Techniques for Spatiotemporal investigations of rhizosphere processes

Ketil Koop-Jakobsen, Alfred-Wegener-Institute - Wadden Sea station, Germany

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
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Agenda:

- **Why aquatic interfaces (plant-sediment, sediment-water) are important in aquatic system?**

- **How to investigate plant – sediment interactions in aquatic systems - a review of methods**

Case study 1: *Plant-mediated sediment oxygenation*
… *in Elymus athericus*

Ketil Koop-Jakobsen, PhD

BIOGEOCHEMIST

Salt marsh specialist

Primary Research Topics:

- **Nutrient Cycling in Salt Marsh rhizosphere**
- **O_2, pH and CO_2 Dynamics in Rhizospheres**
- **Carbon Sequestration in Salt Marshes and sea grasses**

Fieldwork 2018, Plum Island Estuary, MA, USA

Ketil Koop-Jakobsen, PhD

BIOGEOCHEMIST

Salt marsh specialist

Primary Research Areas:

Aquatic systems: Wetlands, Ponds and Coasts

- **Wadden Sea**
- **US Eastcoast**

Fieldwork 2018, Plum Island Estuary, MA, USA

Ketil Koop-Jakobsen, PhD

BIOGEOCHEMIST

Salt marsh specialist

Overarching topic:

Spatiotemporal dynamics of rhizosphere processes

Fieldwork 2018, Plum Island Estuary, MA, USA

Importance of interfaces in aquatic ecosystems

Plant-mediated sediment oxygenation release oxygen into the rhizosphere

Elymus athericus - Wadden sea marshes, Germany

Koop-Jakobsen and Mueller (2021) Frontiers in plant science

Photo © Koop-Jakobsen

Wetland plant rhizosphere

Importance of aquatic interfaces

143 rhizomes with aerenchyma in cross section

~6000 rhizomes with aerenchyma per m^{-2} at -5 cm depth

Morphology of Spartina rhizospheres – structure

20cm

Wetland rhizospheres can develop a very dense biomass

Consequently, there is large area with plant-sediment interfaces

Some of these areas facilitate exchange of chemical compounds between the sediment and the plant.

Other areas have barriers preventing interaction between the sediment and the plant

Plant-mediated sediment oxygenation – How does it work?

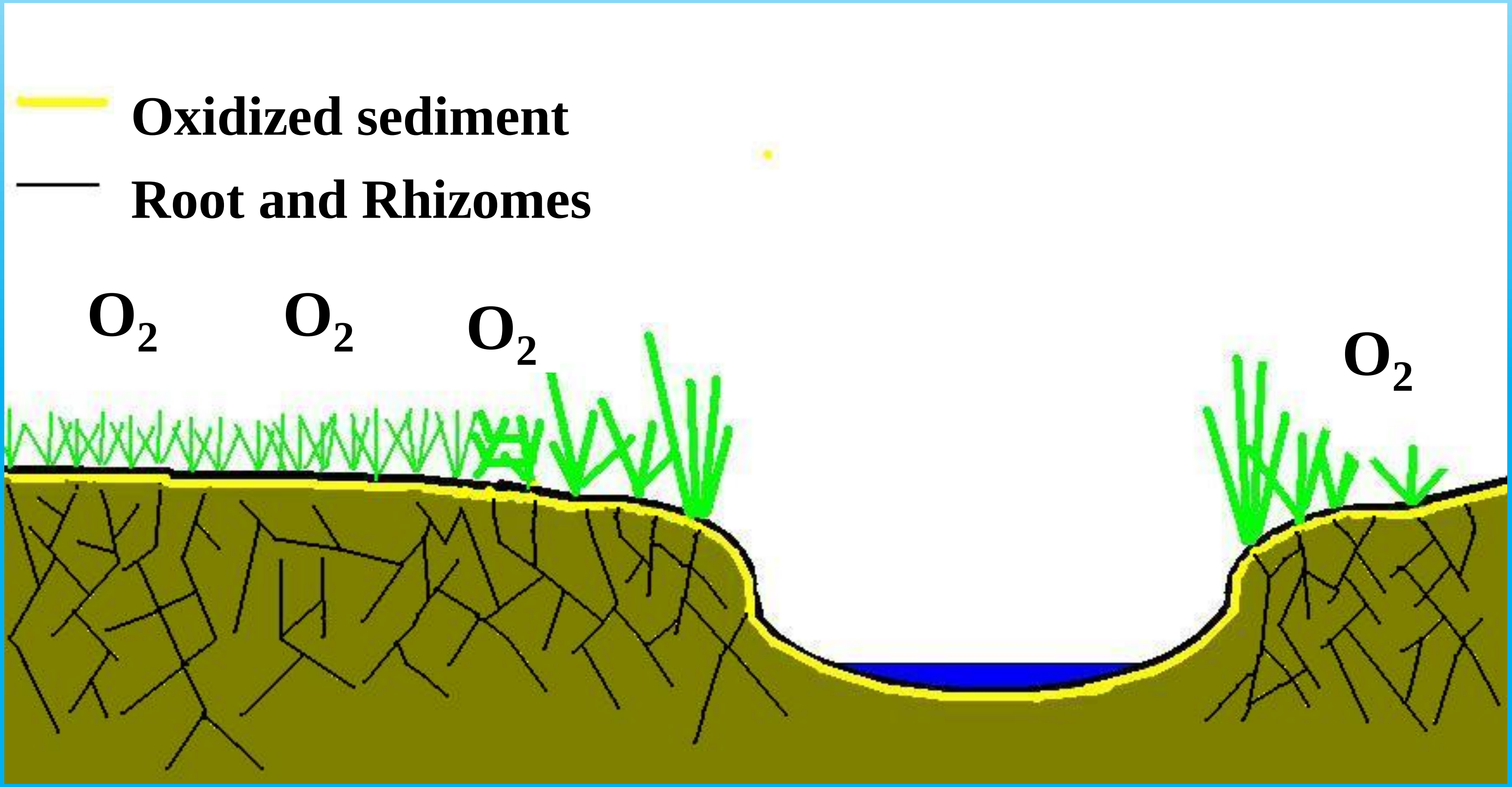
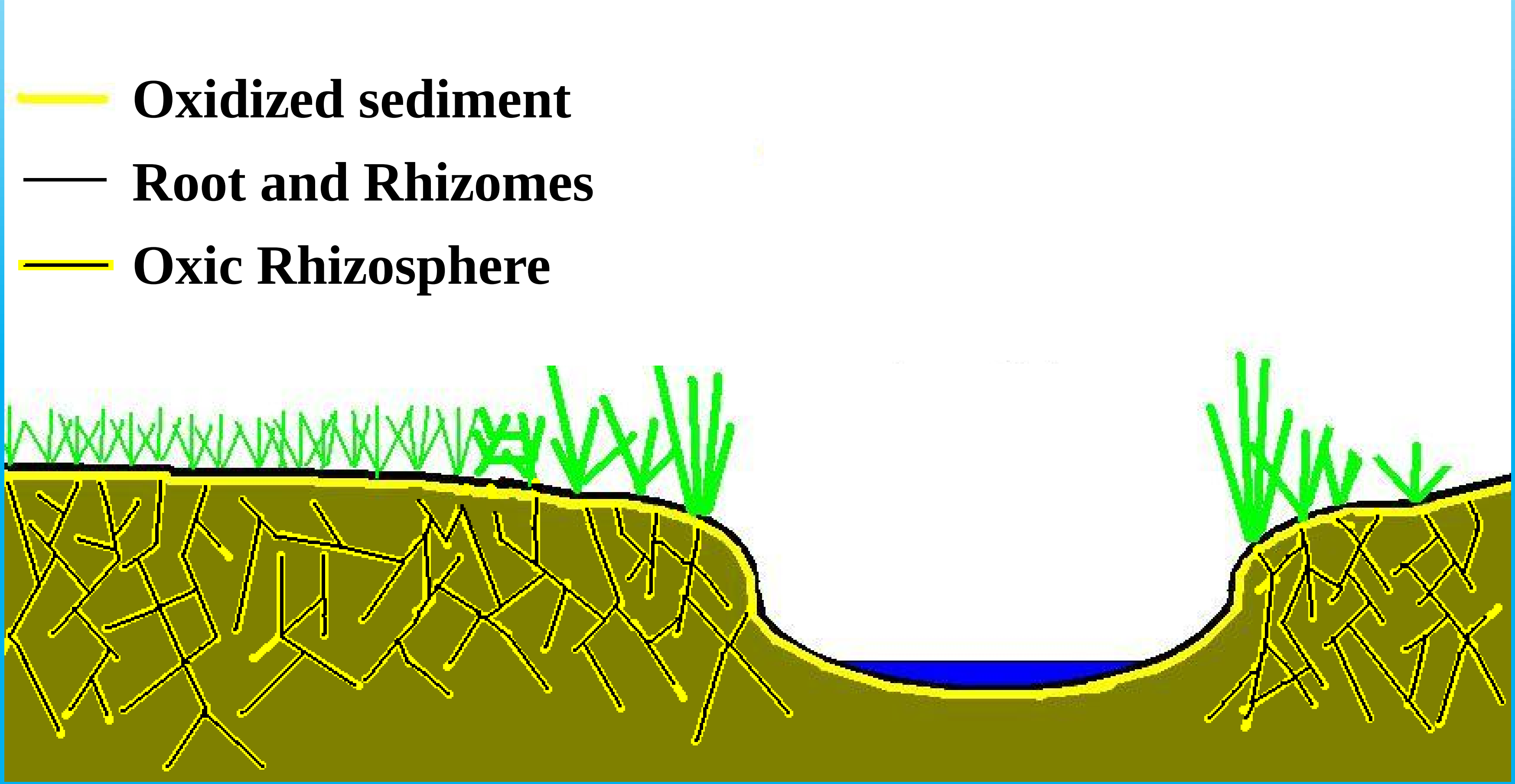


