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Thresholds of Environmental Sustainability
INTEGRATED PROJECT

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Testing thresholds of hypoxia for various indicators of benthic macrofauna

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Executive Summary

Hypoxia is a widespread problem affecting world's coastal and deep-sea waters with severe consequences on benthic communities, causing death and catastrophic changes. Hypoxia is linked to eutrophication and, as eutrophication, forecasted to increase in the future due to the combined effects of eutrophication and warming. We used a broad survey of the published literature to define the thresholds of hypoxia for sublethal and lethal responses of marine benthic communities. Specifically, we addressed the questions: (a) Is there a pattern in the successional sequence during oxygen depletion?; and (b) what are the thresholds of hypopxia for lethal and sublethal response of macrofauna species?, are there consistent differences across phyla?.

1. Introduction

Events of low oxygen can cause serious problems in coastal areas of the world. Some of the severe consequences of hypoxic events include changes in populations of marine organisms such as large-scale mortality, as well as changes in biodiversity, changes in species distributions, physiological stress, and other sublethal effects, such as reduced growth and reproduction (Service, 2004).
Hypoxia in coastal areas is governed by physical and biogeochemical processes. Some of the potential causes of hypoxia in the coastal ocean include: enhanced delivery of nutrients and organic matter in areas with limited circulation and vertical mixing (strong water stratification and long water residence time); upwelling of deep oxygen-depleted waters near-coastal areas and subsequent warming; intrusions of deep waters rich nutrients (than can cause phytoplankton blooms). The combined effect of natural upwelling of low oxygen oceanic water and enhanced availability of nutrients and organic matter can accelerate and intensify coastal hypoxia.
Low oxygen conditions have important consequences in biogeochemical cycles and functioning of biological communities.

2. Methodology

A broad Literature search (Web of Science and Schoolar Google) was used to assess the effects of hypoxia in marine benthic communities. From several thousand entries potentially relevant, about 200 papers with useful data were extracted as containing useful information. The data were extracted into a data set and all the units were standardized.

Compiling the negative effects of hypoxia in marine benthic organisms, most of the data available derived from experimental work in laboratories with individual species. Responses to hypoxia are often assessed from the survival or fraction of impacted populations with changes in O_2 concentration. The toxicity tests for which a broader empirical basis was found in the literature are:

-Sublethal thresholds (Median toxicity concentration): O_2 concentration conducive to the negative effects for 50% of the population.

-Median lethal concentration (LC50**):** Statistically-derived O_2 concentration at which 50% of the organisms in a given population die*.

-Median lethal time (LT50**):** Statistically-derived average time interval at which 50% of a given population may be expected to die following acute administration of a chemical or physical agent (O_2 in this case) at a given concentration under a defined set of conditions*.

*1993, *65*, 2068. IUPAC Compendium of Chemical Terminology 2nd Edition (1997)

3. Results

The effects of hypoxia on benthic communities have been thoroughly reviewed by Díaz and Rosenberg (1995) and Gray et al. (2002). Hypoxia is conventionally defined as waters with oxygen concentrations < 2 mg O_2 L^{-1} (Díaz and Rosenberg 1995, Díaz 2001). However, the vulnerability to low oxygen content varies greatly across marine organisms, so that the oxygen level at which sublethal and lethal hypoxic effects arise differ greatly across organisms. Indeed, a thorough review of the literature by Gray et al. (2002) concluded that many invertebrates already experience acute mortality at oxygen levels below 4 mg O_2 L^{-1}, with larval stages being, in general, more vulnerable than their corresponding adults (Gray et al. 2002). Fish appear to be the most vulnerable group to hypoxia, followed by crustaceans, annelids and bivalves, which are most tolerant (Gray et al. 2002). Most marine metazoans die at oxygen concentrations < 0.5 to 2.0 mg O_2 L^{-1}. Impacts of hypoxia on growth and behaviour are typically observed at higher oxygen concentrations of 4.5 to 6.0 mg O_2 L^{-1}, and other components of metabolism are affected between 2 and 4 mg O_2 L^{-1} (Gray et al. 2002). Whereas fish can be expected to be able to avoid hypoxic waters, fish kills derive from hypoxia are, nevertheless, frequent (Paerl *et al*., 1998, Rabalais *et al*., 1994), suggesting that hypoxia often develops across spatial scales large enough and time scales fast enough as to preclude avoidance by mobile organisms. In addition, hypoxia often occurs along with other stresses, such as warm temperatures or metabolites of anaerobic metabolism, such as sulphide, enhancing the vulnerability of organisms to hypoxia relative to laboratory-derived estimates, typically based on manipulations of oxygen alone (Gray et al. 2002). Further, the length and frequency of hypoxic events affects the vulnerability of organisms, as it allows adaptive changes in the communities and species they contain. For instance, organisms present in fjords and bays with restricted exchange where hypoxia maybe permanent appears to show higher critical oxygen concentrations than those in areas experiencing seasonal or shorter hypoxic events.

