State of the Science FACT SHEET

Oceanic Extreme Events: Marine Heatwaves

This summary of marine heat waves and related extreme events was developed by NOAA scientists and approved by NOAA's Science Council.

Extreme events in the oceans and coastal environments include, but are not limited to, unexpected, unusual, unpredictable severe temperatures, blooms of toxic algae, coral bleaching, and freshwater discharges at the extremes of historical distributions. For the 1994-2020 period, an estimate of the economic cost of these and related extreme events to the U.S. fishery is on the order of US$2Bn in Congressional allocations (i.e., disaster relief), and over US$3Bn in direct revenue cost (Bellquist et al. 2021).

What is a Marine Heatwave?

Marine heatwaves (MHWs) are temporary periods of unusually warm ocean temperatures. They can be thought of as the marine analog for heatwaves over land, which are known for impacting human health, infrastructure, and agriculture. Beyond this qualitative similarity, MHWs can have widely varying forms. A working definition for a MHW is when seawater temperatures are warmer than 90% of a seasonally-varying threshold for at least 5 consecutive days (Fig. 1). Successive heatwaves with gaps of 2 days or less are considered part of the same event.

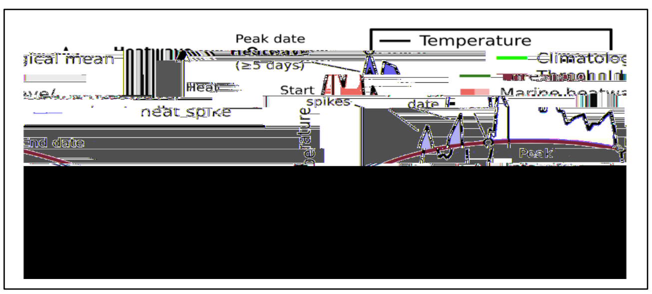

Figure 1. MHW definition from Hobday et al. (2016).

MHW events may be local or cover large portions of ocean basins – millions of square kilometers, and they may fade in a matter of days or persist for years. While the name marine heatwave is new, the phenomenon is not – perhaps the most prominent flavor of marine heatwave is El Niño, which has long been a topic of scientific research and public interest.

Causes of Marine Heatwaves

In general, causes of MHWs fall into three general categories (Sen Gupta *et al.* 2020): (i) changes in how heat is transported through the ocean, such as shifts in major currents, e.g., the Gulf Stream-Labrador current system (Gonçalves Neto *et al.* 2021); (ii) persistent anomalies in large-scale atmospheric systems, e.g., that gave rise to the 2013-16 North Pacific "warm blob" (Bond *et al.* 2015), and (iii) ocean-wide coupled air-sea processes such as those that give rise to El Niño events (Eakin *et al.* 2019).

What are some Impacts of Marine Heatwaves?

MHWs affect ecosystem structure and can change species' distributions, abundance, or populations' structure (Cornwall, 2019). MHWs have been shown to increase mortality of species that are unable to move, including corals, seagrass beds, and kelp forests, each of which provides critical habitat for marine life. Highly mobile species can respond to MHWs by shifting their ranges, sometimes by thousands of kilometers, to find favorable conditions. In doing so they can have socioeconomic impacts as their availability to commercial, recreational, and subsistence fisheries is altered. Additionally, MHWs can give rise to changes in habitat, overlaps between fisheries and protected species, and associated management challenges (Santora *et al.* 2020).

Marine Heatwaves – recent examples

Unusually warm seawater events are not a new occurrence. Over the past two decades, prominent MHW events such as the ones below have been identified throughout our oceans (Fig. 2).

