Geophysical Research Abstracts
Vol. 17, EGU2015-5646-2, 2015
EGU General Assembly 2015

Paleolimnological evidence of global spread of hypoxia in freshwaters caused by local anthropogenic pressures

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The recent development of seasonal or persistent hypoxia in many lakes and coastal environments around the world severely stresses ecosystems, causing a decline of fisheries, a loss of biodiversity, and an alteration of food webs, including mass mortality of fauna. In marine environments, global instrumental surveys showed that the number of hypoxic coastal sites exponentially increased since the 1950s. In lakes, however, long-term instrumental monitoring surveys remain limited, preventing a global reconstruction of hypoxia's dynamic and pinpointing long-term causes of these changes on the continents. Nevertheless, hypoxic conditions are recorded in lakes when varve sediments start to be preserved once thresholds in oxygen-depleted conditions are crossed. Here, we compiled the time when varves started to be preserved in lakes over the last 300 years from 365 sites across the world as an indication of the global evolution of hypoxia on continents, and compared these data with anthropogenic and environmental variables compiled for each of these 365 watersheds. Additional sites in Europe were included in the study to reconstruct changes during the Holocene epoch. Our results show that continental hypoxia started spreading worldwide before AD 1900, mainly because of local growth in population density, human footprint and land uses, leading to eutrophication. No significant correlation was found with changes in precipitation or temperature. Hypoxia in continental realm spread about 50 years prior to marine environments. Finally, no sign of general return to past well-oxygenated conditions are observed despite implementation of local restoration programs and implementation of policies limiting nutrients yields since several decades in Europe and North America. This highlights the low resilience of lacustrine systems in the context of the added likely stress due to global warming and population increase.