3.1 Sublethal thresholds on marine benthic communities.

Some negative effects of oxygen depletion on marine benthic organisms can be produced at higher oxygen content than that adopted in the conventional definition of hypoxia. These negative effects can affect the behaviour or the metabolism of the organisms.

In some fish larvae this sublethal thresholds can be met at 7 mg O_2/l for changes in their metabolism such as change in oxygen dependent metabolism or bradycardia sets.
From the data available in the literature the median oxygen content for sublethal effects on benthic organisms was 66.71 ± 2.25µmol O2/l (2.13 ± 0.072 mg O2/l). Half of the populations suffered negative effects with oxygen content lower than 89.25 µmol O2/l (2.8 mg O2/l).

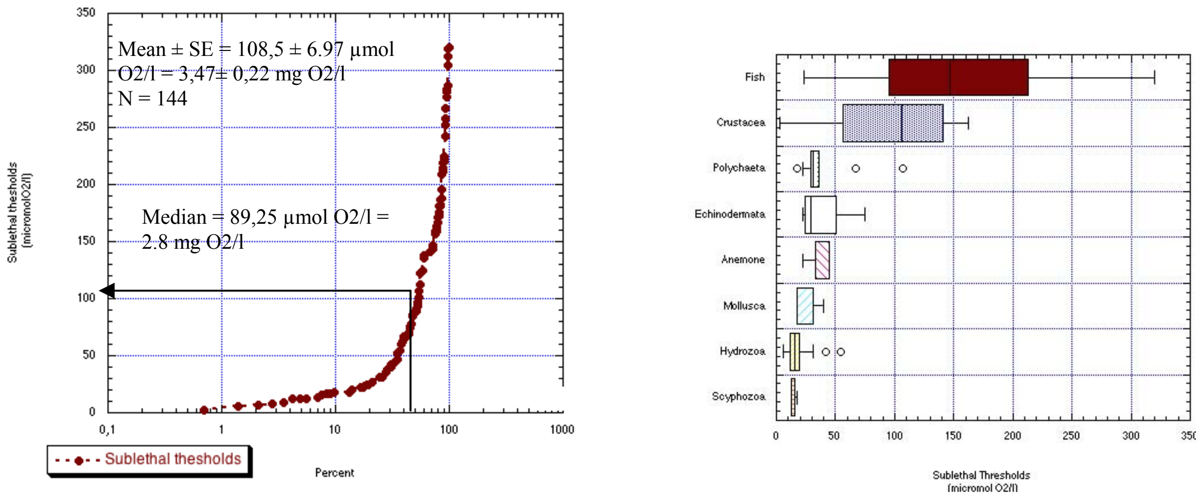

Figure 3.1 Cumulative distribution of oxygen thresholds for sublethal responses of marine benthic organisms (left panel) and its differences between taxonomic groups (right panel).