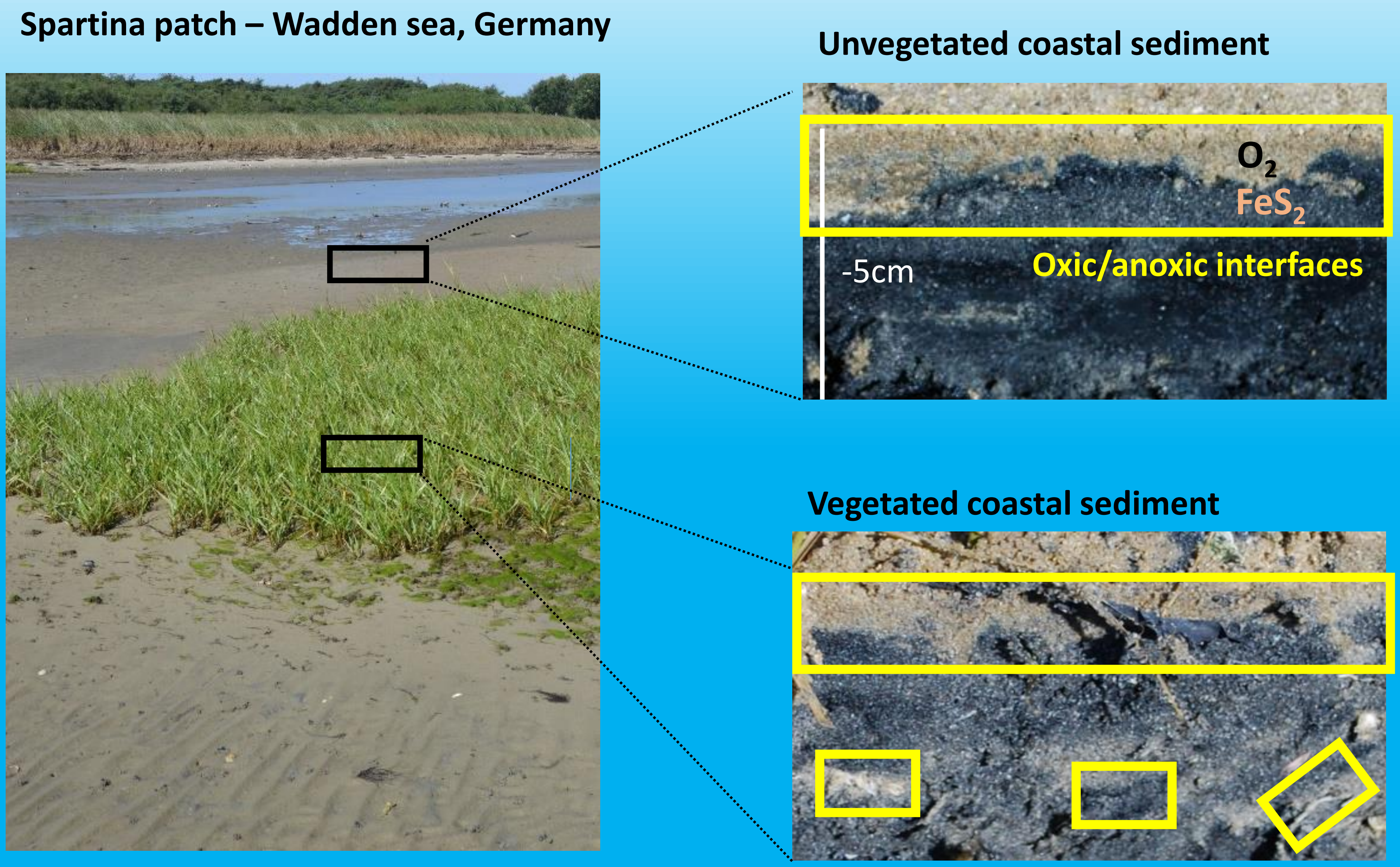
Fig © Koop-Jakobsen

Plant-mediated sediment oxygenation – How does it work?



