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Predicting shifts to oxygen deficiency in the marine environment: constraints from the geological past

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Anthropogenic climate change and coastal eutrophication increasingly result in large-scale deoxygenation in the marine environment, with grave consequences for life, biodiversity, and biogeochemical cycling. Future scenarios of (de)oxygenation, however, contain much uncertainty in many ocean basins and shelf seas, as the interplay of processes involved are complex. For instance, the Baltic Sea showed strong positive feedback mechanisms related to the nutrient cycle causing a sudden and difficult-to-reverse shift into hypoxia. Such tipping point behavior is notoriously hard to predict. However, mathematical theory suggests that several indicators may be useful as so-called early warning signals that can be detected prior to impending regime shifts. To test suitability for these early warning indicators to anticipate fast shifts to oxygen deficiency in the marine environment, we reconstructed the onset of anoxic events in the eastern Mediterranean Sea in the geological past. The sedimentary record was used as a natural archive, using past trace metal accumulation to reconstruct oxygen variability of the bottom water with an unprecedented resolution (years) using novel geochemical analytical techniques. Focusing on eight anoxic events, each lasting several thousands of years, we assess if theoretically derived early warning signals are indeed present at the onset of these events. The sudden shifts between oxic and anoxic states, which provides evidence for strong positive feedback mechanisms involved, are demonstrated to likely relate to stratification and/or nutrient availability. Ultimately, we show that these important early warning signals have the potential to forecast future shifts to oxygen deficiency in the marine environment.