There are differences between taxonomic groups in the responses to oxygen depletion. Fish larvae are the most vulnerable to low level of oxygen content. Mobile organisms such as fishes can avoid hypoxic events swimming to areas with higher concentrations of oxygen. Crustaceans are the next taxonomic group in vulnerability to oxygen depletion. Polychaeta, echinodermata, anemone, mollusca, hydrozoa and scyphozoa are more tolerant to low oxygen concentrations.

3.2 Median lethal concentration for marine benthic organisms.

The average median lethal concentration for marine benthic organisms from the data compiled from the literature is 66.71 ± 2.25µmol O2/l (2.13 ± 0.072 mg O2/l). This oxygen content is higher than the conventional definition of hypoxia. The data belong to 265 different experiments that include 62 species.

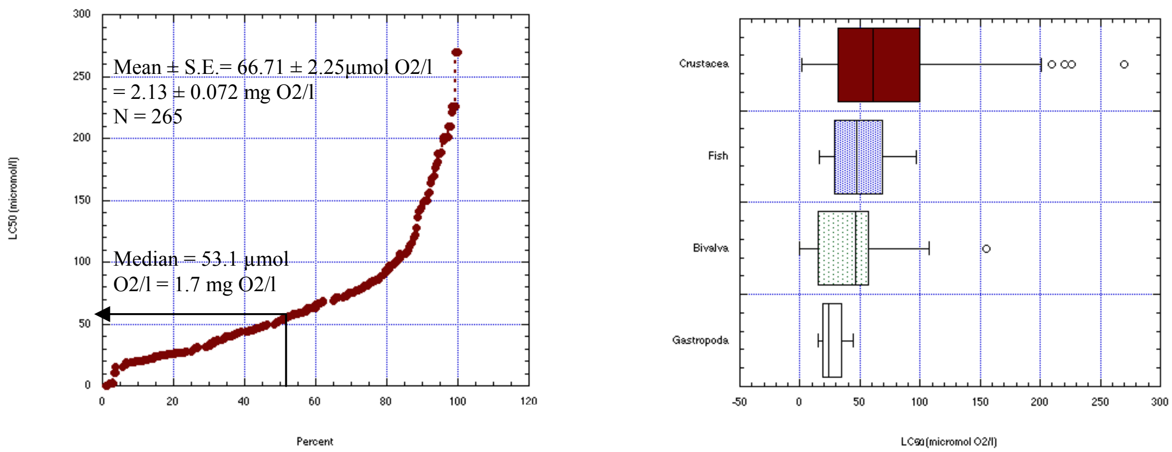

Figure 3.2 Cumulative distribution of median lethal concentration for marine benthic organisms (left panel) and its differences between groups (right panel).

The bigger amount of data available is from commercial species. In this case the most sensitive group is crustaceans, followed by fishes while the more resistant are molluscs.

3.3 Median lethal time for marine benthic organisms.

In water with oxygen content below to 2mg O_2/l a half of the tested organisms will die in the 119 hours following the exposure to this concentration.