Flg © Koop-Jakobsen

Spatiotemporal heterogeneity controls important ecosystem functions



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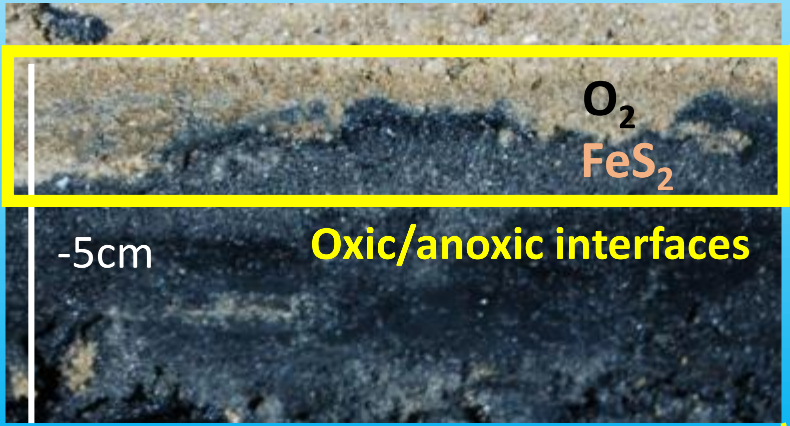
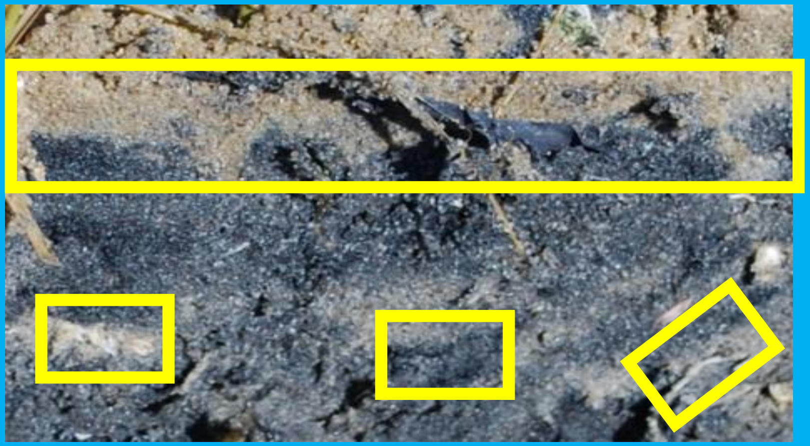
Spatiotemporal heterogeneity control important ecosystem functions

Importance of aquatic interfaces

Unvegetated coastal sediment



Vegetated coastal sediment



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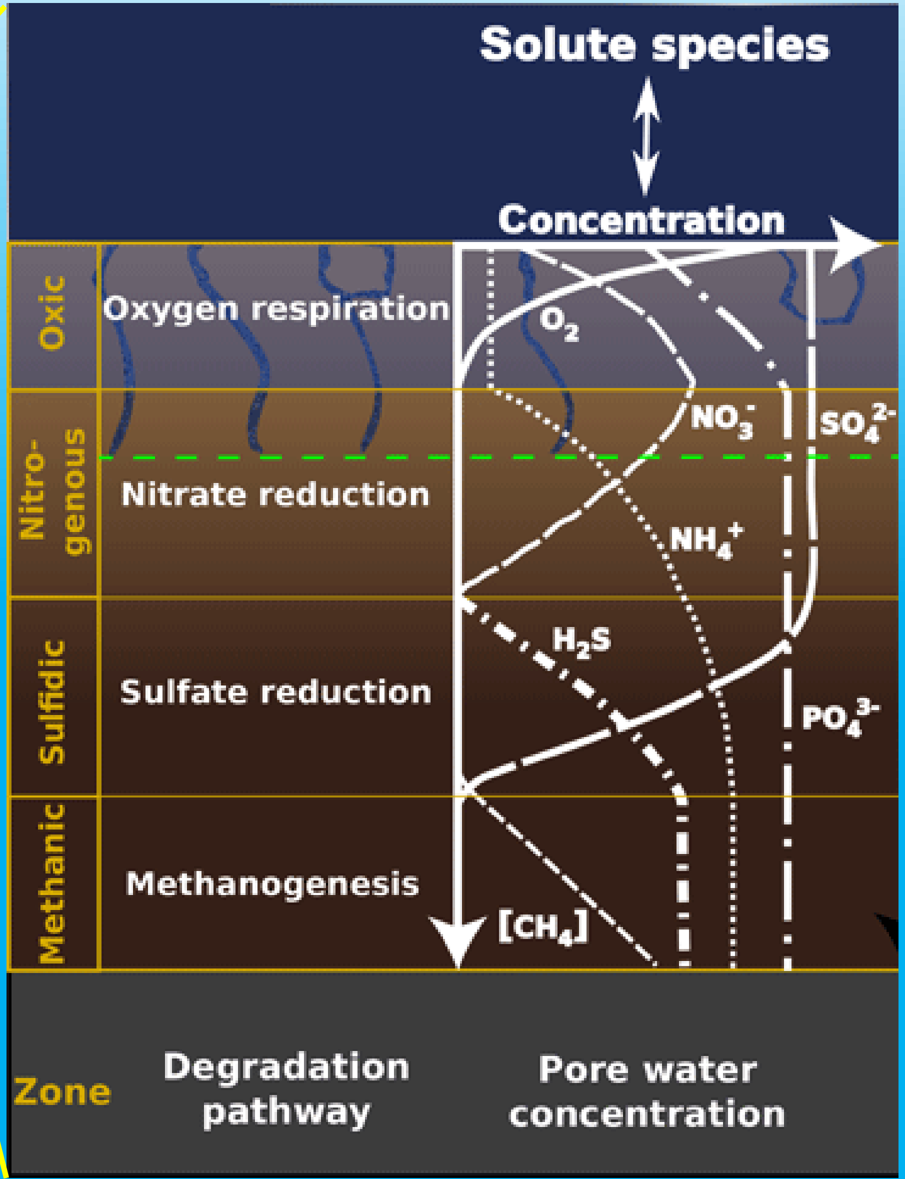
Diagenetic processes



Hülse et al Geosci. Model Dev., 11, 2649–2689, 2018

Ecosystem functions

- Green house gas release
- Carbon turnover and sequestration
- Nutrient retention/turnover

Plant mediated sediment oxygenation

– Plant benefits ?

