DEEP-SEA TECHNOLOGY FOR ASSESSING THE EFFECTS OF CO_2 SEQUESTRATION ON MARINE ORGANISMS

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ABSTRACT

Greater understanding of the expected impacts of carbon sequestration on marine ecosystems is a high research priority. Although the key physiological processes affected by elevated CO2 (respiratory stress, acidosis, metabolic depression) are understood, the expected responses of marine organisms to CO2 / pH changes expected under an ocean carbon sequestration program are known poorly. Nor are studies of most deep-sea animals possible at surface pressures. Here we describe technology developed for carbon sequestration studies.

1) Benthic Respiration System

This respiration system is capable of in situ deployments to abyssal depths for studies of the metabolic responses of seafloor communities and animals to simulated hypercapnia.

2) Hyperbaric Fish-Trap / Respirometer

This system enables the capture and recovery to the surface of deep-sea fishes at deep-sea pressures, followed by metabolic studies evaluating the physiological responses to hypercapnia.

3) Free-Ocean Carbon dioxide Enrichment system (FOCE)

This test system, now under development, emulates terrestrial FACE (free-air carbon dioxide enrichment) experiments, and will allow long-term (i.e. months), small scale perturbation experiments of shallow and deep-sea marine systems.

These systems are under development to advance our understanding of the physiological impacts of deep-sea animals to changes in seawater chemistry expected with a direct ocean carbon dioxide injection program. Elevated pCO2 (hypercapnia) in seawater leads to a shift in the seawater carbonate buffering system that increases seawater acidity (reduced pH), and decreases carbonate ions (CO32-). Metabolic stresses for deep-sea animals are likely to be most severe in relation to shifts in acidity, which have been stable throughout the evolutionary history of most deep-sea species. Shallow water organisms, particularly those with calcium carbonate skeletons or armor (corals, foraminifera, coccolithophores) may be affected principally by the reduced carbonate saturation state, related to the reduction in carbonate ions.

Physiological challenges associated with ocean CO2 sequestration

Reduced pH and / or hypercapnia pose physiological challenges for most marine organisms, including, respiratory stress, acidosis, and metabolic depression.

Acidosis

Chronic immersion in acidic waters may overwhelm the ability of most marine organisms to maintain the optimal acid / base balance of their tissues and fluids, leading to death or reduced metabolic performance. Restoration of proper pH balance may be energetically costly for species tolerating hypercapnia, with consequences including reduced growth and reproduction.

Respiratory Stress

The affinity for oxygen by most respiratory proteins (e.g. hemoglobin) is reduced with increasing acidity. Animals immersed in acidic waters may suffer from reduced oxygen uptake and transport, with metabolic impacts. Compensation for reduced oxygen binding may include increased ventilation rates, higher blood circulation rates, and reduced aerobic scope. Long term impacts may include low rates of growth, reproduction, and survival.

Metabolic Depression

Carbon dioxide has long been known as an anesthetic. Submersion in hypercapnic seawater may induce a state of metabolic depression or torpor, for some species, thereby reducing their activity levels, with consequences similar to those listed above.

Acknowledgements
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Deep-Sea Benthic Respiration System (BRS)

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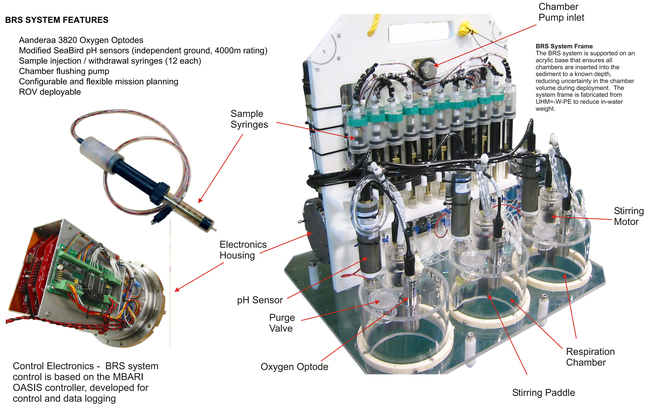
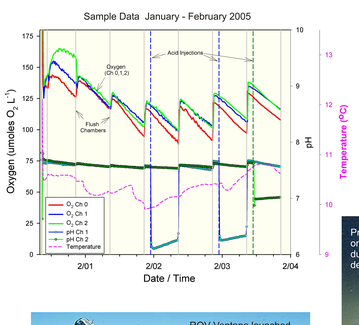
The upgraded benthic respiration system was designed to measure rates of oxygen uptake by seafloor communities in response to acidosis associated with CO2 injection. The respiration system is equipped with sensors (oxygen, pH, temperature), a stirring paddle, sample injection or withdrawal syringes, and a recirculation pump. Aanderaa oxygen optrodes, a commercial off-the-shelf sensor have been reliable, stable, and accurate. Modifications to SeaBird pH sensors allowed greater stability, accuracy, and less sensor drift. Syringes are used for sample injection or withdrawal. The recirculation pump allows all chambers to be flushed with ambient seawater at programmed intervals. This allows long-term measurements or respiration rates while reducing low-oxygen stress. Syringes have been used to inject acid after each flushing events to evaluate long term responses to acidosis. The system, equipped with 3 respiration chambers, is deployed by ROV to abyssal depths (4000 m).

BRS SYSTEM FEATURES

Aanderaa 3820 Oxygen Optodes
Modified SeaBird pH sensors (independent ground, 4000m rating)
Sample injection / withdrawal syringes (12 each)
Chamber flushing pump
Configurable and flexible mission planning
ROV deployable

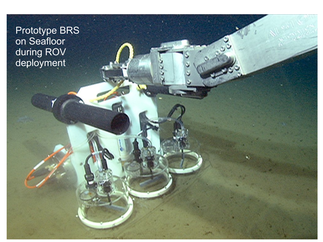


BRS System Frame
The BRS system is supported on an acrylic base that ensures all chambers are inserted into the sediment to a known depth, reducing uncertainty in the chamber volume during deployment. The system frame is fabricated from UHMW-W-PE to reduce in-water weight.



Benthic Respiration System Test Data

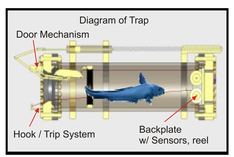
Test data from the MBARI advanced benthic respiration system. Oxygen concentrations (uM) for 3 chambers are shown as solid red, blue, and green lines. Note the reduction in oxygen during each 12 h incubation, and the abrupt rise in oxygen upon flushing of the chambers (denoted by vertical gray bars). pH data for chambers 1&2 are shown as time series of circles, with abrupt changes in pH due to injection of acid (noted wit ha dashed vertical blue and green bars) or flushing of the chambers by pumping. Temperature is indicated by the dashed purple line. Rates of sediment community oxygen consumption (SCOC) are based on the initial portion of the oxygen drawdown period following each pumping event.



Development of a Hyperbaric Trap-Respirometer for the Capture and Maintenance of Live Deep-Sea Fishes

Drazen, J.C.,Barry, J.P., and L.E. Bird
Monterey Bay Aquarium Research Insitute, Moss Landing, CA

A major obstacle to investigations of deep-sea animals is the requirement to retrieve deep-sea organisms at in situ pressures. The capture and maintenance of live deep-sea fishes is difficult due to the rapid decompression and expansion of the gas-filled bladders of some species upon ascent to the surface, and potentially the intolerance of many species to surface pressures. To enable metabolic studies of deep-sea fishes, we have constructed a high-pressure fish trap-respirometer to capture deep-water fishes at depth and return them to the surface alive at in situ pressure and temperature. The trap was designed so that respiration rates, pressure tolerance, and metabolic responses to various gas concentrations (CO2 and O2) could be examined in a controlled environment. The system consists of a stainless steel pressure cylinder (1.2 m long x 30 cm ID) that is deployed from the surface as a free vehicle to depths of 4000 m. After a fish is captured (by hook), a door closure mechanism is tripped, closing the pressure-retaining door. Upon recovery and transfer of the system to the laboratory, high pressure pumps maintain a flow of seawater and a pressure accumulator and regulator system controls pressure within the trap. Internal instrumentation includes a circulating pump, oxygen optode, and low light camera. Experiments to measure the metabolic responses of deep-sea fishes to elevated CO2 levels are underway.



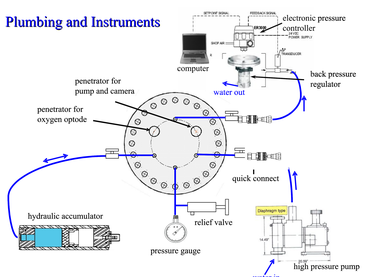
Rear Face of Trap with Plumbing Connections

Fish Trap in MBARI Test Tank

Goals

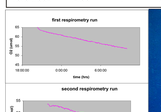
- Measure the metabolic rates of deep-sea benthic and bentho-pelagic species
- Examine the effects of elevated CO2 on metabolic rates
- Examine the pressure tolerances and effects of pressure on metabolic rates
- Various other studies (behavioral, chemosensory, protein expression, etc.)

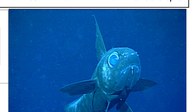
Plumbing and Instruments



Test Deployment Results

Date	Depth (m)	Duration (h)	Pressure (%)	Temp (°C)	Oxygen (µM)	Species
3/12/2004	1430	2.5	38%	11	95	none
3/16/2004	1430	3.75	0%	n/a	n/a	none
3/26/2004	1450	1 week	0%	n/a	n/a	*C. acrolepis*
5/13/2004	1350	25.5	95%	7.1	116	*C. acrolepis*
5/27/2004	1450	3.75	93%	6	84	none
10/5/2004	1500	2	95%	6	90	none
10/6/2004	1430	1	94%	5.9	110	*C. acrolepis*





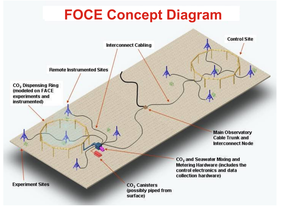
Respiration Rate = 50.1 - 56.0 umol O2 / kg/h

Development of Technology for Free Ocean CO2 Enrichment (FOCE) Experiments

Brewer, P.G., Barry, J.P., Peltzer, E.T., Graves, D., Kirkwood, B, Walz, P., Dunk, R.
Monterey Bay Aquarium Research Institute, Moss Landing, CA

Experimental facilities for long term studies of the chemistry and biology of increasing ocean carbon dioxide levels are largely undeveloped. Unlike land-based facilities, where Free Air CO2 Enrichment (FACE) experiments are commonplace across the globe, the ocean science community has not yet developed instrumentation to study the effects of chronic hypercapnia and associated changes in seawater chemistry. We have developed recently a prototype system for Free Ocean CO2 Enrichment (FOCE) experiments in ocean settings. This system mimics the concept of terrestrial FACE experiments, using a framework of plumbing to inject acid or CO2-enriched seawater at the up-current portion of an small experimental enclosure. An initial test deployment in April 2005 showed that the FOCE prototype was able to maintain a low-pH environment in a 1 m diameter x 0.5 m high volume within the FOCE frame. This is the initial effort for technology to enable long-term studies of hypercapnia in marine settings.

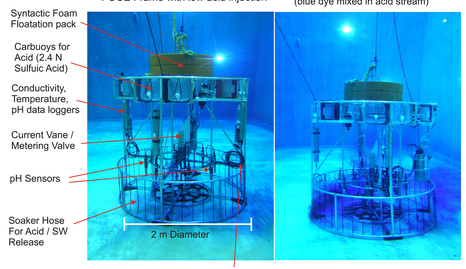
FOCE Concept Diagram



FOCE Trials in MBARI Test Tank

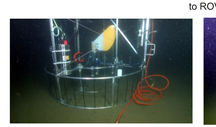
FOCE Frame with low acid injection

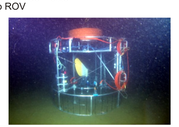
FOCE Frame with higher acid flow (blue dye mixed in acid stream)

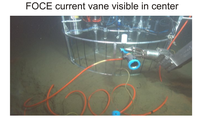


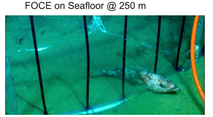
FOCE System Function

The FOCE system is designed with a valve system that directs a seawater / acid mixture to release points (soaker hose) at the upstream side of the frame. The concentration of acid released is determined by real-time feedback from 3 pH sensors mounted in the center of the FOCE experimental volume (1 m diameter x 0.5 m high). If the pH is higher than the pH set point, increased acid is pumped into the SW / Acid stream. This is also modulated by current speed. The FOCE system is optimized presently for 10 to 30 cm / s flows near the seabed. A total of 11 pH sensors are mounted on the FOCE frame. In addition a current meter (Nortek ADV) and 3 Seabird CTDs (conductivity, temperature, depth) are used to log pH data. Blue dye was added to the acid stream to enhance the visual detection of change in acid / SW injection

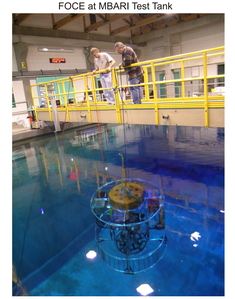

FOCE current vane visible in center


FOCE on Seafloor @ 250 m

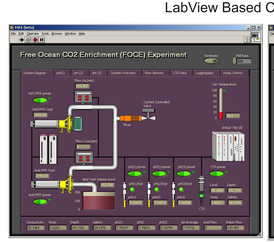

Connecting FOCE electronics to ROV power / comms


Close-up of FOCE Acid Release Hose (with Ling Cod)

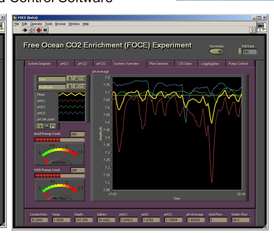
FOCE at MBARI Test Tank



LabView Based Control Software



LabView Schematic of system indicating pumps for acid, seawater, flow rates, and pH data



pH Data from individual sensors (red, green, blue) and average pH Set Point indicated as horizontal line.