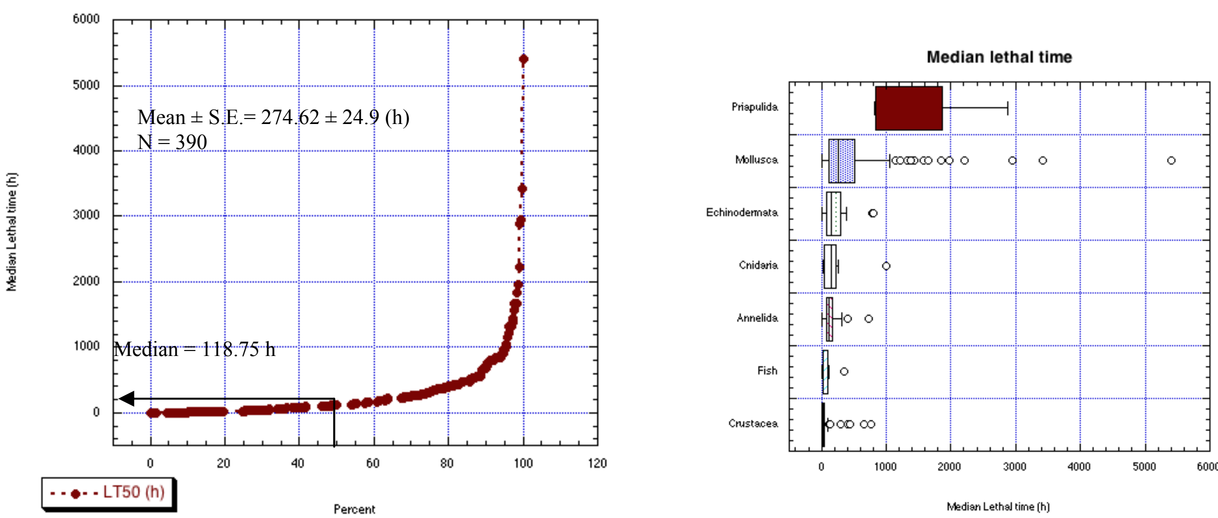

Figure 3.3 Cumulative distribution of median lethal time for marine benthic organisms (left panel) and its differences between taxonomic groups.

For median lethal time the most resistant group is priapulida that live in interstitial habitats, while the most sensitive are crustaceans.

3.4 Factors affecting to thresholds of hypoxia for marine benthic organisms.

Thresholds of hypoxia on benthic organisms are modulated by diverse factors. Some of them are dependent from the organism, like size, sex, life stage… Whereas others depend of the ambient, such as salinity, temperature, presence of hydrogen sulphide…

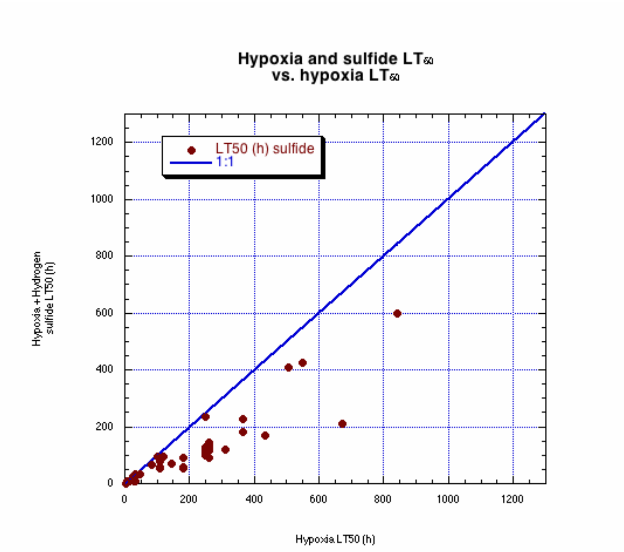

Figure 3.4 Median lethal time in hypoxia conditions vs. median lethal time in hypoxia and hydrogen sulphide for marine benthic organisms.

The presence of hydrogen sulphide reduces the median lethal time. The organism has to cope with hypoxia and with the negative effects of the presence of hydrogen sulphide.

Increases in temperature are also negative for the organisms that suffer low oxygen contents. Temperature is a key factor because is increasing with the climatic change and it increases the organism´s metabolic rates. Increases in temperature are associated with decreases in the tolerance to hypoxia.

4. Conclusions

The conventional definition of hypoxia (2 mg/l) is below the precautionary limits for lethal thresholds, even below the average of median lethal concentration.
Precautionary limits for sublethal thresholds are 4.5-fold greater than traditionally definition of hypoxia.
Precautionary limits for median lethal concentration are 3-fold greater than traditionally definition of hypoxia.
The variability between groups is consistent with the succession of disappearance in the nature. While the fishes are the first group to avoid areas with oxygen depletion, the crustaceans are the most sensible group, followed by annelida, echinodermata and mollusca. The recolonization pattern is not the same pattern of disappearance. The first group in recolonize the depleated sediments are polichaeta, this is because recolonization was predominantly contributed by larval settlement rather than adult migration.
Thresholds of hypoxia are modulated by diverse factors, some of the most important are the presence of sulphide and temperature increases.

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