It is a flood adaptive trait …

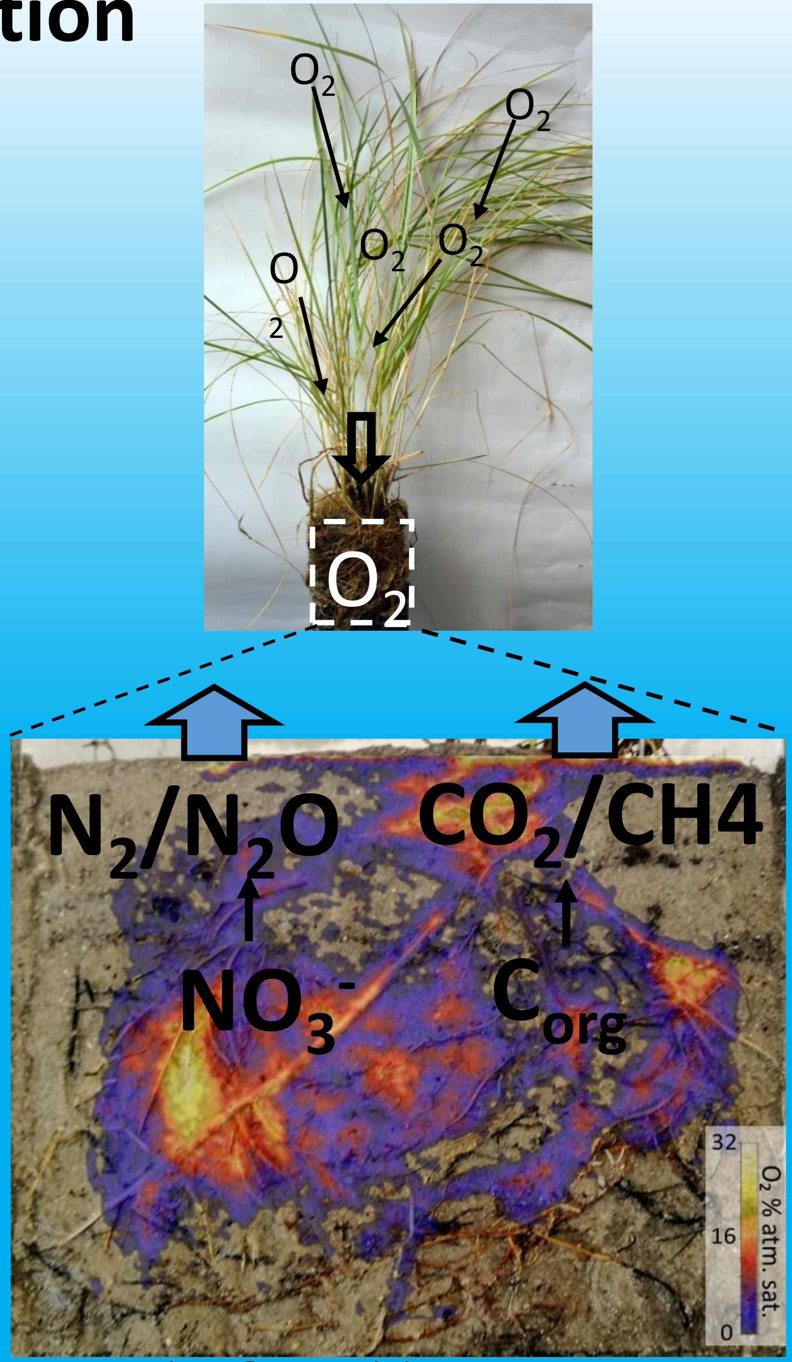
… Facilitating oxygen for aerob respiration in roots
… Increasing nutrient uptake via roots
… Reduce impact of phytotoxin in the rhizosphere

This traits …

… Enable wetland plant if live in waterlogged sediment
… Makes wetland plants competitive under waterlogged conditions

–Impact on Ecosystem services ?

1)… Increase aerob degradation of organics matter affect carbon sequestration
2)… Increase nutrient retention/nitrogen removal
3)… Control GHG release



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Importance of aquatic interfaces

How to measure plant – sediment interactions - a review of methods

Methods for studying root-sediment interactions

- **Microsensors**

Space: 1D-profile
Time: Continuous measures

- **Fiber optodes**

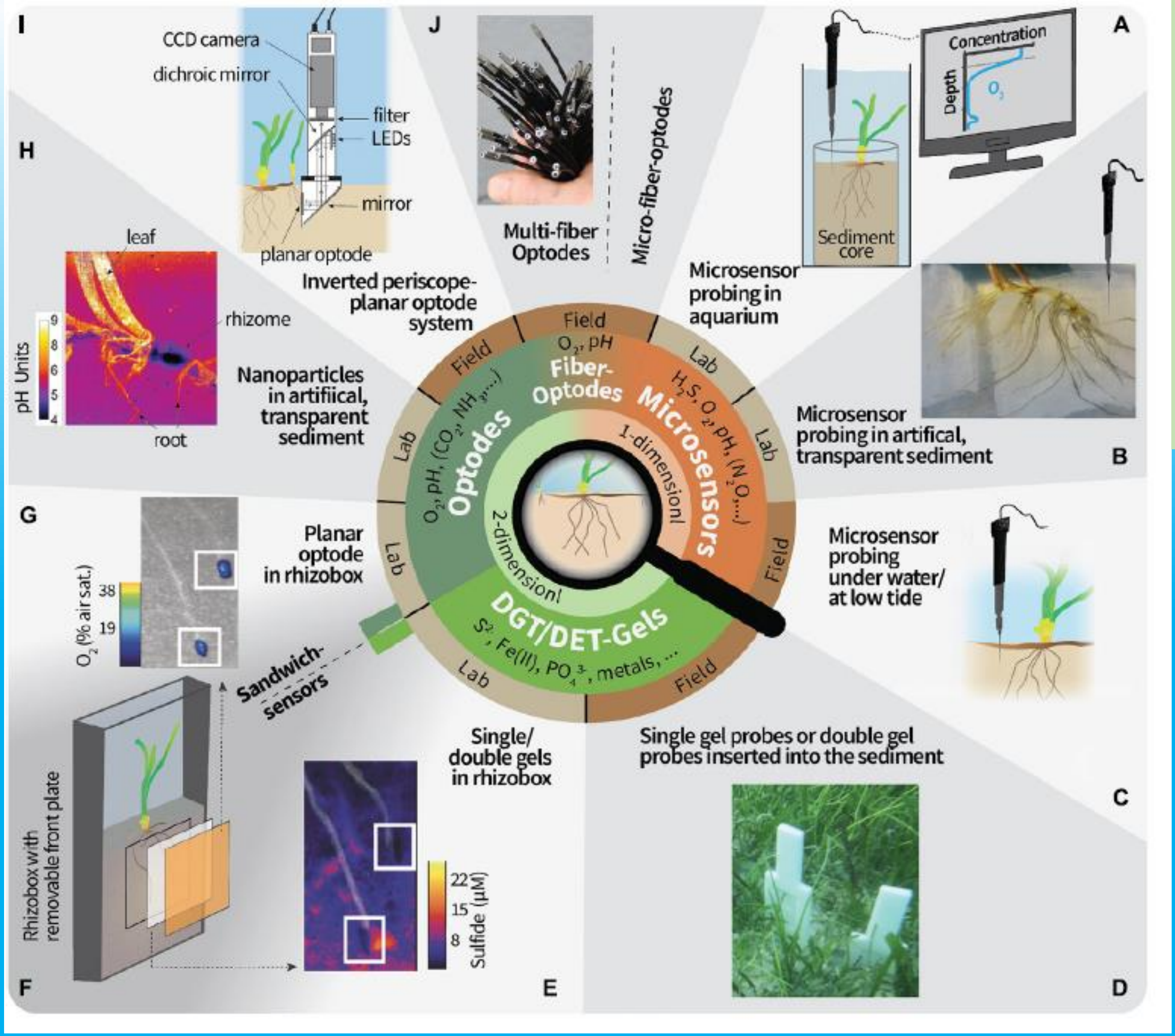
Space: Point measures
Time: Continuous measures

- **DGT DET-Gels**

Space: 2D images
Time: point measurements

- **Planar optodes**

Space: 2D images
Time: Continuous measures



Review of methods

Scholz VV et al (2021) Resolving Chemical Gradients Around Seagrass Roots—A Review of Available Methods. Front. Mar. Sci. 8:771382. doi: 10.3389/fmars.2021.771382