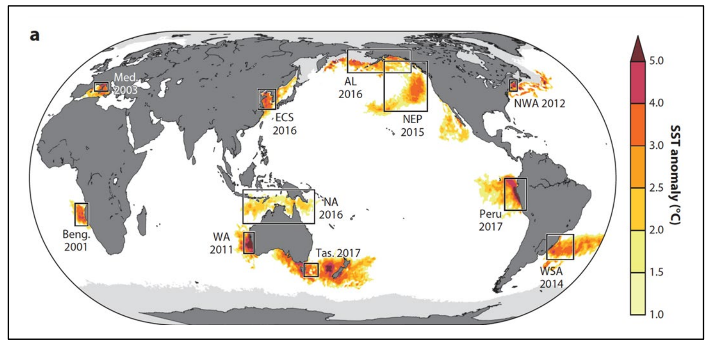

Figure 2. Selected historical MHWs. Sea surface temperature anomalies indicate peak MHW intensity. Light gray indicates areas of sea ice influence. Taken from Oliver et al. (2020).

The North Pacific "blob". The "blob" was a large mass of warm water in the Pacific Ocean off the coast of North America which was detected in 2013 that continued through 2014, 2015, and into 2016. The blob was up to 3 ºC (~5 ºF) above average and extended from Mexico to Alaska and beyond, stretching more than 3,000 km. It reached over 100 m in depth, with patches off the coast of Alaska, Canada, the U.S. west coast, and off Mexico (Fig. 3). The blob significantly changed the local ecosystem, shifting salmon migration, and elevating sea bird mortality, sea lion strandings, and whale entanglements (see https://www.fisheries.noaa.gov/feature-story/looking-back-blob-record-warming-drives-unprecedented-ocean-change).

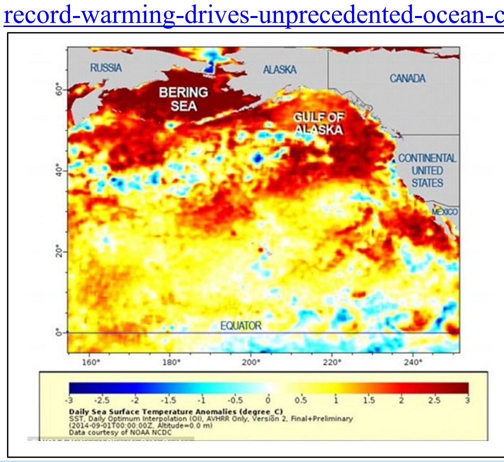

Figure 3. Sept. 2014 sea surface temp anomalies associated with the North Pacific "blob".

<u>*New England and Gulf of Maine warming.*</u> In 2012, the Gulf of Maine was the warmest on record, with the surface ocean temperature 2 ºC (>3 ºF) above average. This MHW affected most of the Northwest Atlantic and the impacts were manifested in local fisheries and economies over a very short time period. The 2012 MHW had a major impact on many fisheries throughout the region but the impacts on the American lobster fishery were among the most significant (Mills et al. 2013). The heatwave began in the spring causing lobsters to move inshore – much earlier than usual – and enhanced molting rates leading to a larger number of legally-sized individuals available to the fishery. This led to a longer lobster fishing season and the highest fishery yield on record up to that point. The economic impacts of this record year were unexpected: high landings exceeded the fishery's processing leading to an oversupply and a substantial decrease in the value of lobster in both the U.S. and Canada (Fig. 4). The 2012 event is an example of MHWs having socioeconomic impacts within a single fishing season.

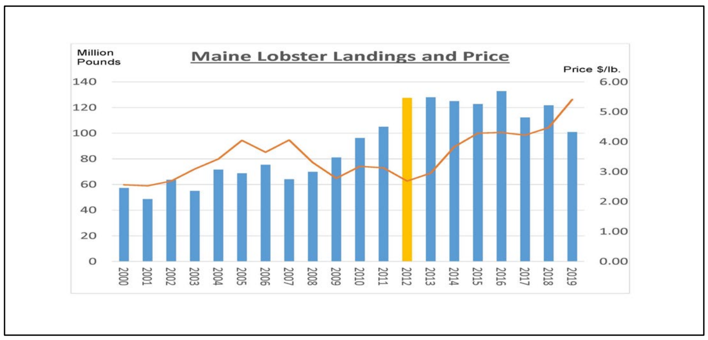

Figure 4. Annual Maine lobster catch (blue bars) and Inflation Adjusted price (orange line) from 2000-2019. Despite the near-record catch in 2012, the prices declined to a 10 year low. (NMFS data)

