RISCS research into impacts & safety in CO_2 storage

A Guide to Impacts of Potential Leaks from CO_2 Storage

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BGS

SEVENTH FRAMEWORK PROGRAMME

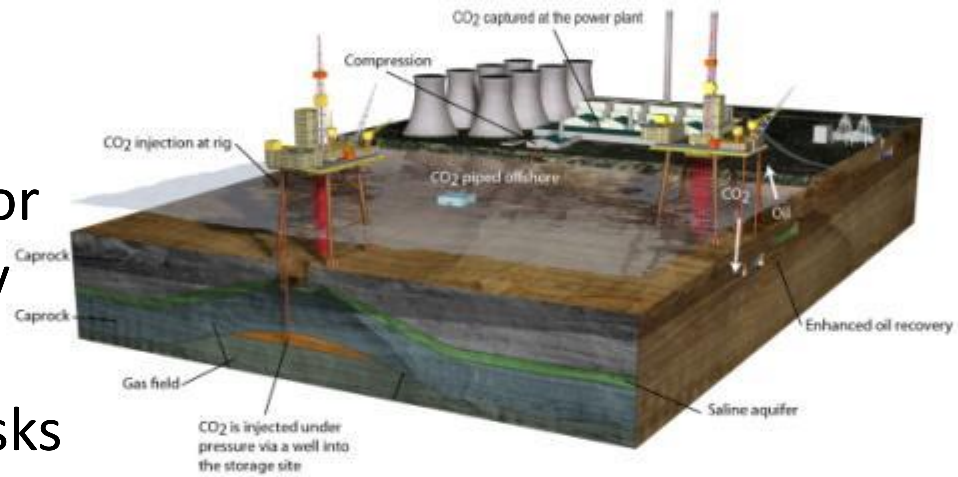
Talk outline

- Rationale and motivation
- Concepts
- Impacts in marine environments
- Impacts in terrestrial environments
- Conclusions
- Recommendations

RISCS research into impacts & safety in CO_2 storage

Rationale

- With appropriate characterisation, design, construction and monitoring leakages from storage sites are unlikely
- RISCS has examined credible scenarios for leakage.
- However it will be necessary for operators to demonstrate they have considered potential impacts, have mitigated the risks and are capable of appropriate monitoring and remediation.



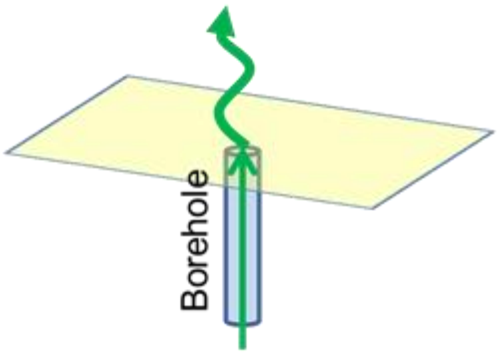
- RISCS is producing a Impacts of Potential Leaks from CO_2 Storage

Motivation

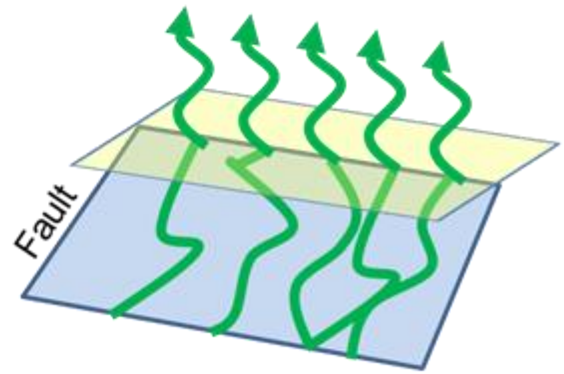
- What to consider when appraising potential impacts in the event of leakage from a storage site
- How to evaluate the potential impacts at the various stages of a storage project development: design stage, construction, operation, post-injection and to enable transfer of site liability to the competent authority
- Options for directly assessing the potential scales (temporal and areal, realistic leakage ranges (fluxes, masses)) and ecosystem responses
- Options for identifying, predicting and verifying the nature of impacts

Leakage patterns

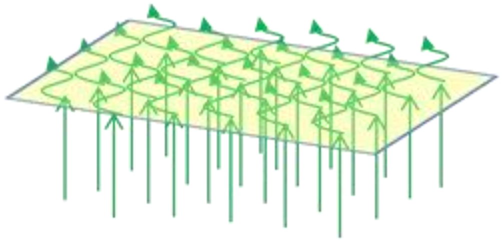
a. Point emission at surface (e.g. leaking well)



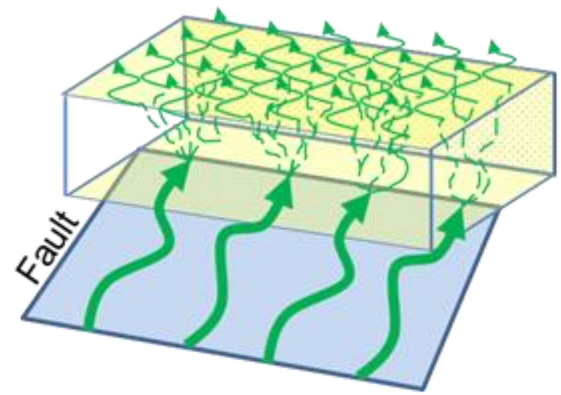
b. Arrays of point emissions at surface (e.g. multiple linear pathways in a fault zone)



c. Diffuse emission at surface caused by diffuse leakage from depth (unclear how could occur)



d. Diffuse emission at surface caused by one or more linear leakage paths at depth, but dispersion of CO_2 in shallow unconsolidated sediments (more likely than c.).

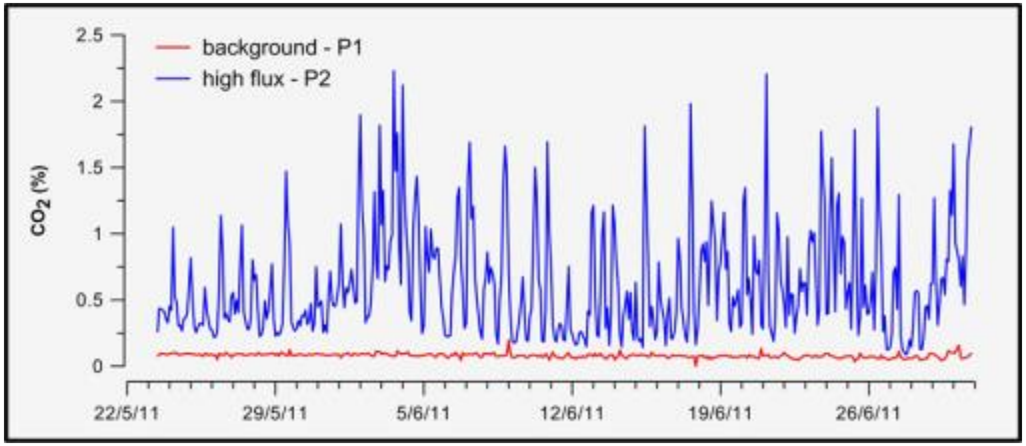


Marine impacts

Marine response summarised (1)