- **Microsensors**

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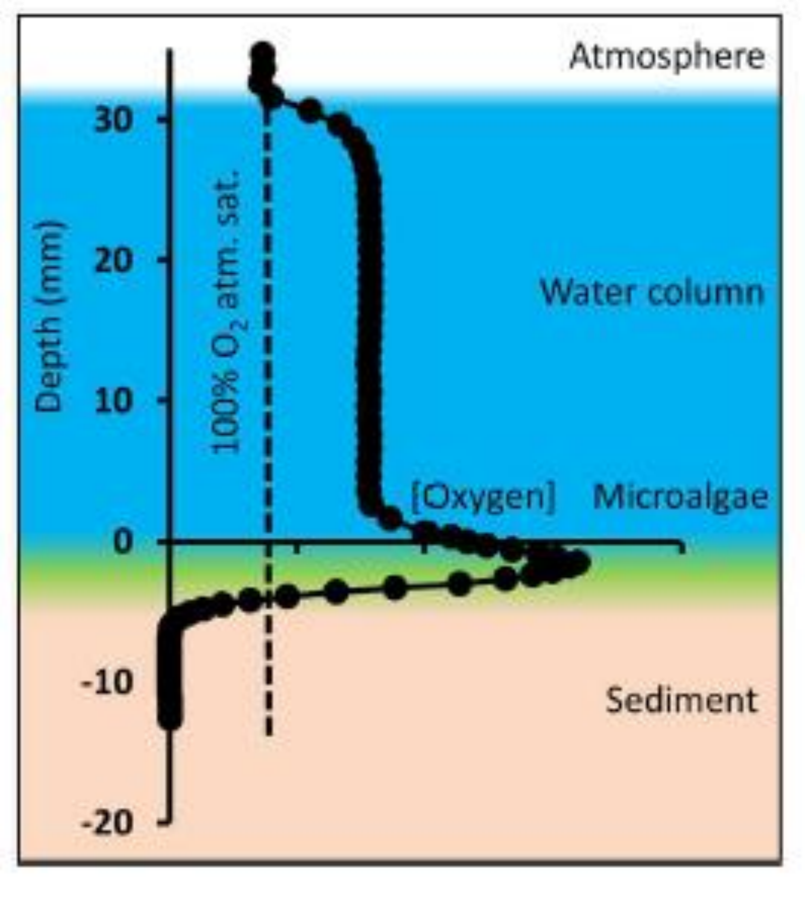
Time: point measurements

1D-profiling



Koop-Jakobsen K and Gutbrod MS (2019) Front. Environ. Sci. 7:137. doi: 10.3389/fenvs.2019.00137

Review of methods

2 Kind of measuring principles

- **Microsensors**

Space: 1D-profile
Time: Continuous measures

- **Fiber optodes**

Space: Point measures
Time: Continuous measures

- **DGT DET-Gels**

Space: 2D images
Time: point measurements

- **Planar optodes**

Space: 2D images
Time: Continuous measures

Micro-electrodes:

Analytes: O_2, H_2, H_2S, N_2O, NO, Redox. (pH and temp)

Signal: Electric current (for most

Material: glass (fragile)

Tip-size: >10µm

Noteworthy: consumes analyte

Micro-Optodes

Analytes: O_2, pH and pCO_2

Signal: Light

Material: plastic optical fibers (less fragile)

Tip-size: >50µm

Noteworthy: consumes analyte

- **Microsensors**

Space: 1D-profile
Time: Continuous measures

- **Fiber optodes**

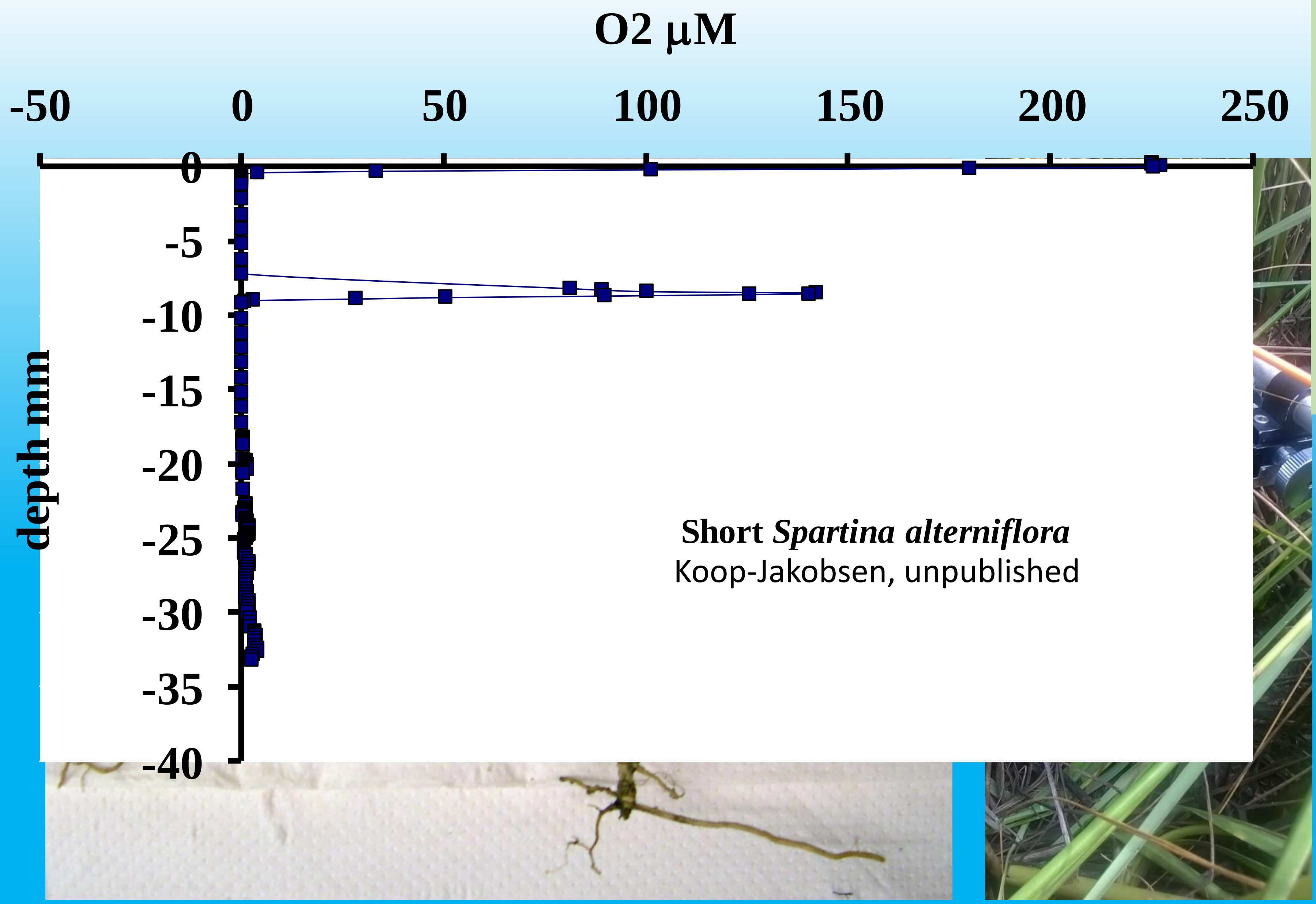
Space: Point measures
Time: Continuous measures

- **DGT DET-Gels**

Space: 2D images
Time: point measurements

- **Planar optodes**

Space: 2D images
Time: Continuous measures



Rhizosphere O_2-dynamics studied with Multi Fiber Optode

- **Microsensors**
  Space: 1D-profile
  Time: Continuous measures

- **Fiber optodes**
  Space: Point measures
  Time: Continuous measures

- **DGT DET-Gels**
  Space: 2D images
  Time: point measurements

- **Planar optodes**
  Space: 2D images
  Time: Continuous measures

Commercially available system – 10 optodes

Photo © PreSens

Diffusive Gradients in Thin-films (DGT) or Diffusive Equilibration in Thin-Films (DET)

- Microsensors

Space: 1D-profile
Time: Continuous measures

- Fiber optodes

Space: Point measures
Time: Continuous measures

- **DGT DET-Gels**

Space: 2D images
Time: point measurements

- Planar optodes

Space: 2D images
Time: Continuous measures

2D images of porewater dissolved ions and gasses:
inorganic nutrient (e.g., P, Fe, Mn)
contaminant (e.g., As, Cd, Pb)
Gases (H2S)

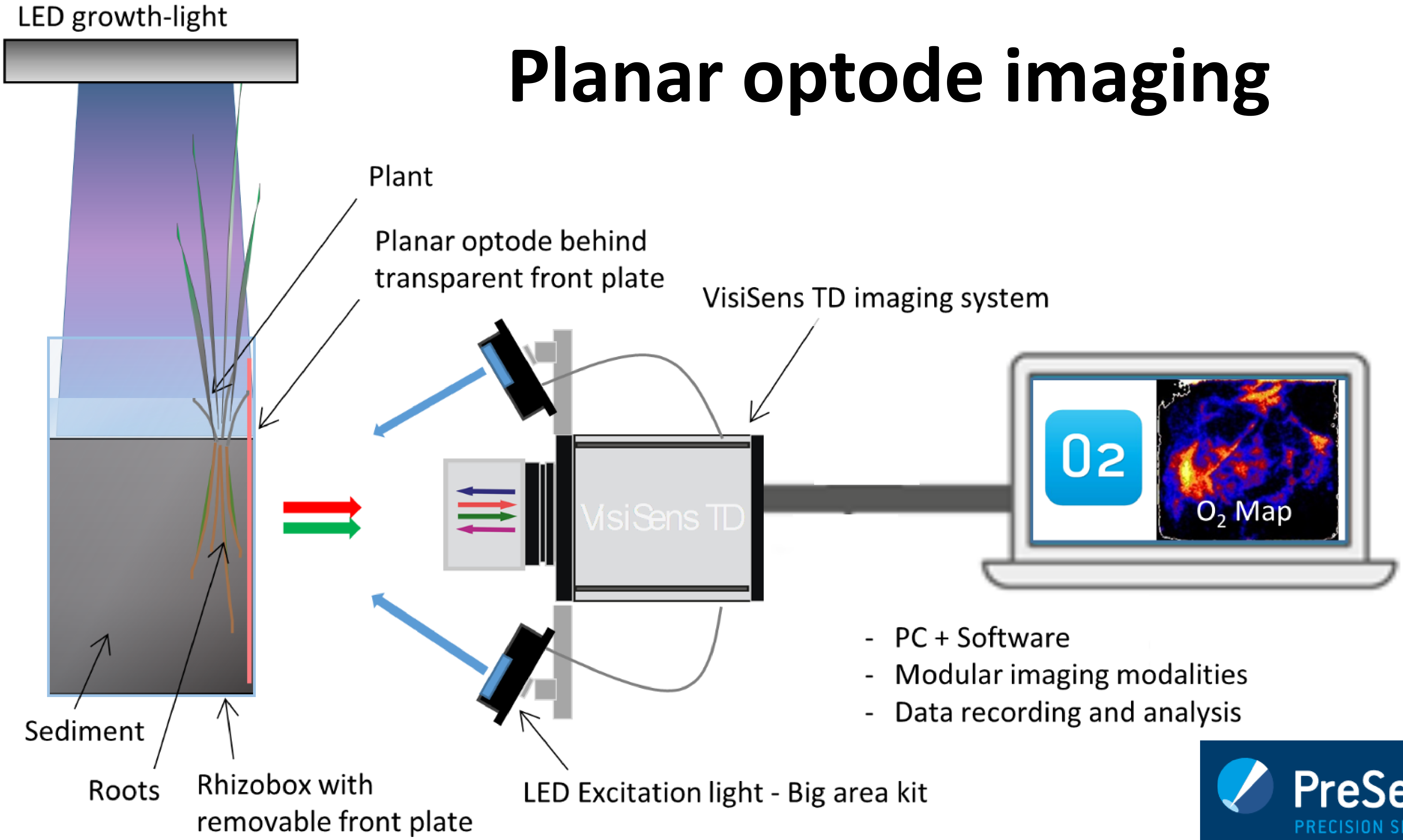
DGT gel: Analyte diffuses into the get and get bound in the gel

DET gel: Analyte diffuses into the get and reach an equilibrium with the pore water

Spatial distribution analysed by as laser ablation inductively coupled mass spectrometer (LA-ICP-MS).
Resolution: 100 µm

Planar optode investigations

Planar optode imaging



- PC + Software
- Modular imaging modalities
- Data recording and analysis

PreSens
PRECISION SENSING

Prepairing rhizobox

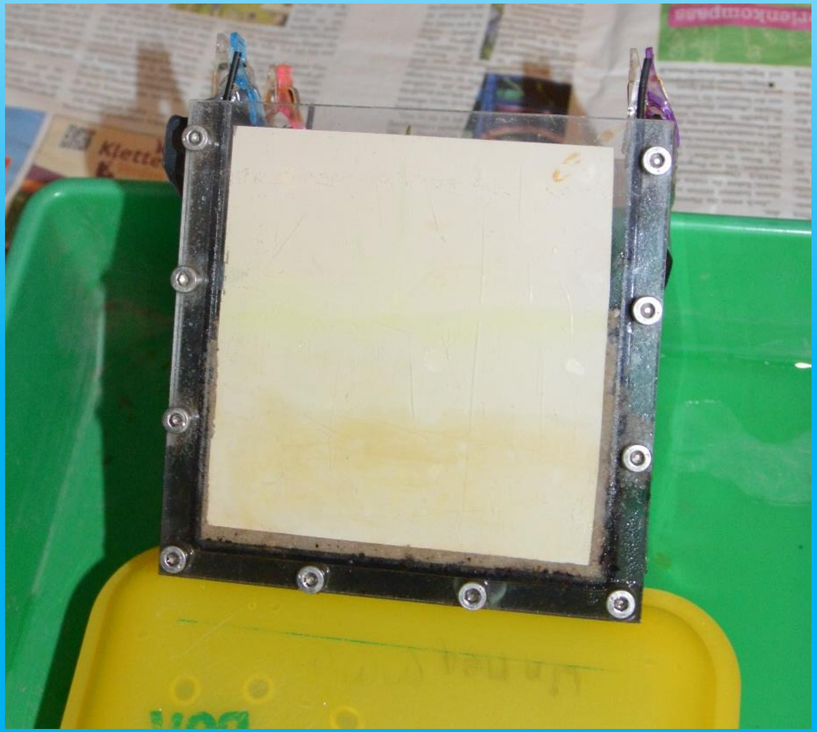
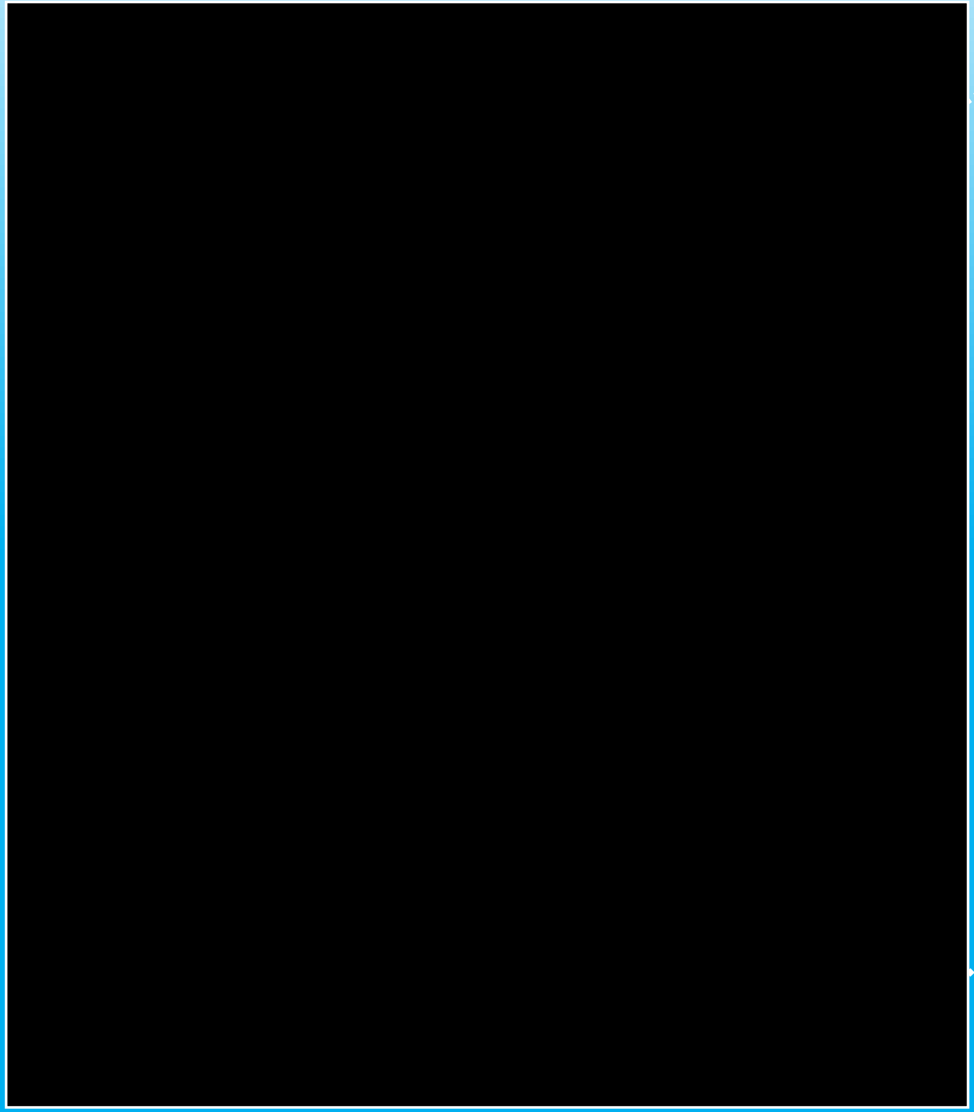


Photo © Koop-Jakobsen

Imaging oxygen distribution



Ref: Lenzewski, Koop-Jakobsen et al, New phytologist 2018

Planar optode imaging is a quantitative technology
- Each pixel in the optode image is assigned an $[O_2]$-value

Visualization of the spatial oxygen distribution as 2D image

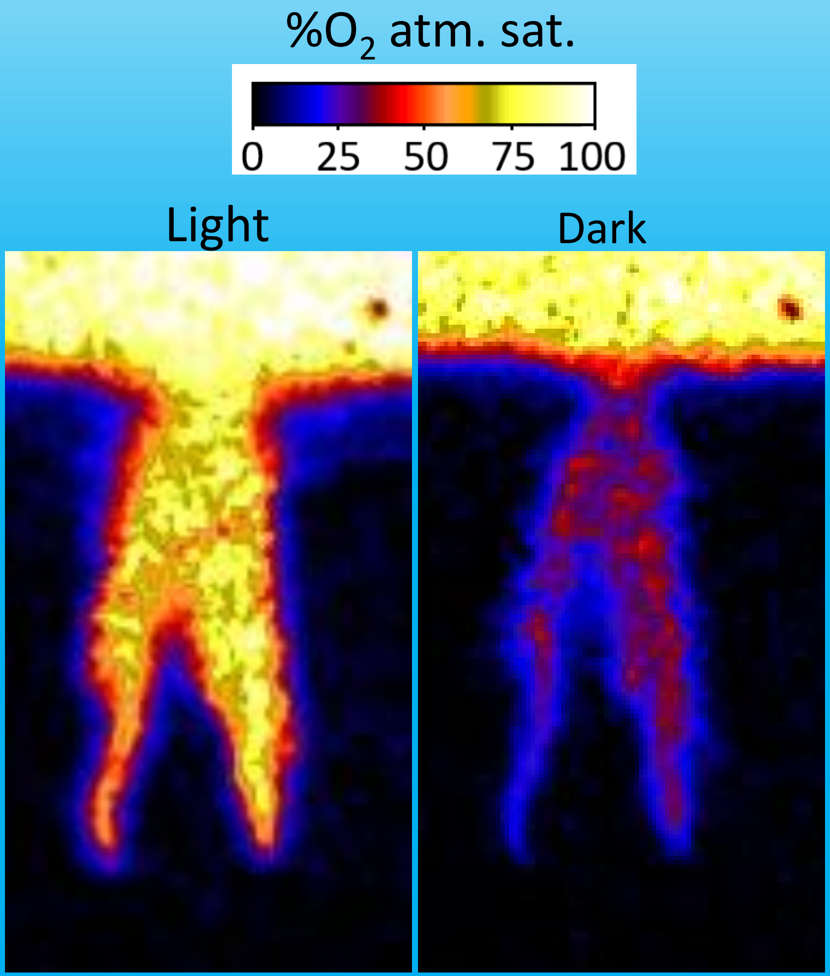
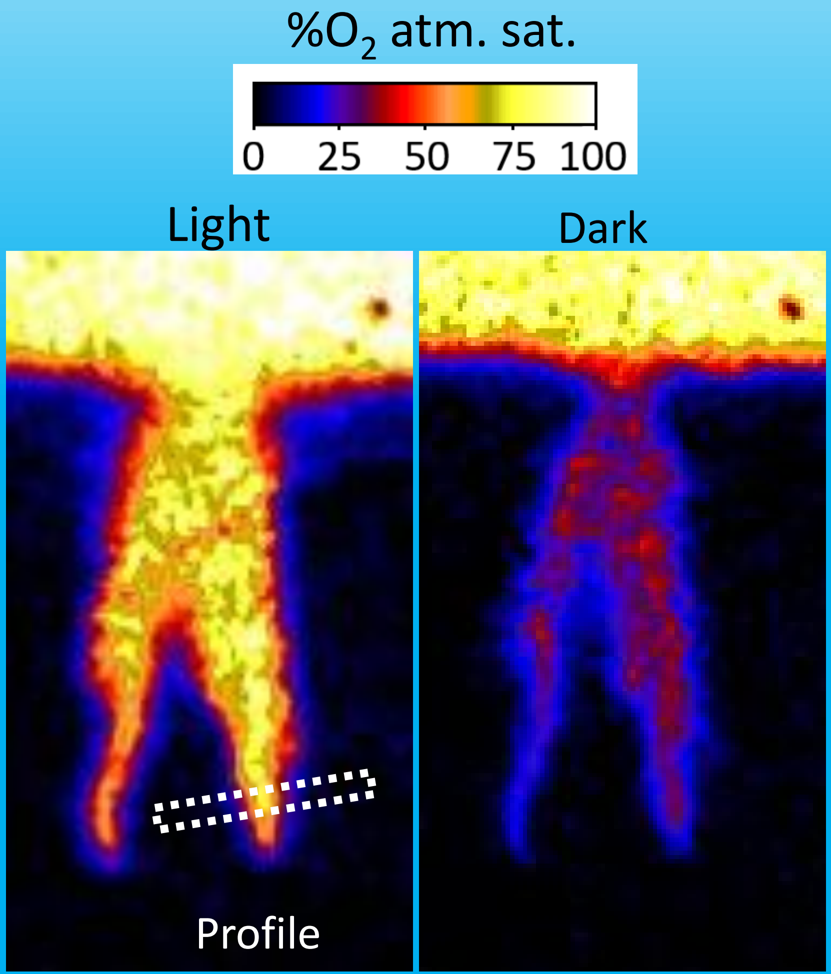


