Deliverable 3.3
“Compilation of existing data on effects of hypoxia on ecosystems at target sites”; month 6
Editors: J. Friedrich, AWI & F. Janssen, MPG-MPIMM with all partners of WP3

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Compilation of existing data on effects of hypoxia on ecosystems at target sites

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SITE NAME

Black Sea – Crimean shelf – Dnepr canyon

DURATION OF OXYGEN DEPLETION
periodically or episodically

NATURAL CAUSES OF OXYGEN DEPLETION
Quasi-periodical vertical depth fluctuations of both the oxycline (STh = 15.4) and the oxic/anoxic interface (STh = 16.2) have been detected. The recurring vertical fluctuations of the O2 / H2S interface cover a depth range of 130-165 m. This 35 m amplitude of the internal waves corresponds to horizontal intrusions of up to 1 km distance along the sea floor, and thereby are potentially aerating the deeper benthal below the permanent pycnocline, or flush the lower part of the oxic benthos periodically with anoxic waters. Locally, gas seepage may cause oxygen depletion due to CH4 oxidation and/or upwelling of CH4-rich waters (Naudts et al. 2006). Gas seeps in the Dnipro Canyon/Crimean shelf are described in the project document “Deliverable 6.2: Report on linking of existing data bases with relevance to oxygen depletion to HYPOX”.

MAN MADE CAUSES OF OXYGEN DEPLETION
None

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
Climate change may cause changes in density structure, stratification, circulation, mixing and wind speed patterns.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
Eutrophication results in an increase of the H2S content of the Black Sea (approx. 0.5 % per year) as well as in a general decrease in O2 content and reduction of thickness of the upper aerobic water layer (Eremeev & Konovalov, 2006). A tendency of benthic macrofauna distribution patterns to move towards shallower waters is observed.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
The benthic community in the vicinity of submarine Dnepr Canyon comprises characteristics of both hypoxic and anaerobic environments. At methane gas seeps are found massive carbonate reefs with thick microbial mats which are typical for those anoxic environments.

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA
Recently found benthic metazoans seem to indicate periodic oxygen supply to the bottom. Larger macrofauna rapidly diminishes in the suboxic zone and is hardly found below 140m
depth. The lower suboxic zone between 150 m and 210 m depth is inhabited by micro- and meiobenthos communities.

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

IBSS and MHI data-set archives.

REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Water column: currents, temperature and salinity, turbidity, O₂ temporal fluctuations

Benthic:

- Taxonomic diversity and abundance of benthic fauna on depths range from 100 m to 300 m
- Living benthic organisms (video imaging) (IBSS, Maksim)
- Microbial chemosynthesis - CO₂ dark assimilation in the both uppermost sediment layer and near-bottom waters (done by MPI-MM ?)

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Nothing specified

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

- What are the oxygen levels and their fluctuations over time?
- There is a lack of knowledge on the frequency and duration of events where the benthos of typically oxic areas gets flushed with anoxic waters and, on the other hand, oxic waters are supplied to the seafloor below the permanent pycnocline.
- Gas origin for all seeps, and eventual relationships with gas-oil fields occurring in the Crimean shells are not completely investigated, yet. Knowing the gas origin is important for the characterization of eventual seepage-linked hypoxia: the different
genetic features of the gas seeps (shallow microbial, deep microbial and deep thermogenic gas) reflect different geological factors (stratigraphic-erosional factors for shallow microbial gas; faults, gas-oil fields for deep microbial and thermogenic gas). Accordingly, it is important to know if and where seepage-linked hypoxia depends on shallow sedimentology or on deep tectonics and petroleum geology.

OBSERVATORY LEADER(S) NAMES AND EMAIL

Antje Boetius, Max Planck Society for the Advancement of Science / Max Planck Institute for Marine Microbiology (MPG)
eMail: aboetius@mpi-bremen.de

Nelli Sergeeva, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: nserg05@mail.ru

Maksim Gulin, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: m_gulin@mail.ru

Sergey Konovalov, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: sergey_konovalov@yahoo.com
SITE NAME

Black Sea - Omega (“Kruglaya”) Bay (Sevastopol)

DURATION OF OXYGEN DEPLETION
Usually from May to September several months (summer hypoxia) in the bottom water.

NATURAL CAUSES OF OXYGEN DEPLETION
Weaker currents in summer result in reduced water exchange between the bay and adjacent areas of the sea, weaker vertical mixing in a smaller downward flux of oxygen. Stratification of the water column in summer restricts the downward flux of oxygen. Higher primary production results in a higher export production. High temperature in summer results in a lower oxygen solubility, in a higher rate of organic matter oxidation and hence higher oxygen consumption. Potentially, discharge of groundwater contains reduced compounds.

MAN MADE CAUSES OF OXYGEN DEPLETION
Discharge of municipal waste waters high in nutrient and organic matter load into Omega (Kruglaya) Bay results in surplus oxygen consumption.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
With increasing summer temperatures, longer periods of stratification diminished ventilation of the bottom water are likely and, hence intensified release of reduced substances from the seafloor.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
Increased primary production would result in a higher export production, and higher decomposition of organic matter on the seafloor increases oxygen consumption.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
macrophyte beds of *Zostera marina*

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA
In zones with periodic sulphide release from sediment occurs dying off of macrophyte *Zostera marina*. Hypoxia spots typically vary from 0.1 to 1.5 meters but eventually reach tens of meters. The total area of hypoxia sites can reach up to 44 % of sea floor in the bay.

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)
IBSS data-set archives.
REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Water column: temperature, salinity, currents (by ADCP; currently not possible), discharge of ground waters (currently not possible), inorganic nitrogen (nitrate, nitrite, ammonium), silicate, phosphate, dissolved and particulate organic carbon and nitrogen (currently not possible), biological oxygen demand

Sediments: Oxygen and Reduced Sulphur species, Organic Carbon, Porosity, Biodiversity and Abundance of benthic fauna.

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Detailed bathymetric map of the Bay

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

- What is the cause for hypoxia in the Kruglaya Bay; antropogenic impacts or effect of gas migrations from seabed sediments?
- Study of both active and passive anoxybiosis of benthic hydrobionts.

OBSERVATORY LEADER(S) NAMES AND EMAIL

Nelli Sergeeva, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: nserg05@mail.ru

Maksim Gulin, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: m_gulin@mail.ru

Sergey Konovalov, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: sergey_konovalov@yahoo.com
SITE NAME

Black Sea - inner and outer Sevastopol Bay

DURATION OF OXYGEN DEPLETION

Inner Bay: months; hypoxia is detected between April and January, and most extreme in July-August

Outer Bay: is well mixed, no hypoxia

NATURAL CAUSES OF OXYGEN DEPLETION

Strong vertical stratification due to warm and brackish riverine surface waters limits the downward flux of oxygen to the bottom water. In addition, weak winds limit the lateral exchange and ventilation of the bottom layer by sea water.

MAN MADE CAUSES OF OXYGEN DEPLETION

Due to an artificial dam that separates the Bay from the open sea, the water exchange is limited. The residence time of the water in the Bay increased as a result, and the flux of oxygen to the bay decreased. A major part of the municipal and industrial sewage waters (~10,000 m³ per day) is discharged to the bay from ~30 sewers without or after minimal treatment. The increasing load of nutrients and organic matter in the bay results in a dramatically increased flux of organic carbon to the bottom waters and sediments. Decomposition of the organic carbon in the bottom sediments result in anoxic/sulfidic conditions and supports a flux of dissolved sulphide to the sediment overlaying water.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS

In summer, intensification of vertical stratification might reduce ventilation and intensify bottom water hypoxia in the inner bay.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION

The increasing nutrient load and organic matter discharge into the bay due to anthropogenic activities results in dramatically increased export production and flux of organic carbon to the bottom waters and sediments.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT

Outer Bay:
The response of the macrozoobenthos vital activity during hypoxia has been investigated in the relic area of the lower Chernaya riverbed that is flooded by sea (shelf near to Sevastopol). The general density of benthos within the paleo-riverbed appears several times less than for the adjacent shelf. The maximum of abundance (7 taxonomic classes) and maximum biomass of benthic organisms located directly in the paleo-riverbed was detected in 22-30 m depth. The accumulation of benthic organisms peaks with the peak of organic matter at 28 meters depth.
KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA

Negative changes in biological and biogeochemical properties have been reported since the 1930's. From 1951 seasonal monitoring of physical, biological, and biogeochemical properties was undertaken. Though seasonal behaviour of oxygen and nutrients remained similar to the open sea, the concentrations of nutrients and biological oxygen demand increased and they were 1.5 to 4 times higher, as compared to other pristine coastal regions of Crimea. In the 1960's sharp increase in the year-round concentrations of nutrients, very high values of biological oxygen demand, intensive eutrophication of the bay, hypoxia in the bottom layer of waters was first detected and reported: the level of oxygen saturation dropped to 42% and the oxygen concentration was 2.19 ml/l in the bottom waters. Result of increased primary production, as the oxygen saturation reached 190% in the euphotic layer. Concentrations of nutrients in the bay increased up to 100-fold and the biological oxygen demand at least doubled from the 1950's to 1960's. The situation worsened in the 1970's, as coastal dams were constructed in 1976-1977 decreasing the water exchange between the bay and the open sea by 50%, while the level of pollution and eutrophication were dramatically increasing. Though sulfides in the water column and sediments were not detected before 2007, the state of biological communities and even the appearance of the bottom sediments revealed extremely negative changes in the Bay's environment. Sediments have become sulfidic and now serve as a source of hydrogen sulfide for the bottom layer of water, further depressing and/or destroying benthic communities. Anthropogenic activities almost completely destroyed the entire ecosystem and its biodiversity, leaving the inner part of the bay in a state of a polluted marine desert. As a result, fishing and the extraction of biological resources declined.

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

MHI and IBSS data-set archives.

REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Water column: temperature, salinity, currents (ADCP, currently not possible), inorganic nitrogen (nitrate, nitrite, ammonium), Silicate, Phosphate, DOC, POC, PON, DON (currently not possible), BOD

Sediments: oxygen and reduced sulphur species, organic carbon, porosity, biodiversity and abundance of benthic fauna.

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Investigation of locations and quantity of the gas seeps within the Chernaya paleo-riverbed.

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

productivity and carbon flux, currents and circulation patterns in the Bay

OBSERVATORY LEADER(S) NAMES AND EMAIL

Nelli Sergeeva, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)

eMail: nserg05@mail.ru

Sergey Konovalov, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)

eMail: sergey_konovalov@yahoo.com
SITE NAME
Black Sea - Tarkhankut region

DURATION OF OXYGEN DEPLETION
Temporary occurrence of hypoxia. There is no seasonal pattern. Seeping of methane at shallow seeps potentially causes spot-like hypoxic areas.

NATURAL CAUSES OF OXYGEN DEPLETION
Methane seepage, short-term storm and seasonal meteorological patterns can have an impact upon hypoxia stability and spreading.

MAN MADE CAUSES OF OXYGEN DEPLETION
None

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
There is some probability of mass emission of methane into the atmosphere during earthquakes. Last time it was detected in September 1927.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
Tarkhankut it is a fishery protection zone. Anthropogenic influence is very much limited. Therefore regional eutrophication is quite unlikely.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
In the northwest Black Sea the main field of methane seeps is located around the underwater Dnieper Canyon. Also, we discovered the offshoot from the main gas seeps field, which is situated around the underwater Dnieper Canyon: reaching from so-called Eupatoria's branch of this canyon up to southern sector of the Tarkhankut Cape, Crimea. The geological data let to draw a conclusion that mentioned gas seep belt is located within the geological structure of the Kalamit Ridge. Acoustic data indicate that the gas seeps are located in the most cases at the underwater hills, ridges and slopes of the seabed. Acoustical surveys show that gas seepages in the NW Black Sea can be situated in the form of long (980 - 2100 m) chains along ridges and slopes etc. In the Tarkhankut area (southern sector) correlation was found between the location of methane gas seeps and geomorphological details of the seafloor mesorelief. We discovered two main near-shore zones enriched by the gas seeps. In all cases methane seeps were associated with microbial microhabitats (mats); fluffy spots, ash-grey in colour from above and black inside. The upper layer of the mats were black and very dense with a thickness of 8-17 cm, silt-like and with macroalgal detritus. This layer was very rich in methane bubbles. The topmost layer is a thin film, white or grey in colour. Seep mats were highly enriched by CH₄ and H₂S. Taxa and abundance of benthic fauna associated with seeps were represented by Gromia, Ciliophora, Nematoda, Polychaeta, Bivalvia and Harpacticoida.
KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA
Nothing specified

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)
Experts at IBSS dept for Benthic Ecology

REFERENCES CITED IN THE TEXT AND FURTHER READING

PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX
Weather and Sea Conditions
Water column: temperature, Eh and pH, inorganic nutrients (nitrate, nitrite, ammonium, silicates, phosphate), BOD, hydrogen sulphide
Sediments and microbial mats: reduced sulphur species and methane, Eh and pH, organic carbon, Fe and Mn cations, microbial as well as micro- and meiobenthos dynamics.

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES
Detailed microbathymetry within the gas seepage area.

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)
- Environmental modeling in the coastal seep field, as part of the general region with the gas emission of a northwest shelf of the Black Sea.
- Study of the active anoxybiosis trigger and trophic activity of benthic organisms associated with seep microbial mats.

OBSERVATORY LEADER(S) NAMES AND EMAIL
Nelli Sergeeva, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: nserg05@mail.ru

Maksim Gulin, A.O.Kovalevsky Institute of Biology of the Southern Seas, Ukrainian National Academy of Science (IBSS)
eMail: m_gulin@mail.ru
SITE NAME

Black Sea – North-western Shelf

DURATION OF OXYGEN DEPLETION
During summer (May to August) hypoxia tends to occur in bottom waters. Hypoxia was recurrent between the 1970's and mid 1990's over period of time from weeks to months.

NATURAL CAUSES OF OXYGEN DEPLETION
Freshwater input from the rivers (Danube, Dniestro, Dniepro) and warming of the surface water cause a thermohaline stratification during summer that limits the ventilation of the near bottom water. In autumn and winter (September to April) due to wind forcing a change in circulation pattern occurs, resulting in a break-up of stratification and ventilation of bottom water.

MAN MADE CAUSES OF OXYGEN DEPLETION
Agricultural fertiliser application and run-off from agriculture, limited waste water treatment, industrial farming and related nutrient input via rivers resulted severe in eutrophication in the past. Decomposition of the surplus organic matter reaching the seafloor resulted in increased oxygen demand. The retreat of the Zernov Phyllophora field offshore due to shading by increased pelagic productivity resulted in decreasing oxygen supply to the underlying Mytilus beds. Overfishing, invasive species outbursts (Mnemiopsis) caused trophic cascades in pelagic systems and damaged benthic habitats.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
Warmer surface water temperature will result in a stronger stratification and lower oxygen solubility. Increased freshwater input from rivers will support stratification and reduce bottom water ventilation.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
Eutrophication will result initially in increasing pelagic and benthic productivity, higher water turbidity, lower light penetration, dying-off of sea grasses and Phyllophora, and hence, reduced benthic oxygen production. Increasing benthic oxygen consumption may result in bottom water hypoxia. Hypoxia will re-occur as a seasonal feature in summer especially in zones situated between 1-20 Nm off the coast and down to 40 m water depth, resulting in a collapse of the benthic ecosystem, eventually.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
Muds and sands with epibenthic species like crustaceans and mollusces (filter feeders), muds populated by worms, remnants of historical beds of red algae Phyllophora spp., remnants of seagrass and Cystoseira beds.
KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA

Reduced light penetration due to increased primary production caused shading and disappearance of the historical Phyllophora habitat (full recovery is not evident). Coastal communities like Cystoseira and Zostera beds declined. Decomposition of surplus organic matter on the seafloor caused extended periods of bottom water hypoxia and dying-off of mussel beds. This resulted in the release of reduced substances and nutrients. Release of nutrients from sediment fuels pelagic primary production. The reduction of deep mussel populations and their juvenile character are signs of the instability and permanent disturbances which gradually extended from coastal zones into the open sea.

Current pathway of recovery of benthic ecosystem from the mass mortalities during the 1970’s to mid 1990’s:

The macrobenthic population is controlled by worms (70% , endobenthic detritophagus organisms). Epibenthic species (crustaceans and some molluscs) are decreasing in numbers. Filter feeders comprise only 9% of benthic population which indicates a critical state of the benthic system. A spectacular spreading of opportunistic species of polychaeta on soft sedimentary and hard substrate is observed. An expansion of small organisms takes place resulting in decrease of biomasses impoverishing the trophic base of benthophagus fishes.

Situation before 1992 (Gomoiu, 1992)

The main changes in the zooplanktonic communities were the qualitative impoverishment in littoral zones, leading to a small number of species, i.e. Acartia clausi, Pleopis polyphaemoides, Rotifera etc.; frequently only 2-18 species appeared in the samples, with one dominating (low diversity index).

A mass development of the jellyfish Aurelia aurita was observed, distributed throughout the whole sea. In the north-western Black Sea and in the zone influenced by the Danube, a stock of 40 million tons of the jellyfish Aurelia had been recorded. The ctenophore Mnemiopsis leydii invaded the Black Sea.

Repeated, explosive developments of the species Noctiluca scintillans similar in type and consequences to the red tides occurred. Densities of 1.0-5.6x10^9 specimens m^-3 and biomasses of 125-560 kg m^-3 have been recorded.

A drastic reduction of specific diversity in macrophytobenthos has been recorded. Some populations of Zostera or perennial brown and red algae (mostly Cystoseira and Phyllophora) have disappeared or considerably diminished. In the Zernovs' Phyllophora field the stocks of this alga have fallen to less than 30%. The red algae field with its entire associated fauna has had a great importance for the equilibrium of ecological conditions in the north-western Black Sea. At the Romanian littoral, of 122 alga species mentioned through the years, only about 70 species have been recorded since 1980, 20-30 of them having a more significant presence. In contrast, opportunistic species of ruderal type, with a common short biological cycle developed (Enteromorpha, Ulva, Ceramium, etc.). They have a quick succession and benefiting from a rich nutritional support they form important biomasses.

Mass mortality of benthic organisms (fish, molluscs, crustaceans) as a result of eutrophication: unlimited nutrient influx — algal blooms — high production of organic matter — oxygen depletion. Numerous benthic species have disappeared because of mass mortalities.
and stocks of Mytilus galloprovincialis and Mya arenaria have been decimated. Mortalities are partially a result from bottom trawl fishing.

In zoobenthos, the changes affected community structure and the population dynamics:
(a) The reduction of biofilter power (before characteristic for the Black Sea). Compared with the 1960s, the diversity index during the 1970s-1980s decreased from 1.87 to 1.32 in the gulf of Odessa (because of hydrotechnical constructions, a predominant anthropogenic factor) and from 1.20 to 0.87 in the zone between the Danube and the Dniester (ecological pressure from the river fresh waters whose chemical qualities have been strongly affected).

At the beginning of 2000’s total or partial (local) extinction of some littoral forms (Solen, Gastrana, Donax, Gafrarium, Donacilla, etc., among molluscs, Arenicola and Ophelia among worms, Erphia and Chthamalus among crustaceans, and so on. Areas decreased that had been occupied by some populations such as Corbula, Mytilus etc.. In the zones of the Danube - Dniester, Dniester - Odessa the commercial stocks of mussels which in the early 1960s formed 33.47 and 66% respectively of the whole stock, were reduced to 7.5, 5.4 and 12.3% respectively, in the 1970’s. Compared with the 1950s-60s the benthic biomasses on the Romanian continental shelf in 1989 represented only 60-70% at 30-50 m, 20-30% at 50-80 m and much less at greater depths.

(b) The exuberant development of opportunistic species with great ecological flexibility, capable of rapid response to any sudden environmental change (Melinna, other polychaeta, Mya, Scapharca).

Major structural modifications of fish and mammal populations in the Black Sea:
Due to hypoxia drastic reduction in the stocks of sturgeon, turbot and other demersal fish occurred. The total catch for the entire Black Sea between 1976 - 1980 in comparison with 1956 - 1970 was 54% for picked dogfish, 33% for sturgeons and 60% for turbot.

Pelagic fish stocks dependant upon the plank-tonic trophic base increased (sprat stocks have been evaluated at 880,000 tons recently and anchovy stocks at 800 000 tons). Sprat, anchovy and the Mediterranean horse mackerel account for more than 90% of the total catch in the Black Sea.

The main features of the coastal ecosystem as a whole during eutrophication can be summarized:
(1) Species diversity is low. This implies also weak biochemical diversity; only the most tolerant forms have remained out of the old associations: few species form the community nucleus; only 1-2 representatives are dominant in number or weight.
(2) Stratification and spatial heterogeneity, as a pattern of diversity, are poorly organized.
(3) There is a lack of balance between the pelagial ("algal blooms") and benthal (obliteration) on one hand, and between autotrophic and heterotrophic organisms or between macro and micro forms, on the other hand.
(4) The role of primary producers and decomposers has increased dominating the metabolic processes of the ecosystem (intensification of microbiological processes follows phytoplankton blooms).
(5) Inorganic nutrients enter the system in great quantities and are no longer limiting factors for the phytoplankton.
(6) The quotient between production and biomass (P/B) is usually high, the primary trophic base being in excess.

(7) Trophic chains are simple and linear (feeding on phyto- and bacterioplankton prevails).

(8) The ecosystem has a weak resistance to exterior disturbances, being characterized by a permanent instability and large population fluctuations, by discontinuous and irregular processes and phenomena.

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

http://metaworks.pangaea.de
www.elme-eu.org


REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Water column: temperature, salinity, currents, fluorescence, transmission, nutrients, oxygen, taxonomic number of phytoplankton and zooplankton (by GeoEcoMar)

Sediment:
At observatory site: bottom currents, benthic nutrient fluxes, benthic oxygen consumption, sediment oxygen penetration depth (by AWI), sediment POC, benthic population abundance (density, biomass) by GeoEcoMar

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES
- Terrestrial and atmospheric inputs of chemicals, fertilizers, toxicants, organic matter input to the coastal zone and their river discharge
- Urban development, industrial development relevant for the coastal zone
- Navigation, Fishing, Tourism, dumping wastes into the sea
- Climatic conditions – climatic changes: Hydrological regime of the coastal zone –
- Biodiversity – type of species – microorganisms, algae, invertebrates, fishes, mammals, Variability of individuals and populations
- Taxonomic and functional groups of organisms, such as producer, food chain structure
- Phenology of the populations
- State of health/abnormalities of individuals and populations
- Alien species
- Human activity information and data
SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

- dynamics of hypoxia formation, i.e. time lags between productivity pulses and formation of bottom water hypoxia and benthic nutrient release, nutrient thresholds for pelagic and benthic system stability, benthic ecosystem recovery, pathway of ecosystem recovery and its consequences for ecosystem services, future impact of hypoxia on benthic and pelagic ecosystem

There is a lack of continuous measurements and data on changing physical-chemical parameters during a process leading to hypoxia, a lack of microbiological studies and a lack of experimental studies on the formation of hypoxia.

OBSERVATORY LEADER(S) NAMES AND EMAIL

Jana Friedrich, Alfred Wegener Institute for Polar and Marine Research (AWI)
eMail: Jana.Friedrich@awi.de
DURATION OF OXYGEN DEPLETION
Permanent below 100 m depth

NATURAL CAUSES OF OXYGEN DEPLETION
The Bosporus Region is characterized by the inflow of saline oxygenated Mediterranean Water (MW) from the Bosporus Strait. On its way across the shelf towards the continental slope, the inflow water dilutes with the less saline Cold Intermediate Water (CIW) of the Black Sea and spreads across the shelf covering an area of approximately 400km² (Özsoy et al. 2001). At the shelf break, the MW cascades down the continental slope before it is injected into the suboxic and anoxic water column of the south western Black Sea (Gregg and Özsoy 1999; Murray and Yakushev 2006). The oxygen depletion in the Black Sea as well as in the Bosporus Region is caused by the co-occurrence of high organic matter input and reduced vertical mixing of oxygen into the deeper water column due to a strong salinity gradient (i.e. density gradient)(Murray and Yakushev 2006). The salinity gradient is maintained by both, a positive freshwater balance and an inflow of saline Mediterranean water through the Bosporus strait. The cooling of surface waters in winter and the increased wind velocities allow for a mixing of the upper 100 m of the water column only.

MAN MADE CAUSES OF OXYGEN DEPLETION
None

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
Climate change can affect the oxygen transport and oxygen consumption in the water column in various ways.

Murray and Yakushev (2006) suggested that cold winters cause an increased mixing of the CIW and a gradual deepening of the upper edge of the suboxic layer, whereas warm winters cause reduced mixing of CIW and a broadening of the suboxic zone to shallower depths. The appearance of cold and warm winters in the Black Sea area was found to correlate with the North Atlantic Oscillation (NAO) (Oguz et al. 2006).

The strength of the thermohaline stratification in the Black Sea depends on the freshwater balance as well as on the volume flow and salinity of Mediterranean water through the Bosporus straight. The freshwater balance can be changed by increased/decreased precipitation in the drainage area and by increased/decreased evaporation of the surface waters of the Black Sea. A climate change related increase/decrease of salinity and volume flow of Mediterranean water through the Bosporus straight also depends on future conditions in the Mediterranean.

Recent climate models (Mariotti et al. 2008) predict a progressive drying of the Mediterranean region during the 21st century that also includes the drainage area of the Black Sea. However, the effect on the relative inflow of saline versus fresh water into the Black Sea and, thus, the effect on the density structure is speculative.
EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION

It has been proposed (Oguz 2005), (Murray and Yakushev 2006) that the increased anthropogenic input of nutrient between 1970 and 1990 enhanced primary production and subsequently increased the export and oxidation of organic matter in the CIW leading to a upward shift of the suboxic layer. However, since the 1990’s the anthropogenic input of nutrients decreased to values comparable to 1960 (Oguz 2005).

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT

Investigations will focus on the water column.

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA

Important microbial processes that are restricted to the suboxic layer like the anaerobic ammonium oxidation (Anammox) (Kuypers et al. 2003; Lam et al. 2007) can be affected by the broadening or the reduction of the suboxic layer leading to a possible change in the nitrogen budget of the Black Sea.

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

Black Sea Data Base (http://sfp1.ims.metu.edu.tr/ODBMSDB/)

REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Water column: Currents, temperature, conductivity, O_2, nutrients, manganese, sulfide

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

1. Investigate the direct impact of the Bosporus inflow on the suboxic and anoxic zone in the south western Black Sea.
2. The role of the Bosporus inflow for maintaining the suboxic zone in the Black Sea is still not well described. Especially the role of Mn cycling for establishing the suboxic zone.
3. Identify relevant microbial processes in the suboxic zone that effect the nutrient cycles in the Black Sea.

OBSERVATORY LEADER(S) NAMES AND EMAIL

Jean-Francois Rolin, French Research Institute for Exploitation of the Sea (Ifremer)
eMail: Jean.Francois.Rolin@ifremer.fr

Serge Le Reste, French Research Institute for Exploitation of the Sea (Ifremer)
eMail: serge.le.reste@ifremer.fr
SITE NAME

**Baltic Sea, eastern Gotland Basin**

**DURATION OF OXYGEN DEPLETION**

The eastern Gotland Basin is a flat basin with gentle slopes with a maximum depth of 249m that displays almost permanently anoxic conditions in its deepest parts (below 200m water depth). During stagnation periods the deep sub-halocline water body consists of a low but constant oxic water layer and a bottom water layer that is frequently anoxic below 110m.

**NATURAL CAUSES OF OXYGEN DEPLETION**

Hydrographical setting

**MAN MADE CAUSES OF OXYGEN DEPLETION**

Discharge of nutrients, eutrophication

**EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS**

Nothing specified

**EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION**

Nothing specified

**BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT**

The Holocene muds exhibit a high concentration of organic matter (10-15% dry weight). The surface sediment of the area of investigation are soft, black organic rich and of high porosity.

**KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA**

Nothing specified

**SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)**

Nothing specified

**REFERENCES CITED IN THE TEXT AND FURTHER READING**

Nothing specified

**PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX**
Temperature and salinity, preferably also currents (water exchange).
Nutrient fluxes, N-species fluxes, oxygen

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)
Nothing specified

OBSERVATORY LEADER(S) NAMES AND EMAIL
Gregor Rehder, Institute for Baltic Sea Research (IOW)
eMail: gregor.rehder@io-warnemuende.de
Ralf Prien, Institute for Baltic Sea Research (IOW)
eMail: ralf.prien@io-warnemuende.de
DURATION OF OXYGEN DEPLETION
Continuous measurements with optodes were started in summer 2004, with a gap in permanent oxygen recordings from mid 2005 till mid 2006, due to a sensor malfunctioning. Compared to 2004/2005, oxygen concentrations in 2006 showed 7-8% lower values, remaining comparably stable till summer 2009; by now we did not recognize any hypoxia events in the area.

NATURAL CAUSES OF OXYGEN DEPLETION
Increasing water temperatures and decreasing oxygen concentrations at HAUSGARTEN are indicative of an altered deep-water transport possibly triggered by global warming.

MAN MADE CAUSES OF OXYGEN DEPLETION
There are no direct anthropogenic causes of oxygen depletion.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
Climate Change induced increasing water temperatures and an associated changing primary productivity may have an impact on oxygen concentrations in the water column.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
There are no signs of eutrophication in the Fram Strait.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
The bathymetry at HAUSGARTEN is characterized by a submarine projection from the Svalbard continental margin, i.e. the Vestnesa Ridge (1000-2000 m water depth) and a deep depression (Molloy Hole) with a maximum depth of 5669 m (Klenke and Schenke, 2004), adjoining the ridge to the west. Near-surface sediments in the HAUSGARTEN area are dominated by siliciclastic components that are supplied by sea ice, downslope transport from the Svalbard shelf and advection from distal source areas with surface and bottom currents.

Settling particulate matter at HAUSGARTEN shows pronounced seasonal patterns and has a quite variable composition, consisting of particulate organic matter and minerogenic particles, principally deriving from two major sources: export from the photic zone and lateral advection (Bauerfeind et al., 2009). Sea ice and material incorporated therein plays an important role in the dispersion of particulate matter of marine and terrestrial origin.

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA
The system is still far away from hypoxia.
SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM
STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

All data generated at HAUSGARTEN is or will be archived in the German PANGAEA
Publishing Network for Geoscientific & Environmental Data (www.pangaea.de).

REFERENCES CITED IN THE TEXT AND FURTHER READING

Bauerfeind, E., Nöthig, E.-M., Beszczynska, A., Fahl, K., Kaleschke, L., Kreker, K., Klages,
the Eastern Fram Strait (79°N/4°E) during 2000-2005: Results from the deep-sea long-term


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Juterzenka, K. v., Matthiessen, J., Mokievsky, V., Nöthig, E.-M., Quéric, N., Sablotny, B.,
Sauter, E., Schewe, I., Urban-Malinga, B., Wegner, J., Wlodarska-Kowalczuk, M., Klages,
observatory in the Arctic Ocean. Oceanography, 18: 46-61.

PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Core measurements at the deep-sea long-term observatory HAUSGARTEN:

Water Column. Water temperature; current velocity direction; particulate organic carbon flux;
calcium carbonate flux; particulate silica flux; biomarker.

Sediment-water interface. Bottom and porewater water oxygen concentrations; sediment
community oxygen consumption.

Sediments. Chlorophyll a, phaeopigments, chloroplasmatic pigment equivalents;
esterase activity; proteins; phospholipids; water contents/porosity.

Benthos. Bacteria (abundance, biomass, mean cell biovolume, diversity); meio-, macro-,
megafauna (abundance, composition, diversity); stabile isotope (δ15N, δ13C).

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT
THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

Within HYPOX, all oxygen data generated at the different HAUSGARTEN sites will be
compiled, validated and finally analysed to study the variability of oxygen concentrations at
an oceanic site on multi-year time-scale, in relation to natural alterations in the Arctic
Oscillation and to Global Warming induced environmental changes. Although the system is
far from hypoxia, HAUSGARTEN will serve as a model site to study possible links between
Climate Change, variations in bottom water circulation and oxygen supply in the deep ocean.

OBSERVATORY LEADER(S) NAMES AND EMAIL

Thomas Soltwedel, Alfred Wegener Institute for Polar and Marine Research (AWI)
eMail: Thomas.Soltwedel@awi.de
PART 2 “LAND-LOCKED WATER BODIES”
DURATION OF OXYGEN DEPLETION

The duration of oxygen depletion depends on two factors, (1) the frequency of bottom water renewal, which was described to take place on average every 16 months (Edwards and Edelsten, 1977), and (2) how rapidly oxygen declines in-between these events. Previous studies have found the bottom water to be moderately hypoxic (20-10% atm. sat.) for more than 6 months in a row in the deep basin (Overnell et al 2002).

NATURAL CAUSES OF OXYGEN DEPLETION

Oxygen depletion in the inner basin of Loch Etive evolves mainly as a consequence of the prevailing hydrographical conditions (Edwards and Edelsten, 1977; Austin and Inall, 2002). Restricted horizontal and vertical water exchange due to the presence of multiple sills in combination with strong salinity-driven density gradients created by a high river run off results in prolonged isolation of bottom water in the inner basin of Loch Etive. The riverine input of terrigenous material in combination with local primary production (which is small relative to the total OM input) results in a relatively high input of organic matter to the sediments and a high benthic oxygen demand between 11-50mmol O₂ m⁻² d⁻¹ (Ansell 1974; Loh et al, 2002; Overnell et al, 2002). This results in hypoxic conditions (as low as ~10% atm sat) and elevated concentration of dissolved Mn²⁺ and Fe²⁺ in the bottom water of the inner basin (Overnell et al 2002). However, completely anoxic condition has never been recorded so far in the bottom waters of the inner basin in Loch Etive, indicating that renewal events are currently frequent enough for the bottom water not to run out of oxygen completely. Recent paleoclimatic studies (Norgaard-Pedersen et al, 2006) suggest that the strength and frequency of renewal events has varied through time in Loch Etive, mainly by changes in relative sea level and freshwater influx to the loch, and that Loch Etive is now going from a more marine to a more terrestrial dominated environment (Murray et al 2003).

MAN MADE CAUSES OF OXYGEN DEPLETION

The large catchment area (1400km²) of Loch Etive is spread over a relatively pristine and to a large extent uninhabited part of the Scottish highlands with low agricultural activity. Significant anthropogenic contribution to the prevailing oxygen depletion in the inner basin in Loch Etive is therefore unlikely. However, it should be mentioned that it has been hypothesized that increased anthropogenic deforestation in the catchment area during the late Holocene might have had an effect on the freshwater input and sedimentation in the loch (Norgaard-Pedersen et al, 2006).

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS

Predicted climate changes may very well increase the duration and severity of hypoxia in Loch Etive, a fjord that already is classed as one of the most sensitive Loch’s in Scotland in terms of oxygen depletion (Gillibrand 2005; Gillibrand et al. 2007; Inall et al 2009). A climate change induced increase in sea surface temperatures and precipitation will enhance water column stratification and possibly reduce the bottom water renewal frequency resulting in
enhanced isolation of deep water in Loch Etive. Additional input of terrestrial organic matter due to an increased river runoff as well as higher surface water temperatures will increase the biological oxygen demand and decrease oxygen solubility which could affect the severity of the hypoxic conditions in Loch Etive even further.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION

As mentioned before, due to relatively low agricultural activity and lack of heavy industry on the Scottish west coast and in the highlands where the Loch Etive catchment area originates from, a significant impact of eutrophication on the oxygen depletion is unlikely. However, it should be mentioned that a few aquaculture farms are located within the loch but these are not predicted to have an eutrophication impact on the loch (T. Nickell pers. com.).

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT

According to literature the soft surface sediments in the outer and inner Loch Etive are dominated by a greeny-black homogenous watery sandy mud occasionally perturbed by methane ebullition (Howe et al, 2002). The inner basin is the main deposition area for terrigenous material carried by rivers Etive, Kinglass and Awe (Howe et al, 2002; Loh et al 2002). Although only semi-quantitatively determined, Loch Etive seem to harbour an abundant benthic fauna but somewhat less diverse compared to other sea lochs nearby, possibly due the high freshwater input (Gage 1972). The same study also showed a higher abundance of deposit feeders in the deep inner basin whereas the outer basin in Loch Etive was dominated by suspension feeders (Gage, 1972). A recent study from Aird’s Bay in Loch Etive showed very high abundances (>1000 ind m⁻²) of the brittlestars *Amphiura filiformis* and *Amphiura chiaeji* (H. Stahl unpublished results).

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA

Not yet studied in Loch Etive

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

SAMS hosts local expertise and a number of data sets/data bases/studies regarding Loch Etive hydrography, bathymetry and geology, biogeochemistry and biology:

Dr. Mark Inall/Dr. Phil Gillibrand (moved) – hydrography and deep-water renewal periodicity/dynamics, baroclinic tidal regimes and forcing as well as modelling of bottom water oxygen concentrations (Austin and Inall, 2002; Inall et al, 2004; Inall et al, 2005; Stashchuck et al, 2007; Gillibrand et al, 2007).

Dr. Overnell (retired)/Dr Tim Brand/Dr Martyn Harvey (retired)/Prof Axel Miller - biogeochemistry, with emphasis on benthic oxygen, iron- and manganese dynamics as well as organic matter input and composition (Overnell et al 1996; Overnell et al 2002; Overnell 2002, Loh et al, 2002)

Dr. Henrik Stahl/Prof Ronnie Glud – benthic biogeochemistry, oxygen and nutrient dynamics

Dr. John Howe/Dr Tracy Shimmield - bathymetry, geology and radionuclide chemistry (Howe et al, 2002; Howe et al, 2001; Shimmield, 1993)
REFERENCES CITED IN THE TEXT AND FURTHER READING ON LOCH ETIVE


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Water column parameters (continuously by moored observatories):
Temperature, Conductivity, Pressure, Oxygen, Currents (speed and direction in bottom, intermediate/surface waters)

Benthic parameters (four separate field campaigns):
In situ benthic fluxes: oxygen (both chamber and eddy correlation lander measurements), DIC, nutrients, Fe²⁺ and Mn²⁺ (only chamber lander measurements)

Meteorological parameters:
Wind speed and direction, temperature, pressure, precipitation
ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Possible analysis of faunal community structure and densities using SPI and grab samples in the two main basins (inner and outer Loch Etive).

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

Very little is known about the temporal and spatial dynamics of bottom water overturning in Loch Etive and even less is known about the biogeochemical response of the ecosystem to these potentially rapid events (Austin and Inall, 2002). Facing the facts of climate change it is highly likely that this will have negative effects on the oxygen conditions in Loch Etive which in turn could result in negative ecosystem responses. The main objective with the Loch Etive study is therefore to establish a permanent observatory, continuously monitoring oxygen conditions and associated parameters in Loch Etive, to be able to detect both rapid (overturning) as well as long term (climate change driven) changes and to use this information both for predicting future scenarios through modelling exercises as well as for driving targeted field campaigns studying the biogeochemical responses to changes in bottom water oxygen concentrations.

Within HYPOX the measured parameters will be used for monitoring of long term changes and for accurately predicting/modelling the renewal frequency of bottom water in the loch, which is the main driver for hypoxia in loch Etive. This will be done by coupling a hydrographical model (POLCOMS) to a submodel for predicting the oxygen concentration in three different layers (bottom water, intermediate and surface layers).

The biogeochemical response of the sediments to hypoxia in Loch Etive is, so far, not well understood. What happens when the pool of oxygen in the sediments starts to be depleted and reduced species of Mn$^{2+}$, Fe$^{2+}$ and eventually H$_2$S are released from the sediments, and how will this affect the severity of the hypoxia in the overlying water column? As Fe-oxides also have the capacity of binding PO$_4^{3-}$, the release of Fe$^{2+}$ will also liberate a pool of PO$_4^{3-}$ acting as an internal source of nutrients which potentially could enhance PP in Loch Etive and as such act as a negative feedback on hypoxia. So these feedback mechanisms and their temporal dynamics associated with bottom renewal events in Loch Etive needs to be further studied together with the importance of the infauna (i.e. importance of bioirrigation and bioturbation). The importance of fauna for reoxygenating the sediments will be derived from total benthic flux measurements of oxygen (i.e. with chambers and/or eddy landers) in combination with microelectrode derived fluxes (only bacterial contribution).

OBSERVATORY LEADER(S) NAMES AND EMAIL

Henrik Stahl, Scottish Association for Marine Science (SAMS)
eMail: henrik.stahl@sams.ac.uk

Mark Inall, Scottish Association for Marine Science (SAMS)
eMail: mark.inall@sams.ac.uk

Ronnie Glud, Scottish Association for Marine Science (SAMS)
eMail: ronnie.glud@sams.ac.uk
SITE NAME

**Koljö Fjord, Sweden**

DURATION OF OXYGEN DEPLETION
Below ca 20 m waters stay anoxic for months to years.

NATURAL CAUSES OF OXYGEN DEPLETION
Hydrographical setting (stratification, ventilation, circulation)

MAN MADE CAUSES OF OXYGEN DEPLETION
The anthropogenic discharge of nutrients only accounts for approx. 25% of the nutrient input to the system while the remaining 75% are of natural origin.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
Nothing specified

EXPECTEDIMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
Nothing specified

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
Nothing specified

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA
Nothing specified

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)
Water column: salinity, temperature, oxygen, hydrogen sulfide, nutrients, total N, total P, chlorophyll, Secchi depth, pH, alkalinity, etc. at the central deepest site (1934-37 [at least annually], 1958-1985 [bimonthly or quarterly], since 1986 [monthly]): Swedish Meteorological and Hydrological Institute (SMHI) in Gothenburg.

Sediment: C, N, porosity, foraminifera, etc.

Modelling results on the influence of climate and hydrographic variations on benthic hypoxia in the Koljoe Fjord: Earth Science Centre, University of Gothenburg (Prof. Kjell Nordberg, kjno@oce.gu.se)
REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Water column: (inside and outside of Koljoe Fjord):
Salinity, Temperature, Oxygen, H₂S, CH₄, N₂O, currents

Oxygen consumption and production in water and in sediments (relative share of sediment fauna and microbial community)
Production of H₂S, CH₄, N₂O in water and in sediments
Oxygen gradients and currents in benthic boundary layer
Sediment oxygen distribution
Organic matter production, export and deposition in sediment
Fish and benthic fauna (abundance, biomass, composition) and the influence of hypoxia

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Nothing specified

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

What are the greenhouse gas fluxes to the atmosphere (CH₄, N₂O, CO₂) at different oxygen levels?

Develop a water, salt and oxygen budget for the fjord, including the exchange with neighbouring basins.

The vertical mixing in the fjord is not well known.

What are the pathways of oxygen consumption in water and sediment (oxidation of organic carbon including methane, oxidation of reduced inorganic compounds, nitrification)?

OBSERVATORY LEADER(S) NAMES AND EMAIL

Per Hall, University of Gothenburg (UGOT)
eMail: perhall@chem.gu.se
SITE NAME

Amvrakikos and Aetoliko lagoons, Greece

DURATION OF OXYGEN DEPLETION

Amvrakikos Gulf

Anoxic conditions appeared in the Amvrakikos Gulf in the last 20 to 30 years. This is concluded from the study of recently collected small sediment cores showed the existence of a surface black mud layer of 5 to 10 cm in thickness which in relation to the sedimentation rates which are about 0.35cm/yr (Tsabaris et al. 2009. and Tsabar is pers. comm., UPAT-group, 2009).

References

UPAT-group (2009) Fjord water circulation patterns and dysoxia/anoxia related processes in a Mediterranean embayment, Amvrakikos Gulf, Greece. (Submitted for publication).


Aetoliko Lagoon

The bottom water layer between 15 and 32 m is anoxic. The hypoxia/anoxia of the bottom layer is well documented by measurements over the last 60 years. Mass mortality of fishes has been reported over the last 150 years suggesting that the lagoon has been suffered from hypoxia/anoxia also in the past.

NATURAL CAUSES OF OXYGEN DEPLETION

Strong stratification of water masses along with gas seepage from the sediment (CH$_4$ and H$_2$S, originating from shallow sediments or from the deep subsurface) are natural causes for anoxia.

Amvrakikos Gulf

The water column is highly stratified due to a high salinity gradient between 5 and 10 m depth (Friligos and Kousouris 1977, Friligos et al. 1997). The surface water layer in the summer (July) has a salinity ranging from 31 to 33 ‰ and temperatures ranging from 23.5 to 27 °C. The bottom water layer has salinities of between 37 to 38 ‰ (Piper et al. 1982) and temperatures of between 17.3 and 19.0 °C. The development of the halocline is attributed to the major riverine freshwater inflows. Recently collected oceanographic data from the Preveza Straits (connecting the Ionian Sea and the Avrakikos Gulf) showed the presence of a horizontal salinity and density gradient which extends from the surface to the bottom indicating the presence of a well developed front due to the outflow of brackish water from the Gulf and inflowing saline open sea water (UPAT-group, 2009, submitted to publication). Additionally, marine geophysical surveys have revealed acoustic characters which are attributed to the presence of fluid (gas) in the surface sediments (0-30m) of the Gulf (Papatheodorou, et al, 1993). The escaping fluids may contribute to the establishment of the hypoxic/anoxic conditions.
Aetoliko Lagoon

The lagoon has a two-layer water column structure. The stratification is mainly controlled by the salinity. The surface layer (epilimnion) is about 10-15 m thick, with temperatures between 14 to 30°C, salinities ranging between 16 and 20‰ and DO concentrations from 8 to 16 mg/l. The bottom water layer (hypolimnion) from 15 to 32 m has almost constant temperature (15-16°C) over the past fifty years, salinities of about 26 to 28‰ and is almost anoxic. The water circulation in the lagoon is almost similar to that of Amvrakikos Gulf, and is characterized by inflow of saline dense water masses originating from the Patras Gulf and the Messolonghi lagoon and outflowing brackish surface waters.

The thickness of the oxygenated upper layer changed over the past 50 years. It ranged from 14 meters in 1951, to 9-13 m during the period 1984-85 and decreased to only 5-7 m in 1995-2003. From these depths to the bottom (about 32 m) the water column is almost anoxic. A recent hydrographic survey showed that the oxygenated upper layer has a thickness of 15-18 m due to the widening of the two communication channels between Messolonghi and Aetoliko lagoons (UPAT, unpublished data).

The bottom layer is characterized by high levels of H2S. The hydrogen sulphide concentration was 28.8 mg/l in 1951 and 45 mg/l in 1995. Recent investigation showed maximum H2S concentration up to 55 mg/l (UPAT, unpublished data; Gianni and Zacharias, 2009). The origin of the H2S, and related O2 depletion could be related to one or a combination of the following three mechanisms:

(i) Low water circulation between Messolonghi and Aetoliko Lagoons,
(ii) Dissolution of gypsum deposits (outcropping diapirs) at the floor of the lagoon at the western margin of the lagoon
(iii) Gas seepages from the lagoon floor

The third hypothesis is suggested by the presence of crater-like features which were detected during a small scale side scan sonar survey. So far the origin of these features has not been determined although seafloor fluid flows are a strong possibility (Papatheodorou et al., 2001). Pockmarks are indicators of gas seepage. Methane anomalies have been recorded in seawater.

Sediment core data from the seafloor of Aetoliko lagoon (UPAT, unpublished data) showed the presence of laminated sediments with black-white colour alterations (varves deposits). This probably suggests annual formation of these deposits and in that case it is an excellent opportunity to study the historical record of the anoxia in the lagoon.

Amvrakikos Gulf and Aetoliko Lagoon

Seepage-linked oxygen depletion may be due to two main processes:
a) Oxygen consumption by CH4 oxidation
b) up-welling (driven by density changes) of deep oxygen-poor water into the photic zone and surface layer


References showing that effect in somewhat similar sites


MAN MADE CAUSES OF OXYGEN DEPLETION

Eutrophication by excessive use of fertilizers on the surrounding agricultural land, increase of farm animal stocks, intensive fish farming and increased sewage discharge add to the natural causes of anoxia.

Amvrakikos Gulf

High levels of eutrophication were detected due to average annual concentrations of PO4-P, NH4-N and NO3-N of about 0.4, 0.45 and 2.2 μg/l, respectively. (Friligos et al. 1997). Therefore, Amvrakikos Gulf contains 3.8, 1.4 and 3.9 times more PO4-P, NH4-N and NO3-N, respectively, than the Ionian and the Aegean Sea (Friligos et al. 1997). Furthermore, preliminary results of U, Ra, Th, K measurements in the gulf sediments show a strong disequilibrium between U and Ra which may suggest U inputs from phosphate fertilizers.


UPAT-group (2009) Fjord water circulation patterns and dysoxia/anoxia related processes in a Mediterranean embayment, Amvrakikos Gulf, Greece. (Submitted for publication).

Aetoliko Lagoon
Elevated heavy metal concentrations (Cu, Zn, Pb) in the sediments at the southern part of the lagoon further support the pollution originated by sewages (UPAT, unpublished data). The construction of a bridge along the two channels connecting the Aetoliko and Messolonghi lagoon prevent the regular circulation of water masses between the two lagoons leading further to oxygen depletion.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS

Gas seepage is mainly driven by endogenic factors like pressure build-up in deep gas accumulation and fault permeability which are not significantly influenced by climate changes. A possible link however, on a long-term change, is the sea-level decrease which may increase seepage (by hydrostatic pressure decrease) and emission of gas into the atmosphere.

Amvrakikos Gulf and Aetoliko Lagoon

The hydrography-driven hypoxia/anoxia at Amvrakikos Gulf and Aetoliko lagoon is mainly controlled by the strong stratification of the water column. The reduction of the surficial salinity and/or the increase of temperature may lead to further intensification of the stratification. Although an increase of temperature is expected due to the greenhouse effect, the prediction of increased precipitation and thus riverine inflows is unsafe since it seems affected by a variety of factors such as North Atlantic Oscillation (NAO).

Regarding the Aetoliko lagoon, the increase of the temperature is expected to enhance the dissolution of gypsum deposits at the floor of the lagoon and thus the H₂S level in the bottom layer.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION

No records regarding the past variability in primary productivity and the frequency and/or the duration of hypoxic/anoxic events exist and thus no connection between them and the increasing man-made eutrophication can be made. However, little information regarding the present-day eutrophication of the water column in Amvrakikos Gulf and Aetoliko lagoon is given. There the fish mass mortality events are discussed.

Amvrakikos Gulf

The Gulf is characterized by high primary productivity with phytoplankton densities between 7.5 x 10^5 and 2.0x10^7 cells/l (Gotsis-Skretas et al. 2000).

Regarding the fish-mass mortality it seems that is related to the upwelling of the anoxic bottom layer (due to massive intrusion of dense open sea water through the Preveza Straits and/or gravity driven river hyperpycnal flows). Increase of man-made eutrophication may extend the spatial and vertical distribution of the anoxic layer (UPAT-group, 2009, submitted to publication).

Gotsis Skreta, O., Psochiou, E., Lempesis, G., Brampa, D., D. Theodorou, and E. Balopoulos. Seasonal variation of phytoplankton and environmental parameters in a semi-enclosed sea...
Aetoliko Lagoon
High concentrations of phosphates (> 10 μg/l), silicates (> 200 μg/l) and ammonia (> 400 μg/l) were observed in the anoxic water layer of the lagoon (Danielides, 1991). There is an increase in concentration near bottom. Silicate concentrations in > 20 m depths were more than 500 μg/l while in surface samples they were below 50 μg/l (Dassenakis et al, 1994). The sudden death of fishes is associated to the upward migration of hydrogen sulfide to the surface waters probably lead by strong southern winds. This type of catastrophic event has been observed several times the last 150 years. In the most recent mass mortality of fishes which occurred in November 1990 and in December 2008, it has been estimated that a large part of the fish stock was lost. Hydrobiological studies suggested that the deaths were due to the high concentration of H2S in the hypolimnion.


BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
Extensive bacteria mats (Beggiatoa sp.).

Amvrakikos Gulf
The sediments in the Gulf shows consist of a sapropelic black mud layer with C_{org} content between 2 and 4%, ranging in thickness from 5 to 10 cm overlying an olive green mud layer (UPAT, unpublished data, submitted to publication). A preliminary examination on foraminifera shows the presence of low species diversity associations dominated by Ammonia spp. Bulimina Spp., Bolivina spp. and Nonionella spp. in the surficial black mud layer. These taxa characterize coastal and estuarine environments. They are euryhaline and tolerant to low oxygen bottom waters. However, it cannot be affirmed whether the foraminifera tests were living or dead specimens as the samples were not treated by rose Bengal. In the olive green mud layer the benthic foraminifera assemblages represent higher species diversity and are dominated by the above mentioned taxa as well as Miliolidae spp. A R.O.V-based survey of the seafloor showed that the oxic seafloor is characterized by brown sands with bivalve shells whilst the anoxic seafloor is covered by a white mat of about 1 to 2 cm in thickness that resembles filamentous beggiatoa like cells (UPAT-group, 2009, submitted to publication). Marine geophysical surveys have revealed acoustic characters which are attributed to the presence of fluid (gas) into the surface (0-30 m) sediments of the Gulf (Papatheodorou, et al, 1993). The escaping fluids may contribute to the establishment of the hypoxic/anoxic conditions.
Aetoliko Lagoon

A small-scale side scan sonar survey has revealed the existence of numerous (about 2000) crater-like features (pockmarks?) on the seafloor of the lagoon. These features are 1.0-1.5 m in diameter and about 0.5-1.0 m deep, and probably are associated to floor fluid flows (cold seeps) (Papatheodorou et al., 2001).


Amvrakikos Gulf

Fish-mass mortalities have been reported in the last five years in the Amvrakikos Gulf. R.O.V inspection of the water column showed that in the dysoxic layer and just above it a high density jellyfish population, possibly Aurela aurita, occurs. Recent studies indicate that jellyfish are tolerant to low oxygen content and prefer areas of low oxygen content for food (UPAT-group, 2009, submitted to publication). The visual inspection of the anoxic environments on the seafloor with an R.O.V. shows that the anoxic seafloor is covered by a white mat of about 1 to 2 cm in thickness that resembles filamentous Beggiatoa like cells (UPAT-group, 2009, submitted to publication).

Aetoliko Lagoon

Mass mortality of fishes has been reported over the last 150 years suggesting that the lagoon has been suffered from hypoxia/anoxia in the past. Two extensive events occurred the last twenty years (1990 and 2008). No data is available regarding bacterial and higher benthic life.

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

No data base exists on Amvrakikos Gulf and Aetoliko Lagoon

REFERENCES CITED IN THE TEXT AND FURTHER READING

Included in the above paragraphs

PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Oceanographic parameters (T, S, density, turbidity, currents)
O₂ in the water column
Eh, pH, C, N₂ and S in the water column
Gas seepage (CH₄, H₂S, seepage rates and gas origin)
Remote sensing techniques (subbottom profiling system, side scan sonar) for seepage sites detection
Visual inspection of the seafloor using R.O.V.
Coring - Sediment sampling for the evolution of palaeoenographic conditions (historical record of hypoxia).

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES
Nothing specified

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)
Assessment of CH₄ and H₂S origin (shallow sediments, or from deep subsurface, eventually related to natural gas accumulations) is an important task to determine if hypoxia is driven by near-surface sedimentary processes or by endogen, geo-tectonic and petroleum geology factors.

Amvrakikos Gulf and Aetoliko lagoon are examples of coastal environments where hypoxic conditions are developed due to strong water column stratification and to strong man-made eutrophication. In addition, seepages seem to contribute in the hypoxia. Both these sites represent unique environments for the study of the exact mechanism causing the hypoxic-anoxic conditions and the response of benthic life (macro to micro) to such conditions. In particular, the study of the microbial life on the anoxic seafloor/floor of both environments is of great importance. Beyond the scientific interest, the study of these wetlands will be of great value for the local society. These land locked water bodies are fundamental for the economy of the region which is based on the fishery and tourism. So far, the development of hypoxia seems to limit fishery leading to a great strain on the local resources. Furthermore, the overall change of the natural environment may lead to reduction of recreation opportunities and thus has a negative impact on tourism. Hypoxia affects the diversity and the density of aquatic species and probably will affect the remarkable faunal and floral habitats of the area.

An example regarding the direct and/or indirect impact of hypoxia to the local society is the following event: A sudden, catastrophic release of gas from Aetoliko lagoon was reported by the Greek newspaper “Estia” on 3 December 1881. The city of Aetoliko was evacuated by the population due to the “rotten eggs” intense smell. After the return of the population, they mentioned that the flowers in the gardens had been destroyed and the silver spoons and forks had been gone to black due to the presence of the hydrogen sulfide. The present day knowledge regarding the hypoxic/anoxic environment of Aetoliko lagoon support the hypothesis that the bulk of gas released was H₂S that had been stored in the lagoon's bottom layer.

Furthermore, assessment of CH₄ and H₂S origin (shallow sediments, or from deep subsurface, eventually related to natural gas accumulations) is an important task to determine if hypoxia is also driven by near-surface sedimentary processes or by endogen, geo-tectonic and petroleum geology factors.

OBSERVATORY LEADER(S) NAMES AND EMAIL
Giuseppe Etiope, National Institute of Geophysics and Volcanology (INGV)
eMail: etiope@ingv.it
George Papatheodorou, University of Patras (UPAT)
eMail: gpapathe@upatras.gr
SITE NAME

Katakalo Bay, Greece

DURATION OF OXYGEN DEPLETION

The oxygen depletion is probably restricted around the seepage sites. No data exist on DO in the water column in the Katakolo Bay.

NATURAL CAUSES OF OXYGEN DEPLETION

Seepage of thermogenic CH₄ and H₂S (Etiope et al., 2006). Bubbles rise from seabed cracks in the order of 10-20 cm in diameter.

Katakolo seeps occur offshore around the local marina. Offshore bubbling plumes are widespread throughout the harbour docks. Bubbles are visible from the wharf over a wide area (order of 10³ m²); divers found bubbles of the order of 20-30 cm in diameter rising from cracks in the seabed that is covered by white bacterial mats. Onshore seeps penetrated and damaged the asphalt pave of the harbour zone. The seeps have a heavy rotten-egg smell. In 1972, a flame blew out from the pave of the main wharf destroying a pole (Etiope et al., 2005, 2006).

Fluxes measurements at the Katakolo Harbour showed values up to 165,000 mg m⁻² d⁻¹. In the harbour, where the pave asphalt is shattered by the gas leakage, the fluxes are 10³-10⁴ mg m⁻² d⁻¹. Katakolo offshore gas vents consist of around 90% CH₄ and 0.02% H₂S. Isotopic data show that seeping gas is thermogenic methane coming from the deep reservoirs of the Mesozoic limestones and is of catagenetic maturation starting from sapropelic kerogen (Type II) (Etiope et al., 2005, 2006). The oxygen depletion around the offshore seepages sites is probably caused by the oxygen demand for the oxidation of gases.


MAN MADE CAUSES OF OXYGEN DEPLETION

The construction of the harbour and the following dredging of the harbour sediments caused increased loading over the seafloor and reduction of the overburdened pressure leading to enhanced seepages.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS

Gas seepage is mainly driven by endogenic factors (pressure build-up in deep gas accumulation, fault permeability) which are not significantly influenced by climate changes. A possible link, on a long-term change, is the sea-level decrease which may increase seepage (by hydrostatic pressure decrease) and emission of gas into the atmosphere.
EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION

Although no relevant data exist, Katakolo bay is an open bay and no eutrophication is expected.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT

Extensive bacteria mats (Beggiatoa sp.) are found on the seafloor at these seepage sites (Etiope et al., 2006). No data regarding the benthic life exists. Remote sensing survey has shown acoustic anomalies which are indicative of gas into the sediments beneath the seafloor (UPAT, unpublished data). So far, no pockmarks have been recorded in the Katakolo bay.


KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA

There is no data regarding the response of ecosystem to hypoxia. No fish mass mortalities have been reported.

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

No data base exists. The www.chemeng.upatras.gr is wrong address. Is referred to Chemical engineering Department which has nothing to do with the HYPOX.

REFERENCES CITED IN THE TEXT AND FURTHER READING

References are included in the paragraphs above

PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

Oceanographic parameters (T, S, density, turbidity, currents)
O\textsubscript{2} in the water column
Gas seepage (CH\textsubscript{4}, H\textsubscript{2}S, seepage rates and gas origin)
Remote sensing techniques (subbottom profiling system, side scan sonar)
Visual inspection of the seafloor using R.O.V.
Coring - Sediment sampling for biotic data.

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Nothing specified
Although no strong evidence of oxygen depletion was observed, the intense release of gas in the water column could reduce the oxygen availability producing local hypoxia/anoxic microenvironments. Katakolo is thus a perfect “natural laboratory” to investigate the relationships between O₂ distribution and natural gas seepage and the diversity of macro to microbial species that developed in such unique environments.

OBSERVATORY LEADER(S) NAMES AND EMAIL

Giuseppe Etiope, National Institute of Geophysics and Volcanology (INGV)
eMail: etiope@ingv.it

George Papatheodorou, University of Patras (UPAT)
eMail: gpapathe@upatras.gr
SITE NAME

Lake Zurich, Switzerland

DURATION OF OXYGEN DEPLETION
Temporary oxygen depletion. The lake is holomictic, but tends to become oligomictic as winters become milder and suppress full circulation.

NATURAL CAUSES OF OXYGEN DEPLETION
Climate induced as temperature rise since the 1980s causes intensified stability of stratification.

MAN MADE CAUSES OF OXYGEN DEPLETION
Waste water (three-stage treatment and chemical precipitation of phosphate), agricultural waste (incl. fertilizers).

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
52 year long (1947-1998) uninterrupted monthly temperature record: T increase of about 0.24 K per decade in upper 20 m and about 0.13 K below; stratification increase by about 20%, extension of stratification period of about 2-3 weeks, (possible future impact of global warming causing higher stabilities and decreased oxygen exchange)

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
Significant management efforts have resulted in Lake Zurich being only weakly eutrophic with slight anoxic tendencies (Jankowski et al., 2006). The lake has been undergoing oligotrophication since the 1980s, when the use of phosphate in detergent was banned in Switzerland.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
No relevant information available to our knowledge.

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA
Hypoxia and changing vertical fluxes of nutrients due to modified local meteorological forcing will likely result in a change in the lake plankton’s composition and a decrease in productivity (Jankowski et al., 2006). Phosphorus dissolution at the sediment-water interface is known to result from uninterrupted oxygen depletion in the bottom layer, leading to algal blooms and fish kills (Carpenter et al. 1998; Jankowski et al., 2006).

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)
Oxygen and water temperature: approximately monthly profiles since 1936.

REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX
CTD profiles – Conductivity, temperature, depth and oxygen
sediment characterization
biomarkers (especially lipids)
stable isotopes of noble gases (possibly)

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES
Nothing specified

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

Motivation:
- long time series of oxygen, temperature and other relevant recordings, during which:
  o significant and successful (?) management efforts to reduce phosphorus input, subsequent change in eutrophication status
  o Observed warming of surface water temperatures in comparison to deeper water, resulting in increasing thermal stability (Livingstone, 2003).
  o Observed period of decreasing oxygen levels in the bottom layer as a result of three mild winters and subsequently maintained stratification (Livingstone, 1997).
  o significant event, summer 2003, of warmest summer on record, and subsequent impact on stratification and oxygen levels an excellent indicator of potential climate change impacts.
- Excellent comparison with Lake Lugano and Lake Rotsee

OBSERVATORY LEADER(S) NAMES AND EMAIL
Carsten Schubert, Swiss Federal Institute of Aquatic Science and Technology (Eawag)
eMail: carsten.schubert@eawag.ch
SITE NAME

Lake Rotsee, Switzerland

DURATION OF OXYGEN DEPLETION

There is strong oxygen depletion from April to November. The lake mixes completely during winter and oxygen is present throughout the water column from November to March.

NATURAL CAUSES OF OXYGEN DEPLETION

Stratification and hydrological setting. The lake was already eutrophic and partly meromictic during the Holocene. This lake is very small and wind shielded which makes mixing of water very difficult and only in combination with cold air temperature the lake mixes. There is no real flow through only an artificial channel build from a river but this apparently is not very efficient. In summer people complain about the smell which stems from the degradation of the huge amount of algae grown in this lake.

MAN MADE CAUSES OF OXYGEN DEPLETION

Sewage, eutrophication:
Between 1850 and 1978 the trophic state further increased through sewage from the town of Lucerne. After sewage treatment plants were build eutrophication decreased, however there are still high amounts of nutrients present leading to high productivity and oxygen depletion in the lowermost 8 m of the water column. There does not seem to be a climatic influence but this has to be investigated using the long time series.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS

Intensified stratification due to increasing water temperatures at the surface.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION

Intensified oxygen consumption by the process of organic matter degradation will lead to a stronger depletion of oxygen and longer periods of hypoxia.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT

Macrophyte flora present. Data on this might exist.

KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA

The tropic state further increased through sewage from the town of Lucerne between 1850 and 1978. Several blooms of Oscillatoria rubescens were observed and an even larger volume of the lake eventually became anoxic (first in 1909 [?]). Before it should have been an important lake for fisheries. Sewage treatment plants drastically reduced sewage input into the
lake since the end of the 1970s. A connection between the River Reuss and Lake Rotsee was built (in the 70s) to bring more oxygen from the river into the stagnant lake.

**SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)**

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<td>P dissolved</td>
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This data exists from 1916 on. Sometimes they changed the depths but rather a complete data set. Data belong to Amt für Umwelt und Energie des Kantons Luzern (Robert Lovas, robert.lovas@lu.ch)

**REFERENCES CITED IN THE TEXT AND FURTHER READING**


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

CTD profiles (conductivity, temperature, depth) and profiles of oxygen, redox conditions, pH, transmission, nitrite, nitrate, ammonium, phosphate, silicates, hydrogen sulfide, TC, TIC, TOC, DIC, DOC, PIC, POC.

sediment characterization: structure, varves or lamination, grain size distributions, turbidite identification, carbon contents (TC, TIC, TOC)

biomarkers: focus on the following lipids originally produced by certain organisms that potentially live and/or lived in the lake: lycopane, okenone, isorenieratene, epicholestanol, chlorobactane, carotene, byphytanes, methylhopane, tetrahymanol, tetrahydrosqualene, pentamethyleicosane, fernene, archeol

stable isotopes of biomarkers

noble gas concentrations and isotopes: He-3, He-4, Ne-20, Ne-21Ne-22, Ar-36, Ar-40, Kr (especially Kr-84), Xe (total concentration), additionally other gas tracers like H-3, SF6, CFC-11, CFC-12

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Nothing specified

SCIENTIFIC TASKS / OPEN QUESTIONS THAT MOTIVATE PROJECT WORK AT THE SITE (WITH EMPHASIS ON QUESTIONS INVESTIGATED WITHIN HYPOX)

Lake Rotsee exhibits a relatively stable stratification in summer with a strong chemocline at around 10 m depth with anoxic waters below. As a consequence of particularly warm spring in 2007, the lake has produced so much organic material that organic matter degradation in summer led not only to anoxia but also to the build up of hydrogen sulfide which eventually was smelled by the people living around the lake. The site thus offers the opportunity to investigate the impact of temperature changes on hypoxia and to look into details of the threshold and trigger mechanism that makes a lake overturning and on what is happening in the water column just shortly before this event.

OBSERVATORY LEADER(S) NAMES AND EMAIL

Carsten Schubert, Swiss Federal Institute of Aquatic Science and Technology (Eawag)
    eMail: carsten.schubert@eawag.ch

Rolf Kipfer, Swiss Federal Institute of Aquatic Science and Technology (Eawag)
    eMail: rolf.kipfer@eawag.ch

David Livingstone, Swiss Federal Institute of Aquatic Science and Technology (Eawag)
    eMail: david.livingstone@eawag.ch
SITE NAME

Lake Lugano, Switzerland

DURATION OF OXYGEN DEPLETION
Since the 1960’s the lake was permanently stratified, leading to 40 years of stagnant and anoxic water below 100 meters (at least since the 1970’s until winter of 2004/2005). The first mixing events occurred in winter 2004/2005. Oxygen renewal occurred during mixing events in winters until today although not reaching saturation in all depths the water column and the lake bottom. Since this first mixing event the lake mixes once a year during winter time.

NATURAL CAUSES OF OXYGEN DEPLETION
Stratification & hydrological setting: Stable stratification keeps vertical oxygen transport too low to compensate for oxygen demand in the lower water column and the sediment. Additional factors that increase such situations are the wind-shielded location of the lake surrounded by mountains and a relatively warm climate. Therefore heat transport can be limited and so oxygen is not well mixed in the lake. But the main factor is seen as anthropogenically caused eutrophication.

MAN MADE CAUSES OF OXYGEN DEPLETION
The lake was meromictic for about 40 years; it ended in winter of 2004/2005. The lower water layer was anoxic due to anthropogenic eutrophication (fertilizers, no sewage treatment in a highly urbanised and industrialized area). In former, less industrialized times the lake used to be oligotrophic.

EXPECTED IMPACT OF CLIMATE CHANGE ON OXYGEN DEPLETION AND RELATED PARAMETERS
We expect intensified stratification due to increasing surface water temperatures. This stagnation supports other factors that showed influence on stratification of the lake which are wind-shielded locations because of high mountains that surround the lake, relatively mild climate regime (with annual mean air temperatures of about 12°C and even January mean temperature of 3.2°C considering the period from 1971 to 2000). Another influence was eutrophication that decreased until today.

EXPECTED IMPACT OF EUTROPHICATION ON OXYGEN DEPLETION
Eutrophication decreased until today and improvements were possible because of water and sewage treatment so this factor doesn’t have the importance today as it had in the past. Eutrophication had an influence in the past; because since the 1940’s eutrophication correlates (although there is a time lag) with increased stratification in the lake which occurred in the 1960’s. Stable stratification until the winter 2005 made oxygen transport to deeper lake depths impossible. Therefore since the 1970’s the water column was anoxic below a depth of 100 meters. Nutrient input increased in process of eutrophication.

BIOTIC AND ABIOTIC CHARACTERISTICS OF THE BENTHIC HABITAT
There is no data on benthic habitats and their biotic and abiotic characteristics available at Eawag. There is some information on the CIPAIMS website (www.cipais.org/home.html). This is an international commission for protection of water in Italy and Switzerland (in Italian).


KNOWN AND EXPECTED RESPONSE OF THE BENTHIC (AND PELAGIC) ECOSYSTEM TO HYPOXIA

Nothing specified

SOURCES OF DATA ON OXYGEN, RELATED PARAMETERS AND ECOSYSTEM STATE AND CHANGES (EXPERTS, DATA BASES, PUBLICATIONS)

The following data exist (in dependence of depth) from location Gandria in the northern basin of the lake. These exist since 24th of January 1984 until 19th of December 2006:

- pH
- O2 ppm
- CO3 meq/l
- alkalinity meq/l
- NO2-N ppb
- NO3-N ppm
- NH4-N ppm
- NT ppm
- HS ppb
- CH4 ppm

The following data exist (in dependence of depth) from location Gandria in the northern basin of the lake. These exist since 21st of January 1987 until 13th of December 2005:

- Temp Celsius
- conductivity micro S/cm
- O2 mg/l
- O2 saturation %
- pH
- transmittance %
- turbidity FTU

Additionally all publications (from the whole list below) included data in their work about oxygen, related parameters and ecosystem state!

REFERENCES CITED IN THE TEXT AND FURTHER READING


PARAMETERS THAT ARE GOING TO BE MEASURED WITHIN HYPOX

CTD profiles (conductivity, temperature, depth) and profiles of oxygen, redox conditions, pH, transmission, nitrite, nitrate, ammonium, phosphate, silicates, hydrogen sulfide, TC, TIC, TOC, DIC, DOC, PIC, POC.

sediment characterization: structure, varves or lamination, grain size distributions, turbidite identification, carbon contents (TC, TIC, TOC)

biomarkers: focus on the following lipids originally produced by certain organisms that potentially live and/or lived in the lake: lycopane, okenone, isorenieratene, epicholestanol, chlorobactane, carotene, byphytanes, methylhopane, tetrahymanol, tetrahydroxysqualene, pentamethyleicosane, fernene, archeol

stable isotopes of biomarkers

noble gas concentrations and isotopes: He-3, He-4, Ne-20, Ne-21Ne-22, Ar-36, Ar-40, Kr (especially Kr-84), Xe (total concentration), additionally other gas tracers like H-3, SF6, CFC-11, CFC-12

ADDITIONAL IMPORTANT PARAMETERS BEYOND HYPOX ACTIVITIES

Nothing specified
Lake Lugano remains continuously stratified throughout the year, and because of limited vertical exchange and high primary productivity (up to > 400 g C m⁻² yr⁻¹) permanently anoxic at depth (Barbieri and Polli, 1992). Although Lake Lugano has been stratified for at least the last 30 years, the severe winter of 2004 with strong wind has mixed the water column down almost to the bottom showing that changes in weather condition can destabilize even seemingly stable lake systems. Besides the potential of Lake Lugano to serve as a study site to look into the effect of eutrophication on oxygen content, mixing in 2004 now offers the unique opportunity to observe biogeochemical conditions of a lake after having taken a deep breath for the first time after a long period of time.

**OBSERVATORY LEADER(S) NAMES AND EMAIL**

Carsten Schubert, Swiss Federal Institute of Aquatic Science and Technology (Eawag)  
eMail: carsten.schubert@eawag.ch

Rolf Kipfer, Swiss Federal Institute of Aquatic Science and Technology (Eawag)  
eMail: rolf.kipfer@eawag.ch

David Livingstone, Swiss Federal Institute of Aquatic Science and Technology (Eawag)  
eMail: david.livingstone@eawag.ch

Mathias Kirf, Swiss Federal Institute of Aquatic Science and Technology (Eawag)  
eMail: mathias.kirf@eawag.ch

Sebastian Naehler, Swiss Federal Institute of Aquatic Science and Technology (Eawag)  
eMail: sebastian.naehler@eawag.ch

Ryan North, Swiss Federal Institute of Aquatic Science and Technology (Eawag)  
eMail: ryan.north@eawag.ch