Editor’s note: The Skimmer is a MEAM feature where we briefly review the latest news and research on a topic. Last week, I had the opportunity to attend the 4th International Symposium on Effects of Climate Change on the World’s Oceans (ECCWO), held in Washington, DC. This symposium gathered scientists and managers from more than 50 nations to discuss the latest science on climate change impacts on ocean ecosystems, identify climate risks and knowledge gaps, and determine best ways to respond to sustain ocean resources and communities. Here is a quick summary of some recent and brand new research findings presented at the symposium on how weather and climate extremes are impacting marine ecosystems, as well as insights shared by speakers. (Learn about climate change tools and resources presented at the symposium in this month’s EBM Toolbox). Part 2 of the Skimmer, coming out next month, will feature more research and insights from ECCWO on how we can manage and conserve ocean ecosystems in a rapidly changing climate.

We know that extreme weather events (such as marine heatwaves) and other climate change-associated effects (including ocean warming, ocean deoxygenation, and ocean acidification) are dramatically altering marine ecosystems. But we are still figuring out the how, how much, and why of these changes. Some perspectives on what we know and what we still need to know:

What we need to do to better understand changes in species distributions (aka “range shifts”)

- As MEAM readers are all aware, the oceans are becoming warmer because of increased concentrations of greenhouse gases in the atmosphere. The average global sea surface temperature has increased by over 1 °C over the past 100 years, and the mean global ocean temperature is expected to increase by another 1–4 °C by 2100.

- As ocean temperatures rise due to climate change, many marine populations are shifting to new areas to keep pace with their preferred environmental conditions. Marine species are moving poleward at an average of 78 km per decade, and many are also moving deeper to cooler water. Between 25 and 85% of species are shifting, with the greatest shifts occurring in areas with the greatest warming.

- According to Gretta Pecl of the Center for Marine Socioecology and the Institute for Marine and Antarctic Studies in Tasmania, Australia, in her plenary presentation at the symposium (watch a recording of the plenary), we are currently looking at range shifts from a species perspective – we look at the local climate velocity (the speed and direction of isotherms – lines of equal temperature – across a seascape), life history traits, physiological responses, and other direct interactions. But range shifts depend on both the “shiftiness” of
species AND the receptiveness of the receiving environment. This is similar to invasion biology where invasions depend on both the invasiveness of the invading species and invisibility of the receiving environment. Characteristics of the receiving environment such as instability of the resident ecological network are critical and represent a new frontier for research to understand range shifts.

- In addition, climate-driven range shifters can have massive impacts on receiving environments, akin to invasive species. In Australia, changes in the East Australian Current are bringing warm currents from New South Wales to Tasmania. The currents have introduced the voracious long-spined sea urchin to Tasmanian waters, and the aggressive grazing of this urchin is reducing kelp beds to “urchin barrens”. Additionally, according to Pecl, our focus on individual species also means we’re not looking enough at the collective impact of multiple shifting species.

**How are these range shifts changing global biodiversity?**

- In a stunning display of number crunching, researchers from the Changing Oceans Research Unit at the University of British Columbia assembled 4 billion records from numerous biodiversity databases and modeled distributions for every decade between 1950 and 2100 for over 40,000 species ranging from phytoplankton to marine mammals under two climate scenarios. The results show that biodiversity hotspots in the ocean will vary among taxa and predict the impact of anthropogenic climate change on global marine biodiversity. In general, there will be big local biodiversity losses, but some high seas and high latitude areas may provide refuges for tropical and temperate species if they provide suitable habitats and appropriate management measures can be taken. Want to see these results? Look for them next year on the Map of Life website.

*Overheard at the symposium:* “Species basically have three choices: adapt, move, or die.”

**Ocean warming will create more ecological “mismatches”**

- Ocean warming is also changing the phenology (timing of seasonal activities) of marine organisms with many annual processes happening earlier in the year than they have historically. These changes are happening at different rates for different species, however. It is hypothesized that many fish species have evolved to spawn during phytoplankton blooms to increase food availability for fish larvae.

- Using an earth system model, researchers estimate that phytoplankton species will bloom an average of 17 days earlier in the second half of the 21st century than they did during the first half of the 20th century under a relatively high “business as usual” climate change scenario. In these simulations, fish species that exhibit fidelity to a specific spawning site spawn an average of 42 days earlier. Of these “geographic spawner” species, 86% would spawn before the phytoplankton bloom started, while only 10% would spawn during the bloom. Missing the bloom could lead to poor survival, growth, and recruitment of fish larvae and declines for the fishery.

