt, C. 2004. The changing ecology of temperate coastal waters during a warming trend. *Estuaries* 27:895-904.

Polgar, C.A. and R. B. Primack, 2011. Leaf-out phenology of temperate woody plants: from trees to ecosystems. *New Phytologist* 191:926-941.

Smith, S.B. and P.W.C. Paton, 2011. Long-term shifts in Autumn migration by songbirds at a coastal eastern North American stopover site. *The Wilson Journal of Ornithology* 123:557-566.

Smith, L. M., S. Whitehouse, & C.A. Oviatt, 2010. Impacts of climate changes on Narragansett Bay. *Northeastern Naturalist* 17:77-90.

Talmage, S. C., and C. J. Gobler. 2009. The effects of elevated carbon dioxide concentrations on the metamorphosis, size, and survival of larval hard clams (*Mercenaria mercenaria*), bay scallops (*Argopecten irradians*), and Eastern oysters (*Crassostrea virginica*). *Limnology and Oceanography* 54, 2072-2080.

(6) Precipitation and Inland Flooding

Climate change is expected to result in more frequent heavy rains, affecting stream flow in Northeastern states, with increases in 3-day peak flows contributing to increases in flooding risks (Demara et al. 2015). Climate change may exacerbate drought conditions and reduce river and stream 7-day low flow events (Demara et al. 2015). Southern RI, Block Island, Jamestown, and Aquidneck Island depend on shallow ground-water wells and shallow surface reservoirs, and are vulnerable to drought.

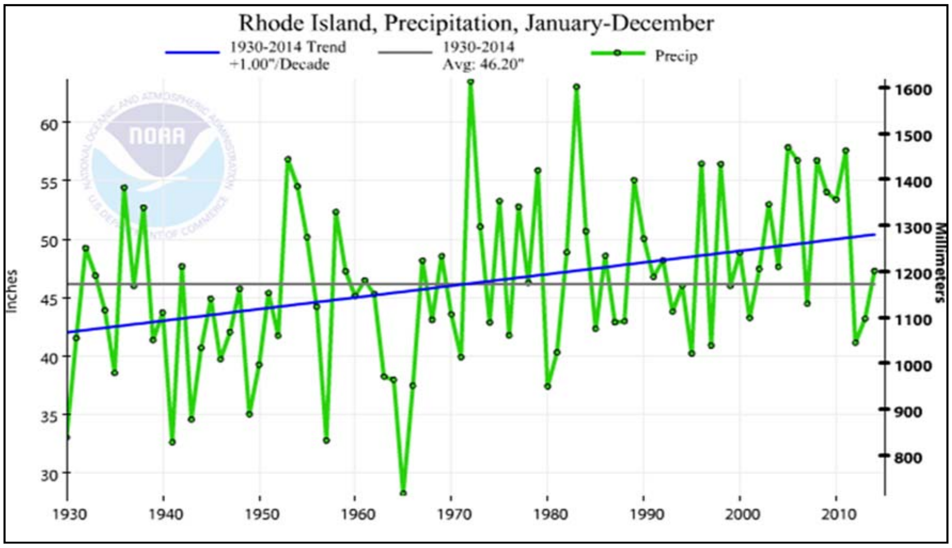


Figure 6.1 Annual precipitation for Rhode Island for the period 1930-2014. Source: http://www.ncdc.noaa.gov/cag

Rhode Island has experienced a significant increase in both flood frequency and flood severity over the past 80 years. RI and throughout most of southern New England has experienced a doubling of the frequency of flooding and an increase in the magnitude of flood events, (Vallee & Giuliano 2014) The NWS tracks flood severity by levels of minor, moderate and major.

Intense rainfall events (heaviest 1% of all daily events from 1901 to 2012 in New England) have increased 71% since 1958 (Walsh et al. 2014). However, this analysis begins with the drought-prone 1960's in New England. Rainfall statistics (1895 to 2015) in Kingston RI, show more interannual and decadal variability in extreme events. The 100 year floods almost always have major" impacts, but are very low frequency.

Multiple climate change models suggest that Green House Gas (GHG) increases will result in increased precipitation in RI (Milley et al. 2008), but observed increases in precipitation in the Northeastern US are greater than models predict (Peterson et al. 2013). Trends of increasing 20th century precipitation may mask risks related to episodic drought.

Land use changes such as increases in impervious surfaces and obstructions to stream flow (culverts and bridges) contribute to flooding. Some RI dams & bridges are at increasing risk of failure during flood events. Climate change increases the costs associated with infrastructure upgrades needed to: 1) protect drinking water, 2) address storm-water risks, and 3) reduce Combined Sewer Overflows

RI should plan to assess vulnerabilities associated with wet and dry extremes. This should include inland flooding risks to: transportation, infrastructure, businesses and homes, public health; and vulnerabilities associated with dry extremes of climate affecting low stream-flow and ground-water supply.

References

Demaria, E.M.C., R.N. Palmer, and J.K. Roundy. 2015. Regional climate change projections of streamflow characteristics in the Northeast and Midwest U.S. *Journal of Hydrology: Regional Studies* 5:309-323. doi:10.1016/j.ejrh.2015.11.007

Milly, P. C. D, J. Betancourt, M. Falkenmark, R.M. Hirsch, Z.W. Kundzewicz, D.P. Lettenmaier, and R.J. Stouffer. 2008. Stationarity Is dead: Whither water management? *Science* 319: 573-574. DOI: 10.1126/science.1151915

National Academies of Sciences, Engineering, and Medicine. 2016. *Attribution of Extreme Weather* Events *in the Context of Climate Change*. Washington, DC: The National Academies Press. doi: 10.17226/21852.

Pederson, N. A. R. Bell, E.R. Cook, U. Lall, N. Devineni, R. Seager, K. Eggleston, and K.P. Vranes. 2013. Is an Epic Pluvial Masking the Water Insecurity of the Greater New York City Region? *Journal of Climate* 26: 1339-1354. doi: 10.1175/JCLI-D-11-00723.1

D. Vallee and L. Giuliano. 2014. Overview of a Changing Climate in Rhode Island. Report developed for the Storm Guidance Working Group of the RI Executive Climate Change Coordinating Council. http://www.planning.ri.gov/documents/climate/11_14/Overview_of_a_changing_climte_%20RI_v2.pdf

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville, 2014: Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT.