The potentially deadly trio of factors – warming, acidification and anoxia – affecting today's oceans

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SUMMARY:
Most, if not all, of the five global mass extinctions in Earth's history carry the fingerprints of the main symptoms of global carbon perturbations (global warming, ocean acidification and anoxia or lack of oxygen; e.g. Veron, 2008*). It is these three factors — the 'deadly trio' — that are present in the ocean today. In fact, the current carbon perturbation is unprecedented in the Earth's history because of the high rate and speed of change. Acidification is occurring faster than in the past 55 million years, and with the added man-made stressors of overfishing and pollution, undermining ocean resilience.*

MAIN TEXT:
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It is these three factors – the 'deadly trio' – that are present in the ocean today. In fact, the current carbon perturbation is unprecedented in the Earth's history because of the high rate and speed of change. Acidification is occurring faster than in the past 55 million years, and with the added man-made stressors of overfishing and pollution undermining ocean resilience.

It is this combination of factors that seriously affects how productive and efficient the oceans are, as ocean temperature, surface stratification (different layers of water densities), nutrient supply, ocean overturning and deep-ocean oxygen supply are all affected.

The process of extinction may have already begun, as Professor Jelle Bjima explains: "From a geological point of view, mass extinctions happen overnight, but on human timescales we may not realize that we are in the middle of such an event, even when keeping close track of the 'red list index' of species extinctions."

Acidification in Earth's history
It is known with a high level of confidence from geological evidence that ocean acidification occurred in the past. The most critical factor is the *rate* of the carbon perturbation.

During the End Permian mass extinction (ca. 251 million years ago), the carbon perturbation is estimated to be on the order of 1–2 Gt CO_2 per year (*Kump et al., 2009*). For comparison, 1 gigaton is one billion tons, or the equivalent of around one billion middle-sized cars.

For the most recent globally significant extinction event – the Paleocene Eocene Thermal Maximum extinction (PETM; ca. 55 million years ago is considered the closest analog to currently ongoing ocean acidification), estimates of the rate of the carbon perturbation vary, but a minimum value of 2.2 Gt CO_2 per year during an estimated span of 5 to 10 thousand years has been proposed (*Zeebe et al., 2009*).

Both these estimates are dwarfed in comparison to today's emissions of roughly 30 Gt of CO_2 per year. It can be said with certainty that today the uptake of CO_2 into the oceans is outstripping its capacity to neutralise it, known as buffering capacity, leading to a reduction in pH and a lowering of its 'saturation state' (*Ridgwell and Hargreaves, 2007*). It is this saturation state of the ocean (denoting the amount of 'building material' for calcifying organisms) that is critical to the functioning of most calcifying organisms such as for instance tropical coral reefs but also planktonic organisms that are at the basis of pelagic food webs, especially in the vulnerable high latitudes towards the Poles.

If the current trajectory of carbon perturbation continues, we should expect more serious consequences for the marine ecosystem than during the PETM, when Earth experienced a major, benthic (deep-sea) extinction. However, it should also be mentioned that although ca. 35 to 50% of the deep-sea species were lost during that time, planktonic organisms (living in the upper part of the ocean) and organisms in coastal waters, while partly replaced by other (better adapted) species, continued to live.

On the other hand, each of the 5 major mass extinctions had different impacts on land and in the ocean and affected different groups of organisms. These events are classified as those involving a loss of a minimum of 75% of species over 2 million years. Comparing the current environmental change with these events is difficult because the rates of environmental change are unprecedented. It is therefore difficult to predict what the outcome of the current anthropogenic experiment will be.

Although it cannot be said with certainty where we are heading, it can be said with certainty that we are pushing the Earth system to its limits. Professor Bijma is convinced that ocean acidification will have huge implications for humans: "It is difficult to predict how our society will be effected, but in my view, it will be the most dramatic challenge faced by an exponentially growing population ever since the evolution of our species, homo sapiens, about 200 thousand years ago. The developed society lives above the carrying capacity of the Earth and its oceans and more than ever, we need to reduce the pressure of all stressors, especially the CO_2 emissions."

Last but not least, it is worth noting that the ocean's chemical restoration after the PETM took ca. 100,000 years, which is equivalent to 4,000 human generations. In addition, the marine ecosystem as we know it today mainly evolved during a time of low atmospheric CO_2 and well-buffered seawater (the last ca. 25 million years) which is not the case anymore. For comparison, it is only 5 to 7 million years ago that the first hominids appeared.

References

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