- Fish species whose spawning location is controlled by environmental factors (e.g., fish move to track changing conditions when seeking out spawning) would fare better with 38% predicted to spawn before the bloom and 60% during the bloom. These simulations suggest that mismatches may become more common as the oceans warm, although species range shifts may decrease the severity of seasonal for environmental spawners in some instances.

**Marine heatwaves – learn to expect the unexpected**

- Ocean warming is not just affecting ocean climates. It is affecting ocean “weather” too.

- So for starters, what are marine heatwaves? A recent paper in *Nature Communications* describes them as “coherent areas of extreme warm sea surface temperature that persist for days-months”. They are becoming more frequent and lasting longer – changes that can largely be explained by increases in ocean temperatures. (See a map of some prominent recent marine heatwaves.)

- What do models say the future holds? It’s not pretty. Researchers looked at the probability of marine heatwave days under a relatively high, “business as usual” (RCP 8.5) and relatively low, strong mitigation (RCP 2.6) greenhouse gas emission scenarios. Under 3.5°C global warming, marine heatwaves would be 41 times more likely than today. The areas projected to be hardest hit by marine heatwaves are the Arctic Ocean and western tropical Pacific.

- And how are marine heatwaves affecting marine ecosystems? The marine heatwave in the Gulf of Maine in the northeastern US in 2012 led to much higher catches of lobster but also much lower prices, which did substantial harm to lobstering communities in the region. The 2013-2016 marine heatwave off the North American West Coast (“The Blob”) led to dramatic shifts in species ranges (more below). And the 2016 marine heatwave off the east coast of Australia led to mass bleaching and even death of corals on the Great Barrier Reef.

- A lot of recent research on the 2013-2016 marine heatwave off the North American West Coast (“The Blob”) was presented at the symposium. The Blob was first detected in the northern Pacific in Fall 2013 and was held offshore by upwelling during Summer 2014. The warm water started to intrude into coastal waters off the west coast of North America in Fall 2014. [In fact, on September 14, 2014, the sea surface temperature at a buoy off Newport, Oregon, went up 6°C in approximately 12 hours (pg. 42).] This heatwave led to unprecedented warm conditions along the coast in 2015 and 2016 and had massive ecosystem impacts ranging from harmful algal blooms, to the collapse of Pacific cod stocks, to die-offs of seabirds dependent on forage fish, to the emergence of tropical species in the North Pacific.

- As extreme ocean events become more frequent, a new classification system for marine heatwaves has been proposed to describe these
events and help communicate them to the public. The proposed scheme combines elements from atmospheric heatwave and hurricane classifications. It assigns marine heatwaves a category level (I, II, III, IV) depending on how much the temperatures exceed the local climatology and a name based on the location and year (e.g., the Category III marine heatwave Northeast Pacific Blob 2015). Use of this system will enable comparison of events, and similar systems are needed for ocean acidification and deoxygenation events. As extreme events become more common, categories can be added, definitions can be updated, and/or baseline periods can be changed to reflect a new “normal”.

Overheard at the symposium while looking at a picture of the boxer Rocky [Weather] and his trainer [Climate]: “If you’re an organism or an ecosystem, the thing that really hits you is Weather. He’s delivering the knockout blows. And behind him is Climate, making him bigger, making him faster, making him stronger, making the events really hard to deal with.”

**Deoxygenation – the next big problem coming into focus**

- Another big climate change impact which doesn’t get much press (yet) is the large-scale deoxygenation of the ocean. In a nutshell, the global ocean has lost about 2% of its oxygen since 1960, and models predict continued loss with additional climate change. (See a map of regional variability in oxygen loss.) Oxygen loss in surface waters is largely due to increased ocean temperature (oxygen is less soluble in warmer water) and biological consumption, while oxygen loss in deeper waters is largely due to increased stratification and circulation changes leading to less ventilation of deep ocean water, as well as biological consumption. The marine conservation and management communities have been talking about small-scale coastal hypoxia events linked to eutrophication for years. This new deoxygenation thing is different and much larger-scale, although coastal hypoxia is also aggravated by global warming.