Chemical/physical response

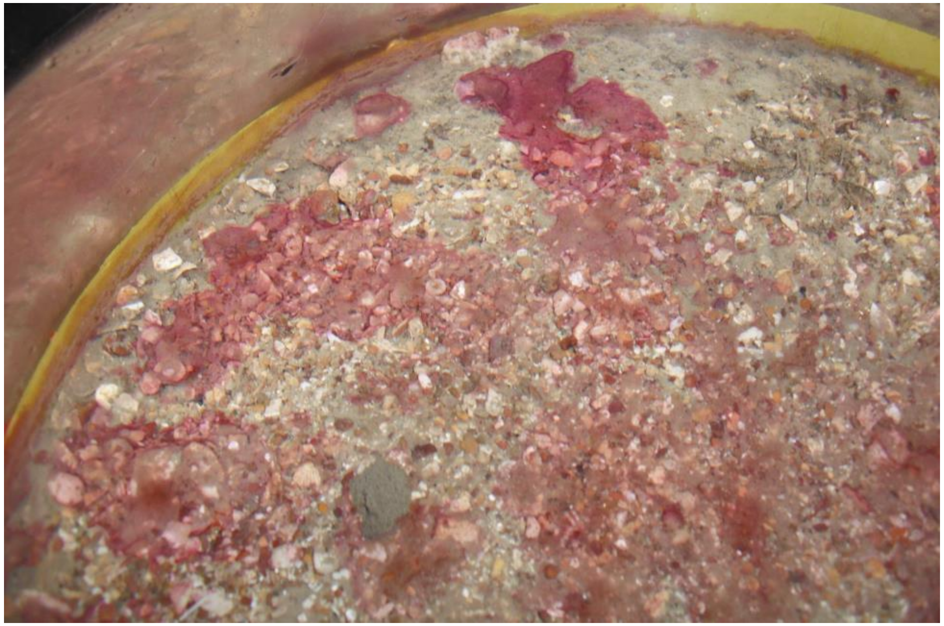
- pH shift/acidification
- No oxygen depletion
- Area affected proportionate to the leakage flux
- Efficient mixing reduces impact



Marine response summarised (2)

Microbial response (increasing primary producers)

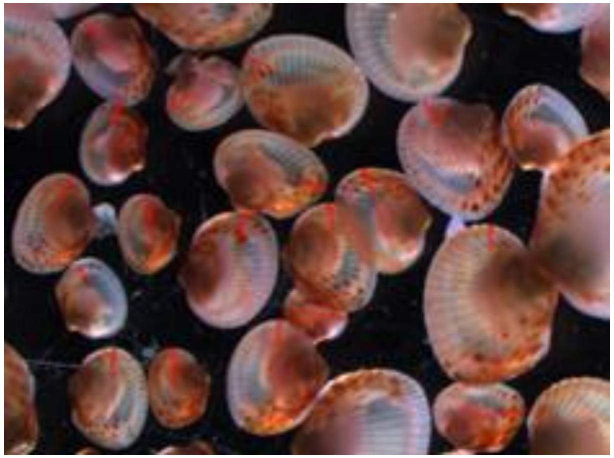
- Rapid planktonic/microbial response
- Benthic cyanobacteria



Marine response summarised (3)

<u>Macro faunal response</u>

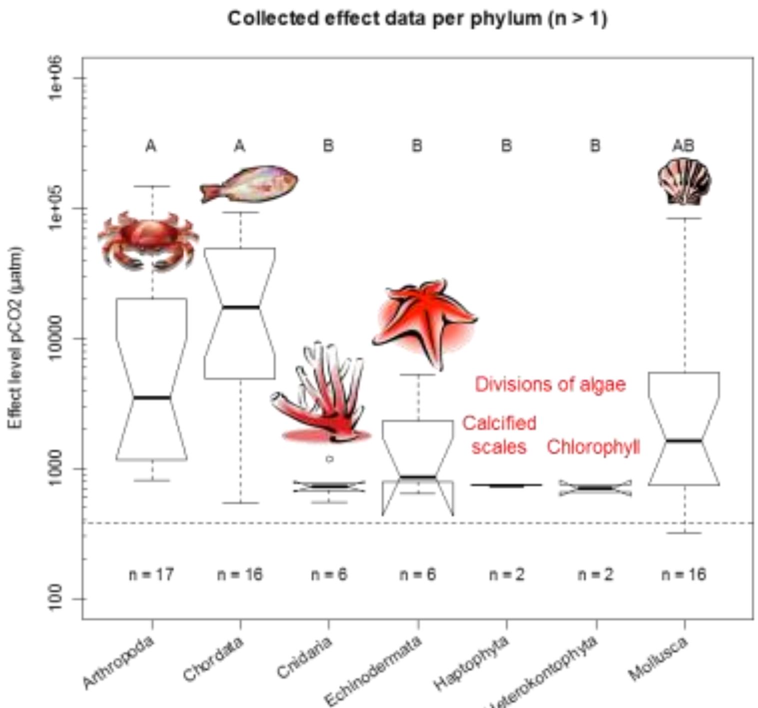
- Increased energy need to maintain homeostasis
- Shell erosion
- Different sensitivity of species (calcifiers<=>prim. producers)
- Early life stages more sensitive

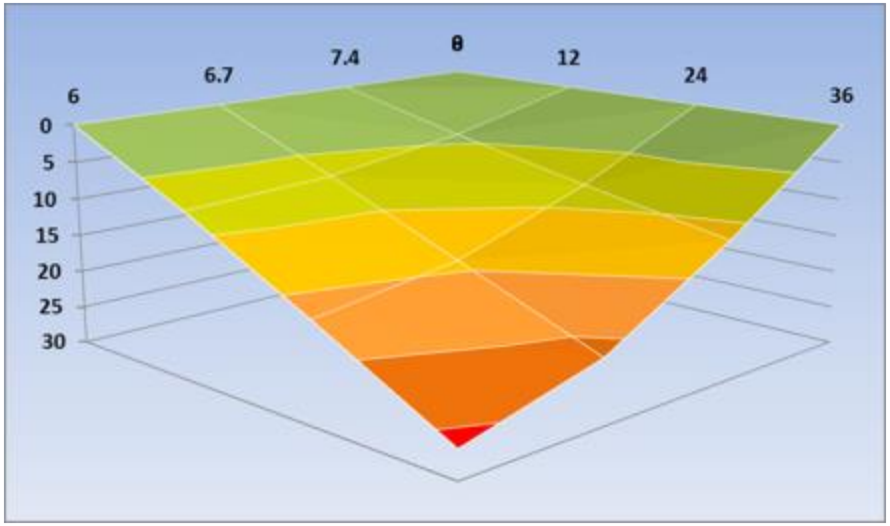


Marine response summarised (4)

