New Jersey Marine Fisheries Administration

Climate Change Curriculum Ideas
March 2019

Impacts of climate change on marine fish and fisheries

Included in this document are summary descriptions of several effects of climate change on marine and estuarine fish and shellfish species. Impacts of climate change on marine species will be wide ranging, affecting individuals, populations, and communities, and we have already begun to see some of the effects of climate change in the marine environment. It should be stressed that direct effects on fish and shellfish often result in indirect effects on humans (primarily socio-economic) because of our many important commercial and recreational fisheries.

The information below is broken into six main impact categories: ocean acidification, shifting species distributions, invasive species, storm events, precipitation, and sea level rise. Within each category, we have provided a short description of how that impact will affect marine fish and fisheries, as well as websites and other reference material (both scientific and layman) that relate to that impact. The descriptions are not intended to be comprehensive or exhaustive; rather, they should be considered a starting point to help guide development of preK-12 curriculum on the impacts of climate change in New Jersey and beyond. Marine Fisheries Administration staff would be willing to assist in further development of any of these topics, if requested.

As staff was developing this document, we discussed several ideas that do not fit into any one of the categories listed below but we thought were important to share. First, although there is scientific evidence for climate change and real or expected impacts, there is still great uncertainty with regard to the extent of those impacts. As an analogy, meteorologists have models to predict the weather, and most days the forecast is close…but not always. Climate scientists have models to predict many things too. The accuracy of those models will not be known until the future arrives. Second, the term "impacts" generally carries a negative connotation; however, it was noted by staff that there will be both "winners" and "losers" through climate change. For example, many species compete with one another for resources (e.g. habitat, food), so a negative effect on one species may result in a positive effect on another. Third, the effects of climate change will require changes to fish and wildlife management practices as well. How, when, and where we sample, and the analytical techniques we use to summarize and decipher the data, may all need to adapt along with the species.

On a broader note, during development of this document, several staff members noted that NJ DEP is linked to several national environmental education programs, including:

- Project WET https://www.projectwet.org/
- Project WILD https://www.fishwildlife.org/projectwild
- Project Learning Tree https://www.plt.org/

Each of these organizations has curriculum activities that target or include references to climate change for K-12 students that may be helpful to this process.

Species distribution shifts

There is substantial evidence from studies throughout the Mid-Atlantic region and U.S. east coast that climate change is currently having, and will continue to have, impacts on marine fishery resources. Climate change alters the suitable habitat available to our marine resources here in New Jersey. As average ocean water temperatures continue to rise, some marine species are moving poleward and/or into deeper waters to remain in their optimal thermal range instead of attempting survival under suboptimal conditions. For example, Atlantic surf clams in New Jersey waters have shifted northeast over the past 30 years of surveying performed by the NJDEP. The species prefers the cooler waters. Shifting stocks can mean ecological functions of a species may change as they move into new areas. For instance, there could be a mismatch between predatory species and their typical prey species. Shifts in the distributions of stocks also present large issues for fishery managers. Managers will need to respond to these shifts, as this may mean fishermen may no longer be able to catch a species their livelihoods depend on, or will now be able to exploit new species that were not typically found in our region. Identifying shifts in species can be complicated by fishing pressure in general, as other factors may affect impact the distribution of fish stocks as well. For instance, shifts in black sea bass and scup (two important species in the Mid Atlantic) have been identified as climate-driven, while summer flounder distribution shifts have been attributed to a decrease in fishing pressure (Bell et al. 2015). Adaptive management strategies will need to be implemented and constantly reevaluated as substantial climate-driven change will have impacts for years to come.

Scientific papers:

Richard J. Bell, David E. Richardson, Jonathan A. Hare, Patrick D. Lynch, Paula S. Fratantoni; Disentangling the effects of climate, abundance, and size on the distribution of marine fish: an example based on four stocks from the Northeast US shelf. ICES Journal of Marine Science, Volume 72, Issue 5, 1 June 2015, Pages 1311–1322, https://doi.org/10.1093/icesjms/fsu217

Nye JA, Link JS, Hare JA, Overholtz WJ (2009). Changing spatial distribution of fish stocks in relation to climate and population size on the Northeast United States continental shelf. Mar Ecol Prog Ser 393:111-129. https://doi.org/10.3354/meps08220

Websites:

Spatial Analysis Distributional Shifts (has animations):
https://www.nefsc.noaa.gov/ecosys/spatial-analyses/

Northeast Fish and Shellfish ClimateVulnerability Assessment:
https://www.st.nmfs.noaa.gov/ecosystems/climate/northeast-fish-and-shellfish-climate-vulnerability/index