<u>*Pacific Coral Bleaching.*</u> Coral reefs are among the most valuable ecosystems globally. The increasing frequency of MHWs disrupts an essential symbiosis between corals and algae leading to coral bleaching that can lead to mass coral mortality. These ecosystems form the cultural heritage for many indigenous island and coastal communities, support 25% of all marine biodiversity, provide more than $3.5B/year in tourism and $200M from fisheries revenue in the U.S., and protect 61,000 US citizens/year from catastrophic storms. Coral bleaching is a stress response that individual corals can experience due to a variety of reasons; however, it is most commonly caused by exceedingly warm water temperatures.

Global bleaching events can be expected during El Niño conditions; but the most recent event, from 2014 to 2017, included non-El Niño extreme conditions. During this event, reefs bleached and died, including half of the Great Barrier Reef (Fig. 5; also see https://coralreefwatch.noaa.gov/satellite/analyses_guidance/global_coral_bleaching_2014-17_status.php).

Figure 5. Coral bleaching event in the Great Barrier Reef during a 2017 MHW. (From McDermott, 2020.)

What Can We Expect for the Future of Marine Heatwaves?
Studies have suggested that climate change will alter the dynamics of the climate system such that ocean temperature variability will increase, and MHWs will become more intense. Such changes are likely to be regionally dependent, with certain regions (e.g., high latitudes with future reduced ice cover) more susceptible than others. However, MHWs are occurring against the backdrop of long-term climate change, as ocean temperatures have warmed over the past century and will continue into the future. This warming trend implies that even if MHW amplitudes do not become larger, temperatures that we now consider extreme will occur more often (Jacox, 2019). As such, by the mid- to late-21st century many regions of the ocean could permanently experience temperatures that are currently only reached during MHWs.

MHWs will compound the stress of the warming trend, as they continue to push ocean temperatures to unprecedented levels. Such a marked change in the physical ocean environment will likely drive redistributions of marine species, requiring measures for marine resource-dependent communities and economies to adapt to both lost and emerging opportunities while promoting sustainable ecosystems. NOAA's ocean and climate scientists continue to track ocean conditions and research impacts of anomalous events through observations and directed research projects. Their work provides critical information to the general public and decision makers to help manage against potential impacts from MHW events. As an example, see the California Current's Integrated Ecosystem Assessment Marine Heatwave tracker: https://www.integratedecosystemassessment.noaa.gov/regions/california-current/cc-projects-blobtracker.

References

Bellquist *et al.* (2021), *PeerJ*, DOI 10.7717/peerj.11186
Bond, N.A. *et al.* (2015) *Geophys. Res. Lett.* 42:3414–3420.
Cornwall W. (2019) *Science*, 363:442-445.
Eakin, C.M. *et al.* (2019) *Coral Reefs,* 38:539–545.
Gonçalves Neto, A. *et al.* (2021) *Commun. Earth Environ.,* 2:74.
Hobday, A.J. *et al.* (2016) *Prog. in Oceanography*, 141:227-238.
Jacox, M.G. (2019) *Nature*, 571:485-487.
McDermott, A. (2020) *PNAS*, 117:2232-2235.
Mills, K.E. *et al.* (2013) *Oceanography*, 26:191-195.
Oliver, E.C.J. *et al.* (2021) *Ann. Rev. Mar. Sci.*, 13:313-342.
Sen Gupta A. et al. (2020) *Scientific Reports*, 10:19359.
Santora, J.A. *et al.* (2020) *Nature Communications*, 11:536.