- This is really new science. Models don’t yet do a great job reproducing historical trends, and there is a lot of uncertainty associated with forecasts, particularly for the tropics and upwelling regions. Which all means we don’t really fully understand the dynamics of large-scale ocean deoxygenation just yet.

- Some of the biological impacts from deoxygenation that were discussed at the symposium include:
  - These changes are leading to habitat loss for pelagic species (e.g., blue marlin have been observed to avoid low oxygen zones), crowding them into smaller areas and making them more vulnerable to fishing pressure.
  - Modeling of the biological response of over 600 species to decreasing oxygen levels suggests that body weight could shrink by 14-24% globally from 2000 to 2050.
  - Demersal fish diversity is lower in areas with low oxygen levels (see pg. 72), although there are fish (such as cat sharks and cusk-eels in the Gulf of California) already adapted to low and extremely low oxygen environments. Increased deoxygenation in the oceans may offer an opportunity for range expansion of these fishes, but it will likely lead to decreased demersal fish diversity globally.

**And ocean acidification, “global warming’s equally evil twin”**

- Roughly a third of the CO₂ released by anthropogenic activities into the atmosphere gets absorbed by the ocean. And some of this CO₂ dissolves to form carbonic acid which lowers the pH of the oceans. Since the 1700s, it is estimated the oceans have become 30 percent more acidic. This change in pH has negative effects on calcifying organisms, including numerous types of zooplankton and commercially and culturally important shellfish species, and is a stressor for other ocean organisms.

- There are now numerous initiatives to gather global data and share information on ocean acidification (see this month’s EBM Toolbox column).

- One system affected by ocean acidification that is relatively well studied is the California Current System off the west coast of the US. It is expected to become more acidic in the future as atmospheric CO₂ increases. A model of lower trophic levels, harvested and protected species, and fishery catches predicts that the strongest direct effects of ocean acidification will be on epibenthic invertebrates such as crabs, shrimps, sea urchins, and bivalves. Demersal fish such as rockfish, sharks, and Dungeness crab would be indirectly affected because they prey on species directly affected. The model predicted relatively little effect on coastal pelagic species and virtually no effect on phytoplankton, zooplankton, birds, and mammals. While these biological impacts would be strongest in the southern part of the California Current System, the model also suggested that the biggest economic impacts would be felt by northern ports in the region because of their reliance on Dungeness crab.

Overheard at the symposium: “Ocean acidification is heavy on losers, light on winners, and some of the winners aren’t that tasty.” [Kaplan, pg. 151]

**Insight: We can’t depend on the past as a guide to the future. Extreme events can help us figure out what impacts future climate change may have**

- A critical point made by many speakers at the symposium is that we cannot rely on the past for understanding what we will see in the future. We are already experiencing conditions that have never been seen before, even in deglaciation periods. According to Alistair
Hobday of CSIRO Oceans and Atmosphere in Tasmania, Australia, extreme events like marine heatwaves and marine “hotspots” are a natural laboratory for learning quickly about the impacts of climate change and possible adaption and management actions. Watch a recording of this plenary for additional insights and a great (and amusing) overview of marine heatwaves.

**Insight: We need to accept and embrace variability in species response**

- Another major point made by many speakers during the symposium, particularly by plenary speaker Stephen Widdicombe of the Plymouth Marine Laboratory in the United Kingdom, is that the response of individual organisms to changing ocean conditions is determined by the individual’s own physiological responses, its interactions with other organisms, and the interactions of these things. This means that not all individuals or even populations of the same species will respond in the same way to climate change impacts. For instance, **males and females** of the same species may respond differently from each other. And **populations from different parts of a species’ range** may respond differently from each other. Individual variability is to be expected (and, indeed, is what drives adaptation) and more consideration needs to be given to the range of responses to climate change rather than the mean response. Watch a recording of this plenary for more great insights about conducting climate change research.

**Overheard at the symposium:** “No experiments and studies are perfect mimics for climate change except one, and it’s not wise to wait for the results of that one.”

Coming soon to MEAM: Part 2: Conservation and management of marine ecosystems with shifty species; hot, acidified water; and not enough oxygen.

Illustration credit: Bas Kohler for the 4th International Symposium on the Effects of Climate Change on the World’s Oceans. See more Kohler illustrations from the conference (available for use in science communications).

[1] The symposium was organized and funded by numerous entities, including the four primary sponsors ICES, PICES, IOC, and FAO and the local sponsor NOAA Fisheries.

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