Mid-Atlantic Regional Council on the Ocean (MARCO): http://midatlanticocean.org/wp-content/uploads/2018/05/Climate-Change-Vulnerabilities-in-the-Coastal-Mid-Atlantic-Region.pdf

Ocean Adapt: http://oceanadapt.rutgers.edu/

EPA Climate Change Indicators report: https://www.epa.gov/climate-indicators

Submerged aquatic vegetation
- https://www.vims.edu/ccrm/_docs/climate_change/sav.pdf
- https://www.tandfonline.com/doi/full/10.1080/20964129.2017.1353283

Articles:
Climate change to shift many fish species north, disrupting fisheries: https://phys.org/news/2018-05-climate-shift-fish-species-north.html

Marine species distribution shifts will continue under ocean warming: https://www.sciencedaily.com/releases/2017/05/170527110628.htm

Data sources:
Northeast Fisheries Science Center Trawl Survey
NEAMAP
NJ Ocean Trawl Survey

Ocean acidification
Ocean acidification (OA) is the ongoing decrease in the pH of the Earth's oceans which is caused by the uptake of carbon dioxide from the atmosphere. As carbon dioxide absorbs into the ocean, it forms into carbonic acid, thus making the ocean more acidic and affecting millions of organisms that rely on a good pH balance. Increase in carbon dioxide in the atmosphere are caused by the burning of fossil fuels, which releases carbon dioxide, and deforestation, which limits the uptake of carbon dioxide by vegetation. It has been proven that carbonic acid lowers the ocean's pH, which inhibits shell growth in shellfish and other invertebrates, such as corals, oysters, shrimp, lobster and many other planktonic organisms. This can have significant impacts on NJ bivalve shellfish with cascading effects on ecosystem health and our state's thriving wild harvest and shellfish aquaculture industries. Larval and veliger stages are especially vulnerable life stages, resulting potentially in malformed, pitted, or softened shells, which increase the likelihood of death by predation or failure to reach adulthood. OA also greatly affects skeletal growth of marine vertebrates, affecting fish development and reproduction, especially during their early life stages. Pankhurst and Munday (2011) found that increased CO_2 and lower pH in fish tissue causes acidosis which could be detrimental to many cellular processes during the developmental stages throughout their life cycle. High increases of CO_2 and lower pH also leads to higher mortality in fish larvae during the early life stages, leading to major consequences for

the sustainability of fish populations in the future (Panhkurst and Munday 2011, Munday et al. 2010).

Scientific publications:

Bignami, S. I C. Enochs D. P. Manzello S. Sponaugle and R. K. Cowen. "Ocean Acidification Alters the Otoliths of a Pantropical Fish Species with Implications for Sensory Function." Vol. 110. 2013. 7366-70.

Booth, D. J. N. Bond and P. Macreadie. "Detecting Range Shifts Among Australian Fishes in Response to Climate Change." Vol. 62. 2011. 1027-42.

Cooley, S. R. and S. C. Doney. "Anticipating Ocean Acidification's Economic Consequences for Commercial Fisheries." Vol. 4. 2009. (8pp).

Hall, Jr. L. W. "Acidification Effects on Larval Striped Bass, Morone Saxatilis in Chesapeake Bay Tributaries: a Review." Water, Air and Soil Pollution 35 (1987): 87-96. Rec #: 17852

Heath, M. R. F. C. Neat J. K. Pinnegar D. W. Sims and P. J. Wright. "Review of Climate Change Impacts on Marine Fish and Shellfish Around the UK and Ireland." Vol. 22. 2012. 337-67.

Ishimatsu, A. M. Hayashi and T. Kikkawa. "Fishes in High-CO2, Acidified Oceans."Vol. 373. 2008. 295-302.

Munday, P. L. D. L. Dixson M. I. McCormick M. Meekan M. C. O. Ferrari and D. P. Chivars. "Replenishment of Fish Populations Is Threatened by Ocean Acidification." Vol. 107. 2010. 12930-34.

Pankhurst, N. W. and P. L. Munday. "Effects of Climate Change on Fish Production and Early Life History Stages." Vol. 62. 2011. 1015-26.

Urho, L. M. Hildén & R. Hudd. "Fish Reproduction and the Impact of Acidification in the Kyrönjoki River Estuary in the Baltic Sea." Environmental Biology of Fishes 27 (1990): 273-83.