Community response

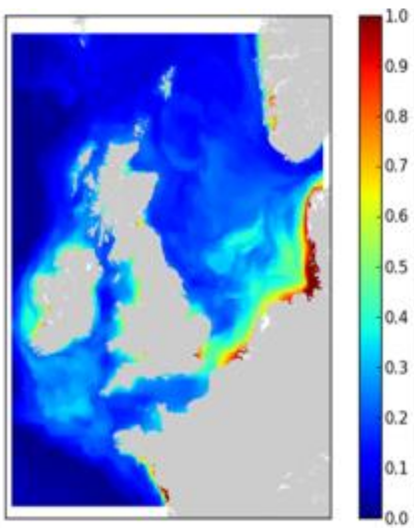
- Depends on exposure vs duration
- Benthic community shifts can be expected (10 wks at pH <7.5)
- Higher sensitivity expected at less favourable conditions

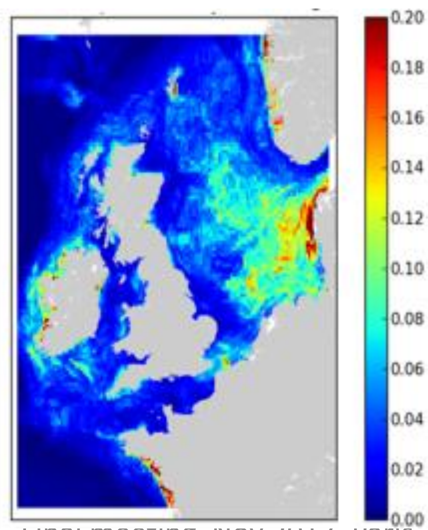




Suggestions for Site characterisation

- Year round pH measurements
- Identification of potentially sensitive species / structures / functions
- Characterise the composition of the benthic community
- Characterise the age distribution of long living bivalves



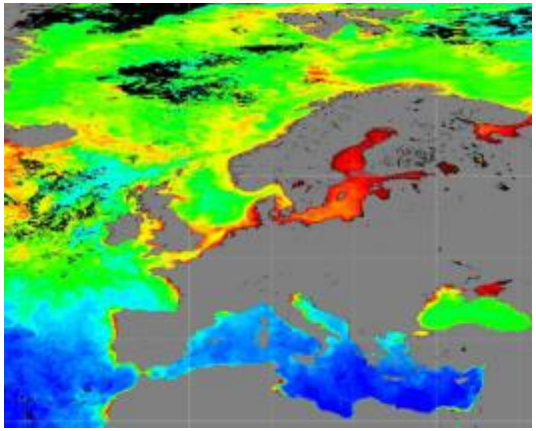


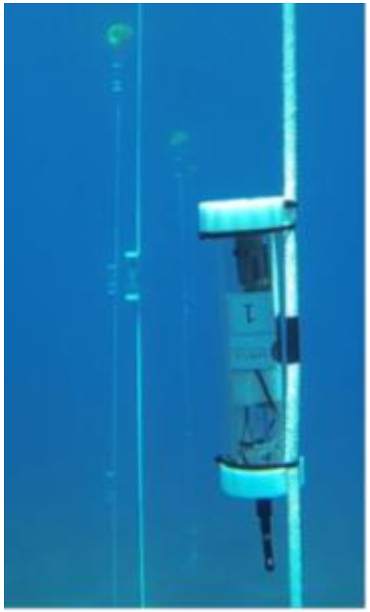
Ocean quahog (Arctica islandica)

Suggestions for monitoring (1)

Chemical/physical

- pH measurements (+ O2 and T)
- Detection of CO2 bubble streams
- Changes in chl-a/primary production in the water column?

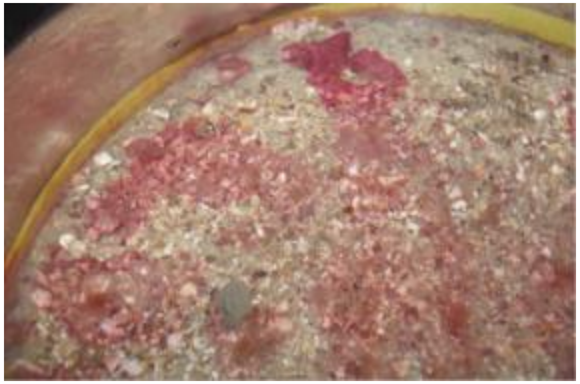




Suggestions for monitoring (2)

<u>Biological</u>

- Development of algal/cyanobacteria mats
  Reduced settlement of juvenile bivalves
- Signs of erosion on bivalve and gastropod shells
- Behavioural responses ?



Suggestions for remediation

- **Stop the leak asap**
- Prevent bottom disturbing fisheries
- Trust on nature's high recovery potential

Consequences for site selection

- Locations with limited water mixing or risk for stratification
  - Higher exposure levels
  - Reduced re-colonisation capacity
- Ecosystems substantially depended on calcifying organisms
  - Corals, shell fish beds
  - Structure and function
- Ecosystems under pressure
  - By natural stressors, e.g. low salinity, oxygen depletion,
  - By anthropogenic (pollutants) stressors (heavy metals!)

Terrestrial impacts

Methods

Our approach:

- To develop different leakage scenario and reference environment to provide context for experiment and modelling
- To conduct:
  - ➢ Studies at experimental sites in Norway and the UK
  - ➢ Lab experiments in Norway
  - ➢ Field observations in Greece
- To compare results with:
  - ➢ previous studies (e.g. Latera, Laacher See) → CO2GeoNet, CO2ReMoVe
  - ➢ Results from other projects (CO2 Field Lab, COOLTRANS)
- To provide input for modelling, experimental design and to extend scope of research