Websites:

- https://www.climaterealityproject.org/blog/global-warming-ocean-acidification
- https://www.epa.gov/climate-indicators/climate-change-indicators-ocean-acidity
- https://www.epa.gov/ocean-acidification/what-epa-doing-address-ocean-and-coastal-acidification
- https://oceanservice.noaa.gov/facts/acidification.html

- https://www.state.nj.us/dep/sab/SAB%20OA%20Report_FINAL%20Approved%20(08-12-15).pdf
- https://www.nrdc.org/sites/default/files/state-vulnerability-NJ.pdf
- https://oceanacidification.noaa.gov/WhatWeDo/EducationOutreach/TabId/2994/PID/14968/evl/0/TagID/613/TagName/OA-curriculum/Default.aspx
- https://www.skepticalscience.com/Ocean-Acidification-is-Fatal-To-Fish-.html
- https://www.mdsg.umd.edu/onthebay-blog/will-ocean-acidification-create-%E2%80%9Csuper-crabs%E2%80%9D-bay-maybe-not
- https://oceanleadership.org/bivalves-blue-crabs-acidification-brings-challenges-new-marine-life/
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5595845/
- https://www.noaa.gov/topic-tags/ocean-acidification
- https://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F
- https://www.nrdc.org/sites/default/files/state-vulnerability-NJ.pdf
- http://scienceandpublicpolicy.org/wp-content/uploads/2015/03/ocean_acidification_marine_bivalves.pdf
- https://marine.rutgers.edu/main/saba/research/climate-change-ocean-acidification-and-warming

Lesson Plans from NJ Sea Grant:
- http://njseagrant.org/wp-content/uploads/2014/02/Ocean-Acidification.pdf
- http://njseagrant.org/wp-content/uploads/2018/08/OA_LegoGame.pdf

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Invasive Species

Among the many concerns associated with climate change is the spread of invasive species and the detrimental impacts they may have on fishery and ecosystem resources along the coast of New Jersey. Invasive species are plants and animals that through intentional or accidental introduction by humans, or through natural dispersion, take hold in a habitat that they are not native to and compete with native species for resources. There are two main climate change impacts that have the potential to be the drivers that expand the spread of invasive species: warming water temperatures and the increased intensity and frequency of major storm events. Water temperatures, especially in the northwest region of the Atlantic Ocean are increasing at a rate that may outpace native species ability to adapt through natural selection and evolution. This leaves the door open for invasive species from other parts of the world that are already adapted to warmer water temperatures to out compete and possibly displace native species. Similarly, the potential for increased severity and frequency of storm events as a result of climate change may also lead to the spread of invasive species. Severe storms such as hurricanes and nor'easters can transport individuals from distant areas and often damage or completely destroy seagrass beds, shellfish beds, coral reefs, and salt marshes. This may allow invasive species to gain a foothold in environments where they were previously excluded from by native species.

This would have cascading effects on food webs and trophic structures. Impacts to fisheries could be dramatic if drastic changes are seen in these types of habitats as many commercially, recreationally, and environmentally important fish species use sea grasses and salt marshes as spawning and nursery sites.

Scientific Papers:

Rahel, F. J., & Olden, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology, 22(3), 521-533. doi:10.1111/j.1523-1739.2008.00950.x

Stachowicz, J. J., Terwin, J. R., Whitlatch, R. B., & Osman, R. W. (2002). Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. Proceedings of the National Academy of Sciences, 99(24), 15497-15500. doi:10.1073/pnas.242437499

Websites:

Climefish Project – Sustainable Fisheries and Aquaculture in a Changing Climate
https://climefish.eu/climate-change-and-impacts-on-fisheries/

How Climate Change is Helping Invasive Species Take Over - Smithsonian Magazine
https://www.smithsonianmag.com/science-nature/how-climate-change-is-helping-invasive-species-take-over-180947630/

Invasive Species and Climate Change - Climate Institute
http://climate.org/archive/topics/ecosystems/invasivespecies.html

Invasive Alien Species and Climate Change
https://www.iucn.org/resources/issues-briefs/invasive-alien-species-and-climate-change

Invasive Species and Climate Change – USDA
https://www.invasivespeciesinfo.gov/subject/climate-change

Storm events

Climate change and sea-level rise is projected to result in more intense storms, larger storm surges and increase forceful flooding over the next 100 years. This can have a detrimental effect to our coastal community as well as marine habitat. In response to climate change and being prepared for more intense weather events, increased efforts in beach nourishment are being done to bolster the shoreline and protect the communities that are in danger of flooding and coastal erosion. As sand is mined from offshore sand lumps in the ocean to accommodate for these programs, key habitat for shellfish and finfish species is being removed or changed. Sand lumps off the coast of New Jersey have a contoured bottom that houses key invertebrate species and

attracts recreationally and commercially important species to these areas. This loss of habitat not only effects the ecology of the area but could also result in a loss of prime fishing grounds which can adversely affect the economic benefit New Jersey gains from its recreational and commercial fishing industries. The fishing industry supports tourism for New Jersey shore towns, providing customers for party and charter vessels, restaurants, and bait and tackle shops.

Websites:

- https://academic.oup.com/bioscience/article/55/10/887/274435
- https://www.nyharbornature.com/blog/what-are-the-costs-of-beach-nourishment
- https://motherboard.vice.com/en_us/article/ezv4ez/climate-change-will-hit-new-jersey-hard
- https://njadapt.rutgers.edu/docman-lister/conference-materials/167-njcaa-stap-final-october-2016/file
- https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2013EF000135

Sea level rise

Sea level rise potentially allows for marine species to colonize areas previously unavailable to them, by way of salinity intrusion and access to previously dry land areas. Submerged aquatic vegetation, for example, could migrate into areas that are now too fresh for their survival. The same applies to oysters, who can survive in salinity level as low as 5ppt. The expansion of seagrass meadows and oyster reefs could increase suitable habitat for other marine species, especially juvenile finfish that use these areas as nursery habitat. These species groups are examples of potential "winners" while coastal wetlands, dunes, and human-occupied uplands would be "losers" as habitats are inundated by sea water.

Websites:

- https://sealevelrise.org/states/new-jersey/
- https://www.nj.gov/dep/njgs/enviroed/infocirc/sealevel.pdf
- https://geology.rutgers.edu/images/stories/faculty/miller_kenneth_g/Sealevelfactsheet7112014update.pdf
- https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level

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Precipitation

Rising temperatures and shifting rainfall patterns are likely to increase the intensity of both floods and droughts (EPA 2016). Precipitation from extremely heavy storms has increased 70 percent in the Northeast since 1958 (EPA 2016). There are a number of potential effects from

climate change induced alterations in precipitation. For example, New Jersey is home to one of three principal spawning sites of Atlantic Striped Bass (*Morone saxatilis*). Increases in light to moderate rainfall events may expand available spawning habitat, while heavy rainfall events may physically remove spawned eggs, larvae, and young fish out of suitable habitat. Drought conditions may reduce spawning habitat. Hence, potential impacts on fish recruitment are complex. Additionally, seawater warming and changes in seasonal patterns of precipitation may lead to a reduction in plankton production, with a decline of habitat suitability for clam growth and aquaculture (Wong et al. 2014). Reduction in salinity caused by excess precipitation can exacerbate ocean acidification (OA) by diluting concentrations of substances acting as pH buffers (Pörtner et al. 2014). Impacts to fish and fisheries from OA are described elsewhere in this document. Additional freshwater from increases in precipitation, combined with warming ocean water, increases ocean water layer stratification, leading to less mixing between cold, deep, nutrient rich water and nutrient limited surface waters with consequences to the oxygen content of water, and ultimately marine and estuarine community composition. For example, large, active fish cannot live in oxygen-poor waters, while more simple specialized organisms with a lower need for oxygen can remain and may even thrive in the absence of predation from larger species (Pörtner et al. 2014).

Literature cited and other useful references

Pörtner, H.-O., D.M. Karl, P.W. Boyd, W.W.L. Cheung, S.E. Lluch-Cota, Y. Nojiri, D.N. Schmidt, and P.O. Zavialov, 2014: Ocean systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 411-484. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap6_FINAL.pdf

Environmental Protection Agency (EPA). 2016. What Climate Change Means For New Jersey. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-nj.pdf

NJDEP. 2018. Climate Change in New Jersey: Temperature, Precipitation, Extreme Events, and Sea Level. Environmetnal Trends Report, NJDEP Office of Science. 7 pp. https://www.state.nj.us/dep/dsr/trends/

Wong, P.P., I.J. Losada, J.-P. Gattuso, J. Hinkel, A. Khattabi, K.L. McInnes, Y. Saito, and A. Sallenger, 2014: Coastal systems and low-lying areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel,

A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 361-409. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap5_FINAL.pdf

FAO. 2018. Impacts of climate change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options. Eds Barange, M, T. Bahri, M. C. M. Beveridge, K. L. Cochrane, S. Funge-Smith, and F. Poulain. FAO Fishers and Aquaculture Technical Paper 627. 628 pp. http://www.fao.org/3/I9705EN/i9705en.pdf

Pershing, A.J., R.B. Griffis, E.B. Jewett, C.T. Armstrong, J.F. Bruno, D.S. Busch, A.C. Haynie, S.A. Siedlecki, and D. Tommasi, 2018: Oceans and Marine Resources. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 353–390. https://nca2018.globalchange.gov/downloads/NCA4_Ch09_Oceans_Full.pdf

Data sets

Office of the New Jersey State Climatologist at Rutgers University
https://climate.rutgers.edu/stateclim/

NJ Weather and Climate Network
https://www.njweather.org/data/daily