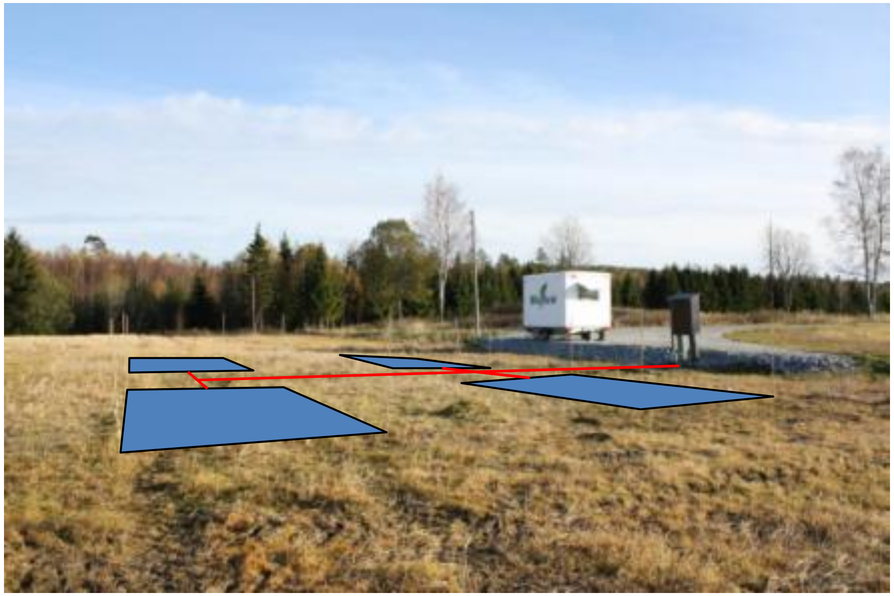
Studied sites and experiments

Grimsrud Farm, Norway

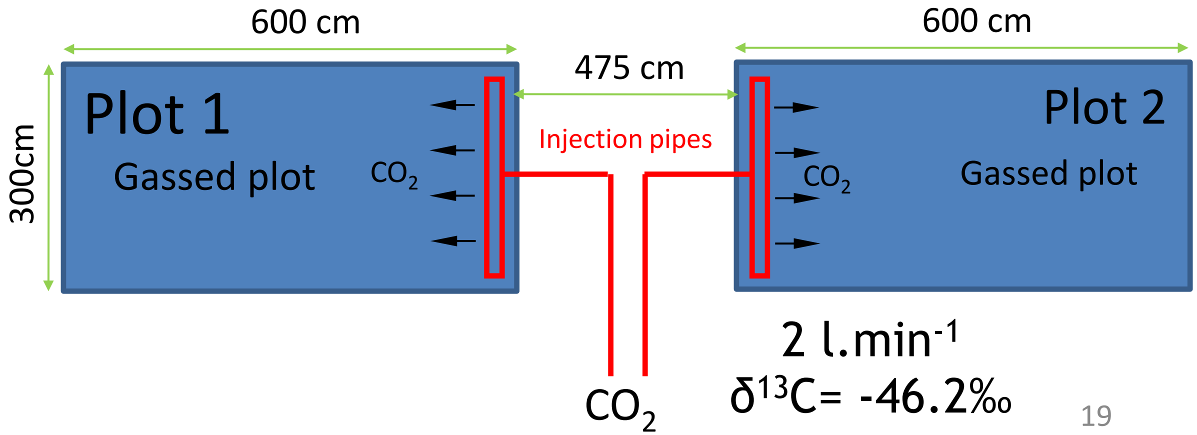
Four experimental plots (6m X 3m)

Gas injection one side at a depth of 85 cm

Idea: to create a gradient along the plots so effects of differing exposure could be assessed in crops (oats)



In 2012



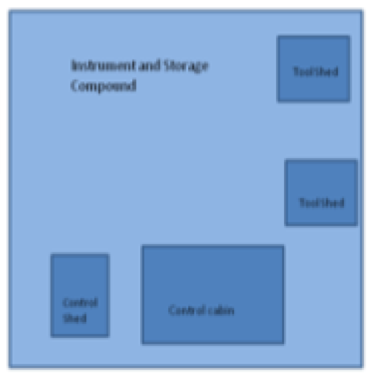
2 $l.min^{-1}$

$\delta^{13}C = -46.2‰$

ASGARD site, UK

Old plots

Pasture



New plots: crops

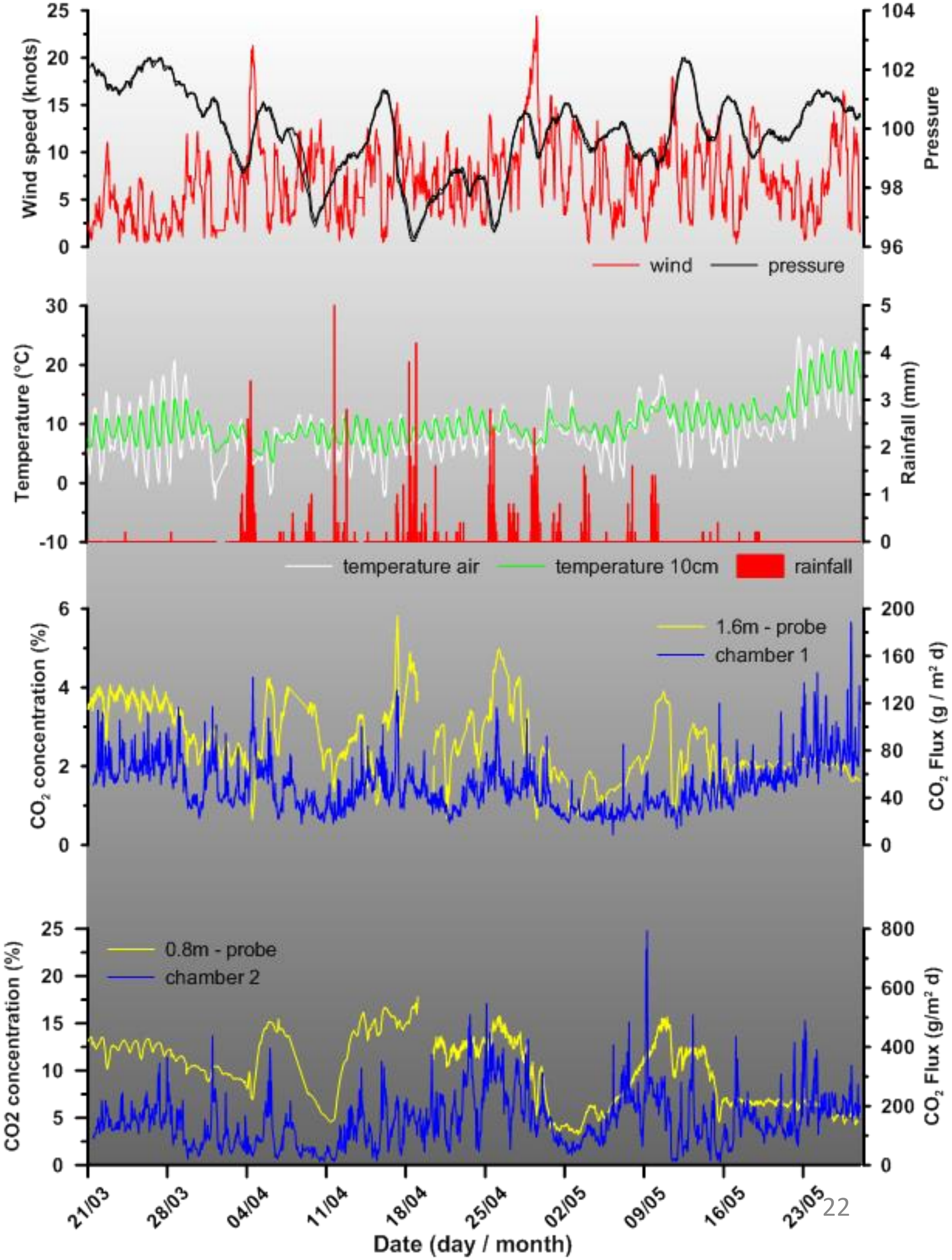
2010	Grass/Clover	Spr. Barley	Spr. Oilseed rape
2011	Grass/Clover	Wheat	Beetroot
2012	Grass/Clover	Aut. Barley	Aut. Oilseed rape

Process of CO_2 dispersion in unsaturated soil and atmosphere

ASGARD 2012

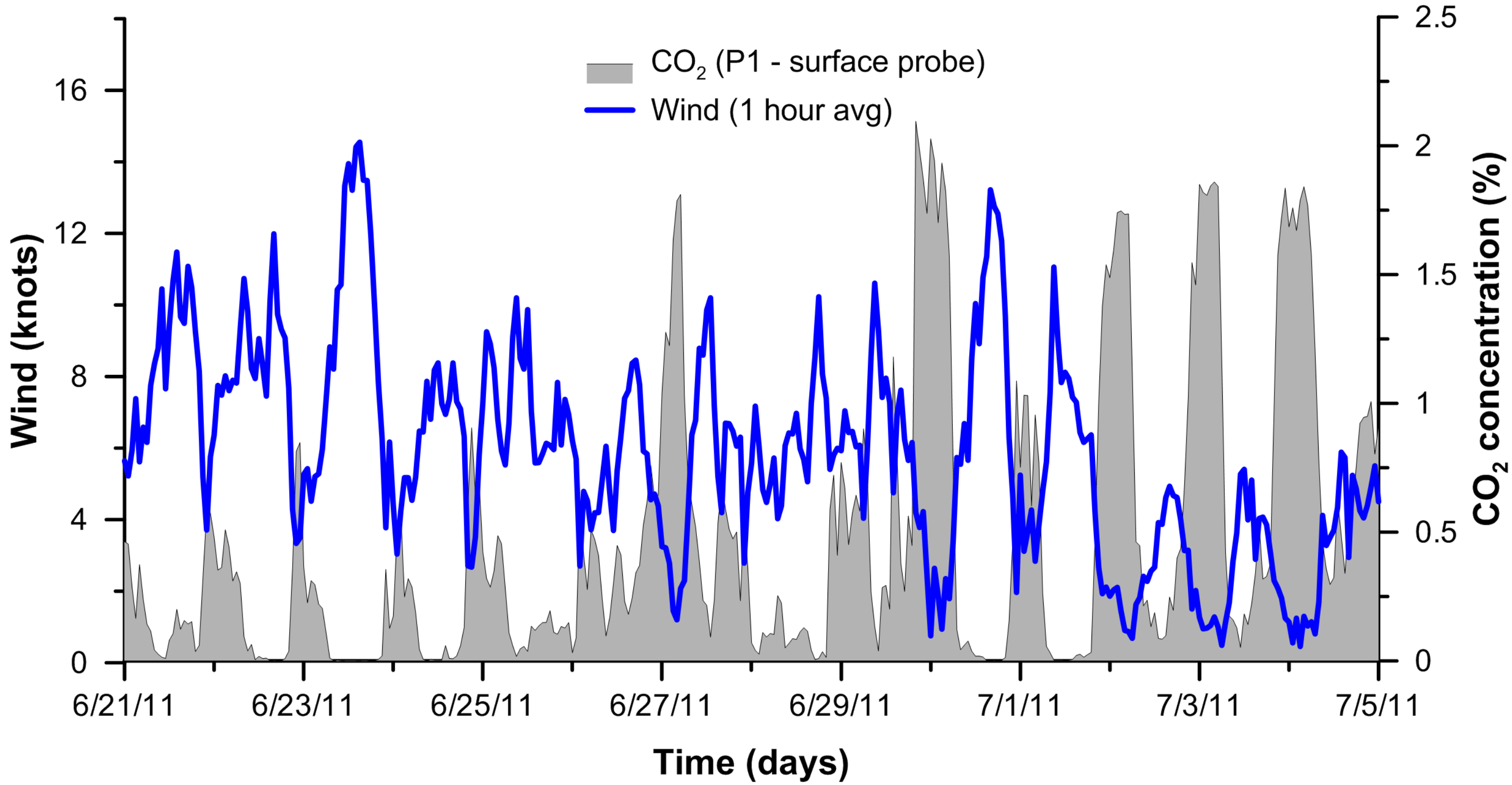
Continuous measurements:

- Meteorological parameters
- Soil gas and flux



- Close correspondence between flux and concentration
- No clear association with specific meteorological event

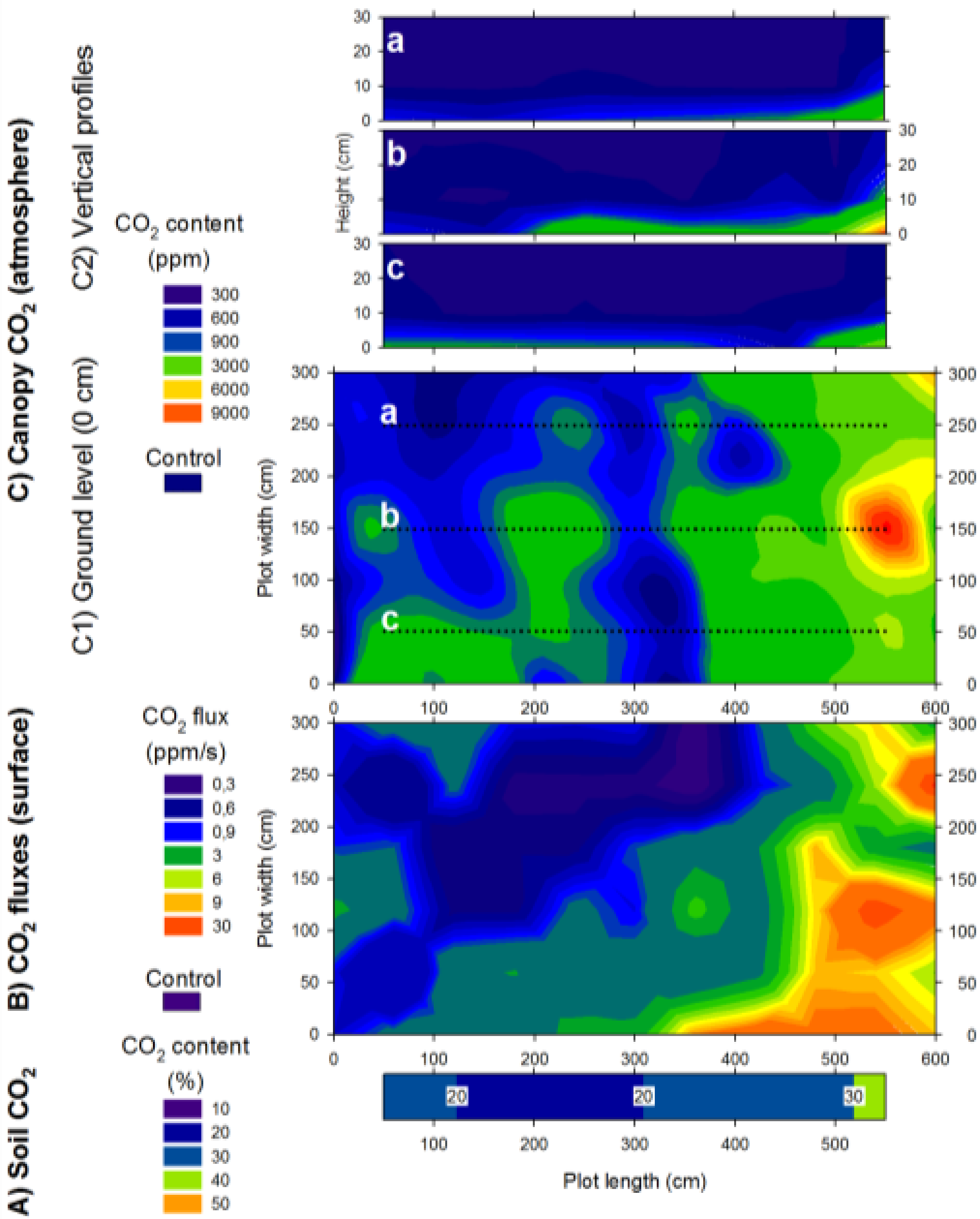
ASGARD 2011



Diurnal cycles:

- Turbulent mixing during the day
- Photosynthesis interruption at night

Leaking CO_2 within the soil-atmosphere continuum



Results

- It was possible to track the injected CO_2 in the soil-canopy-atmosphere continuum

- Leakage was localised and was diluted quickly in the atmosphere

- Isotopic labelling allow to identify 3 zones of CO_2 transfers in soil

Grimsrud Farm, Norway

Effects of CO_2 leakage on Crops

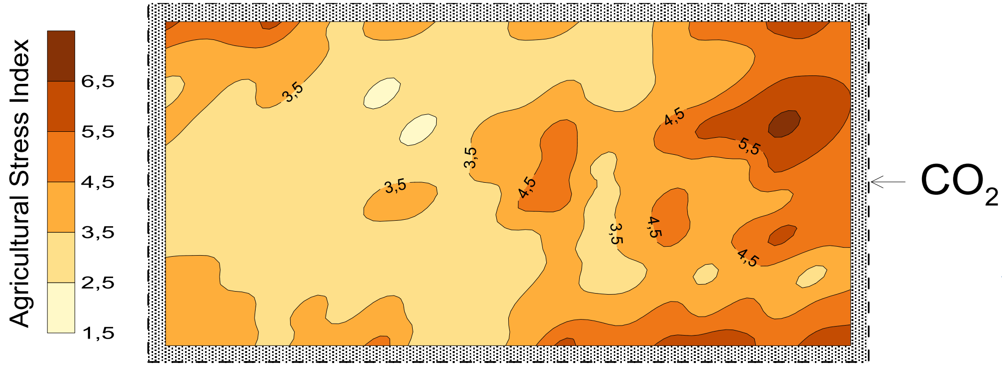
CO_2 impact on plant Health

Hyperspectral monitoring

60 x 60 cm grid sampling pattern

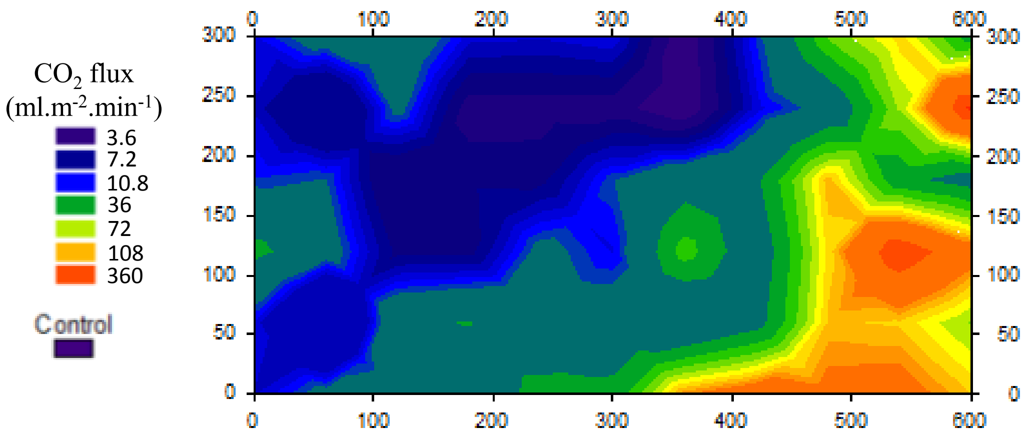
Agricultural stress index = fct (NDVI, PRI, WBI)

NDVI → Chlorophyll (Photosynthesis)
PRI →Carotenoid pigment (Light use efficiency)
WBI → Water content



- CO_2 leakage had a stress effect on the oats crop which was visible on the oats spectral signature

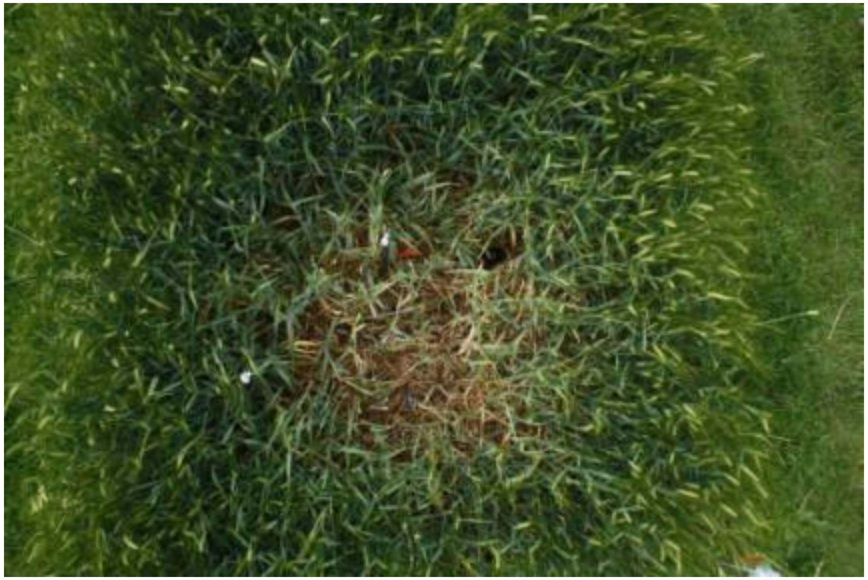
significantly correlated (P<0.001)



- Agricultural stress index → Good indicator for CO_2 stressed vegetation

Visible symptoms

ASGARD: 2012 results



Autumn sown barley

Autumn sown oil seed rape (Canola)

Stress signs visible after **two weeks** of gassing

- Yellowing of the leaves
- Bare patch in the high gas zone

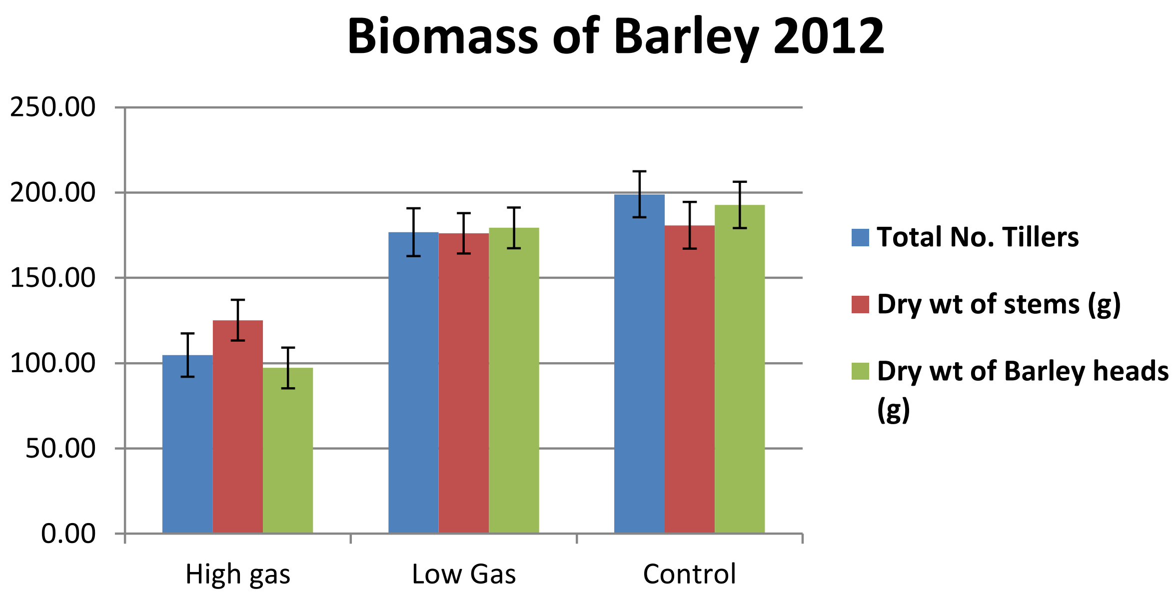
No visible symptoms

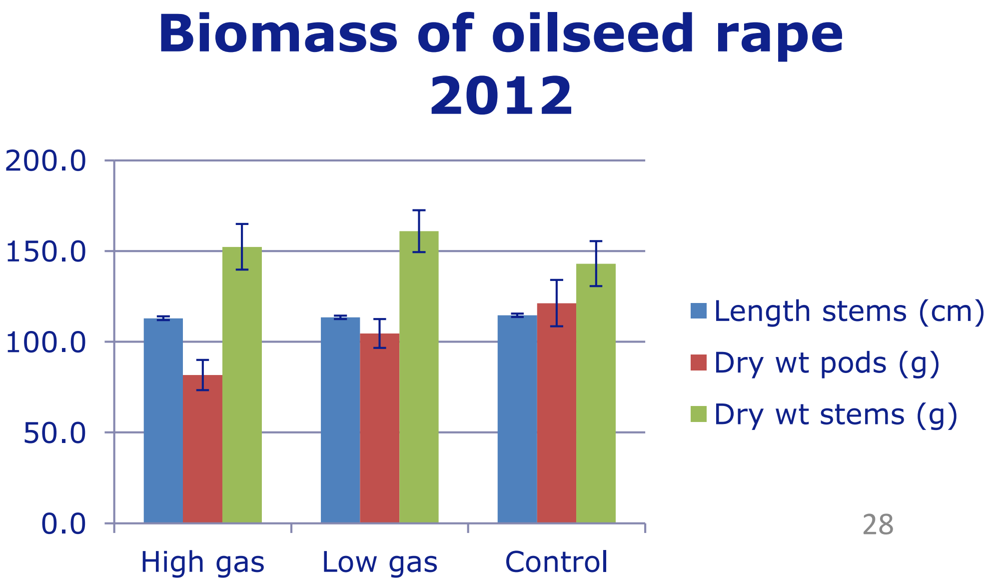
Oppose 2010 results with spring sown OSR

- Purple discoloration / 7 days of gassing

→ Difference of root system establishment

ASGARD: crop biomass 2012





ASGARD: Crop biomass summary

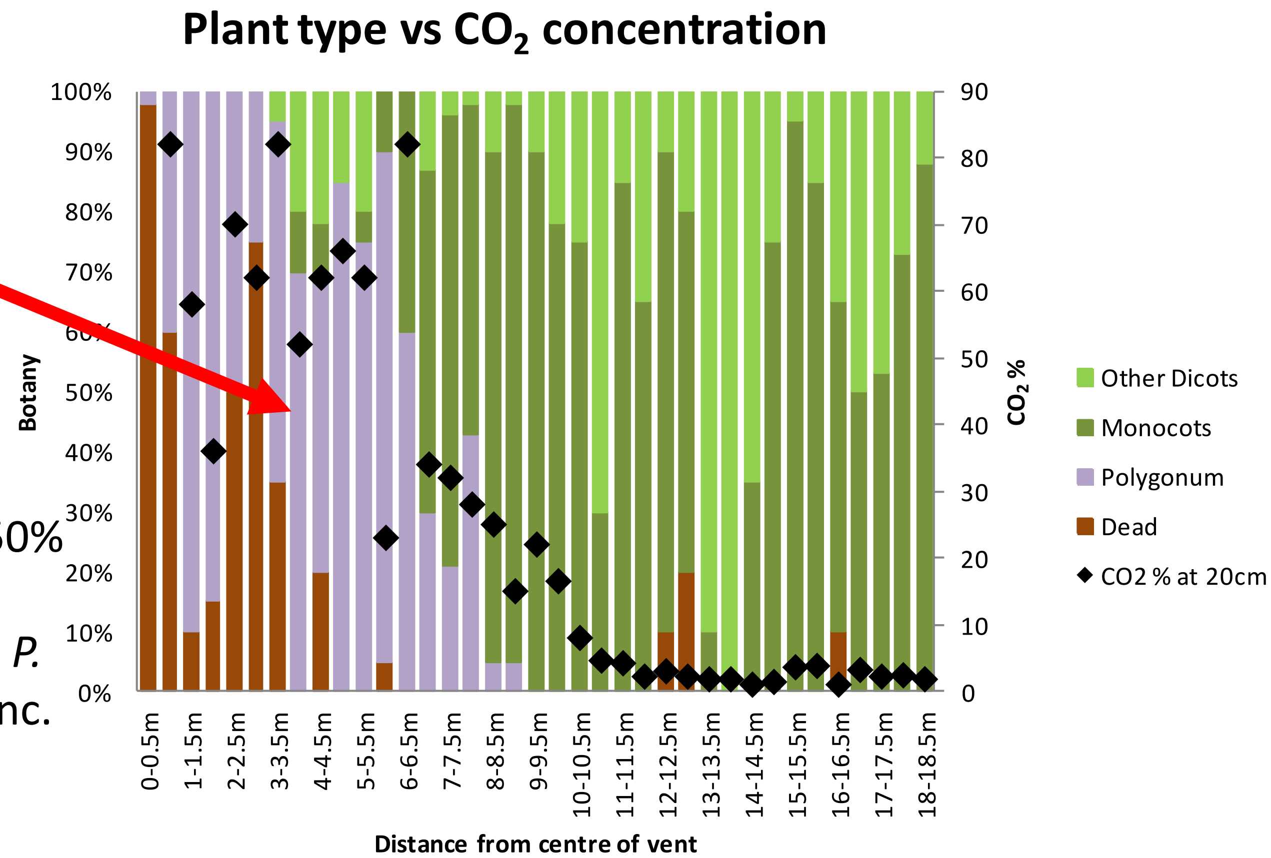
	Oilseed rape (Spring)	Oilseed rape (Autumn)	Barley (Spring)	Barley (Autumn)	Beetroot
Plant / Stem no.	↔	↔	↓	↓	↔
Height	↓	↔	↓	↓	
Stem dry weight	↓	↔	↓	↓	
Pod / Grain no.	↓	↓	↓	↓	
Leaf dry weight	↓				↓

Effects of CO_2 leakage on pastures

Florina - % plant coverage with soil gas at 20 cm (July 2012)

Polygonum aviculare

- *P. aviculare* (dicot) indicator plant above ~50% CO_2 at 20 cm.
- Grasses (monocots) and *P. aviculare* where CO_2 conc. is 10-50% at 20 cm).
- CO_2 conc. below 10% balance both monocots and dicots.



Summary of botanical results

- Below 10% CO_2 conc at 20 cm – subtle changes.
- Above 10% CO_2 conc at 20 cm appears to be the threshold for observing changes in plant coverage.
- Between 10 to 50% CO_2 conc monocotyledenous (grasses) plants dominate. Fertilisation/competition effect?
- Above 50% - rapid decrease in plant coverage.
- Changes can be rapid (days).
- Observed in pristine and natural sites. Not related to climate.
- Raised CO_2 concentrations may be of benefit to cereal crops.

However

- 2 *Polygonum* spp (dicotyledenous) plants act as bioindicators (Laacher See and Florina) of high CO_2 concs (above ~50%).
- Genus often located in compacted ground, waste-ground, roadsides etc. Long viability.
- A new biological tool?

Conclusions – CO_2 impacts on Pasture

CO_2 concentration	Plant coverage	Microbiology
Below 10%	Little change.	None observed.
15-20%	Grass coverage increasing.	
Above 20%	Grasses predominant. Indicator plants appearing (dicots!).	Increase in microbial activity.
20-50%		Microbial community changes in natural sites.
Above 50%	Decreasing vegetation. Bare patches.	Acidophilic, anaerobic communities (methane and SRB).

- **Not climate specific.**
- **Unknown impacts on soil fertility.**
- **Microbiological community changes not seen in pristine sites.**

Overall conclusions for terrestrial impacts

- Impacts spatially limited - small effect on overall yield with implications for monitoring
- Fertilisation effects may counteract the impact
- Effects are due to soil gas accumulation rather than atmospheric [CO_2] (rapid dispersion in atmosphere)
- Impact mostly caused by high [CO_2], but is also caused by the low soil [O_2] resulting from replacement by CO_2
- Impact only above ~10% CO_2 at 20 cm
- Effects rapid (1-4 weeks), recovery and impact on long-term fertility less clear

Overall conclusions for terrestrial impacts

- Different species sensitivity (better bioindicators or indicator species)
- Plant development stage and timing of exposure important
- Effects blurred by seasonal/annual factors
- Effects can be used for monitoring

  (limitations → effect could be seasonal and not CO_2-specific)
- Impacts appear to be manageable & small compared with other climatic/meteorological factors or pests

Conclusions and recommendations

Conclusions

- Leakage is of low probability if site selection, characterisation and storage project design are undertaken correctly.
- Our research (& others) indicates that there are no reasons why storage could not take place in any of the environments that have been studied.
- Potential impacts will be further reduced by careful site selection and monitoring.

Conclusions

- Current evidence would suggest that if leaks were to occur they would tend to be localised.
- Impacts from CO_2 leakage are expected to be relatively small compared to impacts caused by other stressors.

- The scale of the likely impacts means that they are considered manageable both by the ecosystem and by relevant stakeholders (operators and regulators).

Conclusions

- Onshore:
  - For some environments certain species may indicate the scale of an impact and the efficacy of any remediation.
  - Monitoring technologies have been developed and tested that allow the impacts of CO_2 in terrestrial environments to be assessed.
- Offshore
  - Natural recovery in dynamic marine systems is expected to be rapid i.e. within one ‘growing cycle’.
  - The timing and duration of the exposure will influence the scale of the impact.

Conclusions

- Leaks may have a cumulative, additional impact on ecosystems already stressed by other factors.
- Marginal systems might have larger negative responses than systems that are not as stressed.
- In terrestrial systems, replanting of crops should be possible in affected areas once leakage has ceased, as no long term effects are expected.
  - Longer term recovery of pasture land has not been evaluated.

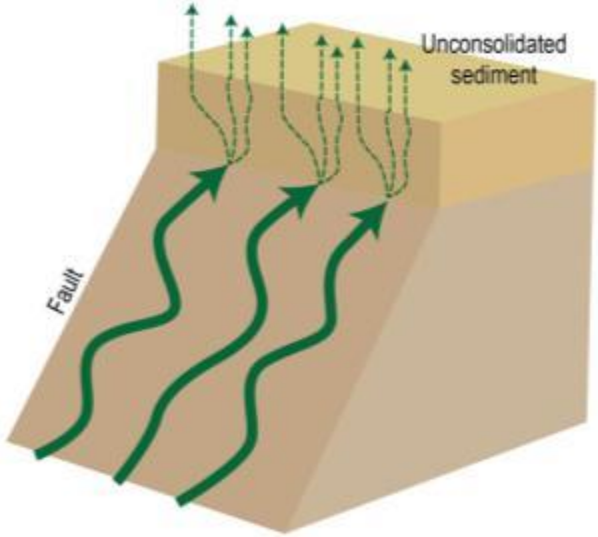
research into impacts & safety in CO_2 storage

Recommendations

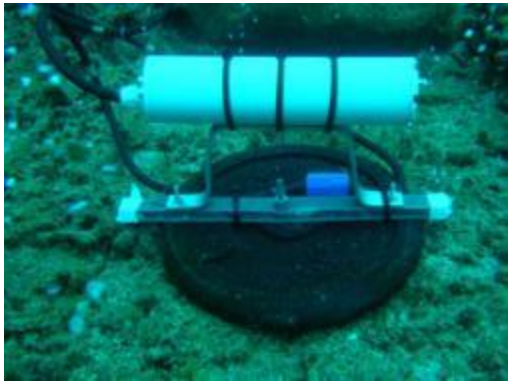
- Potential impacts that might arise from a leak must be evaluated.
- Evaluation of risks of leakage and potential impacts should be undertaken at each site.
- Designated reference sites, both onshore and offshore, could provide ongoing baseline data against which storage sites can be compared.
    - Sites managed via joint industry initiatives may enable a smaller number of reference sites to be used by several storage projects.

Recommendations

c. Diffuse emission at surface caused by one or more linear leakage paths at depth, but dispersion of CO_2 in shallow unconsolidated sediments



- Monitoring a number of parameters allows separation of natural variations from leakage
  - nitrogen, oxygen and isotopic contents of soil gas
  - temperature and oxygen in marine systems
- Baselines are fundamental to demonstrating site performance.
  - Account for full range of natural variation, which may occur over more than one year.
  - Changes due to other external factors should also be taken into account.
- Affected areas will be small in size and will occur in very localised areas (up to a few 10s m^2)
  - Groups of these seeps might occur along fault zones.
  - Monitoring must be able to detect leaks at these scales in large areas.



Thank you