Photo © Koop-Jakobsen

Planar optode imaging is a quantitative technology
- Each pixel in the optode image is assigned an $[O_2]$-value

1. Key Feature: Quantification of Spatial Variation



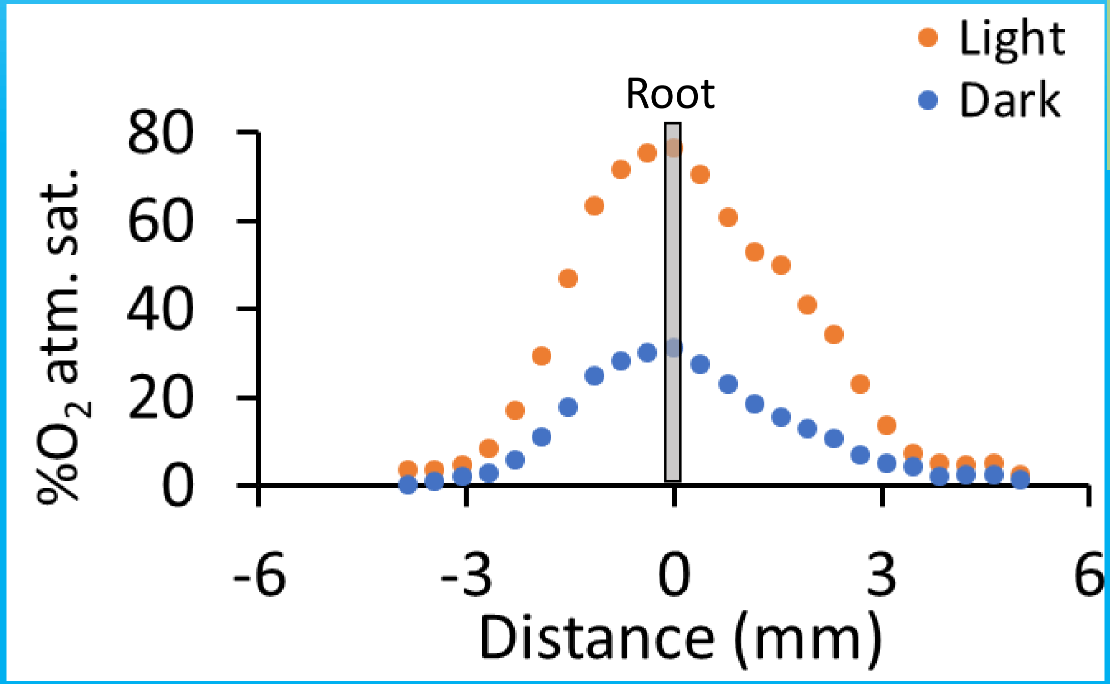
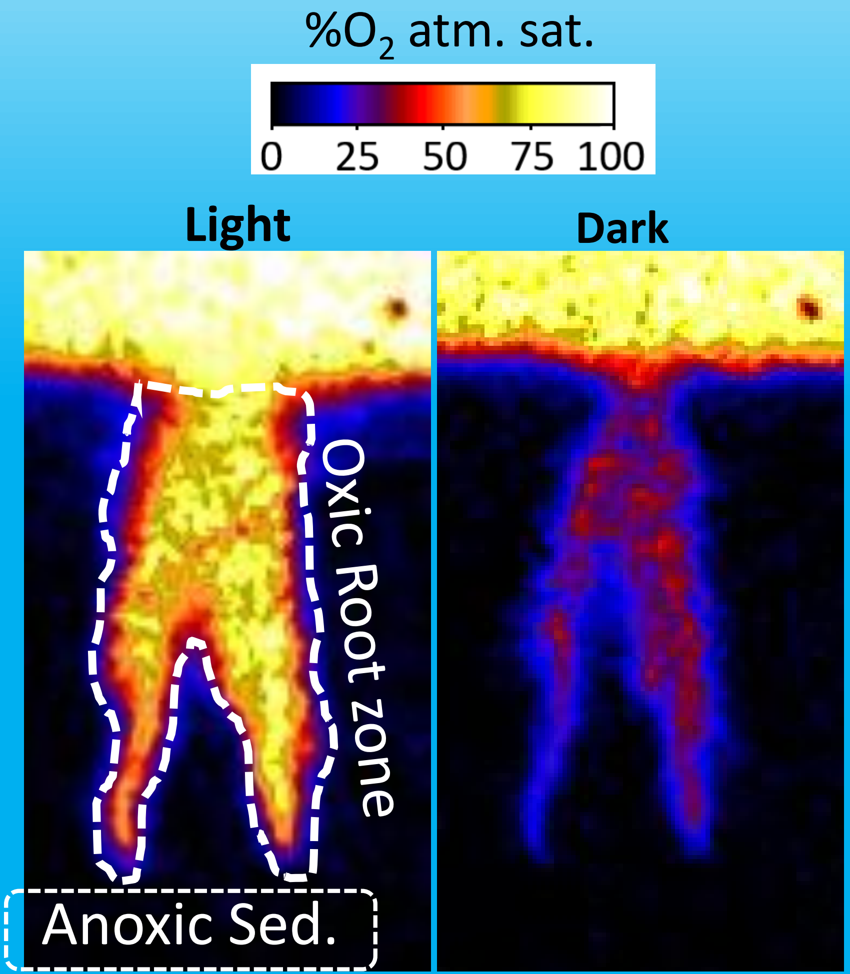
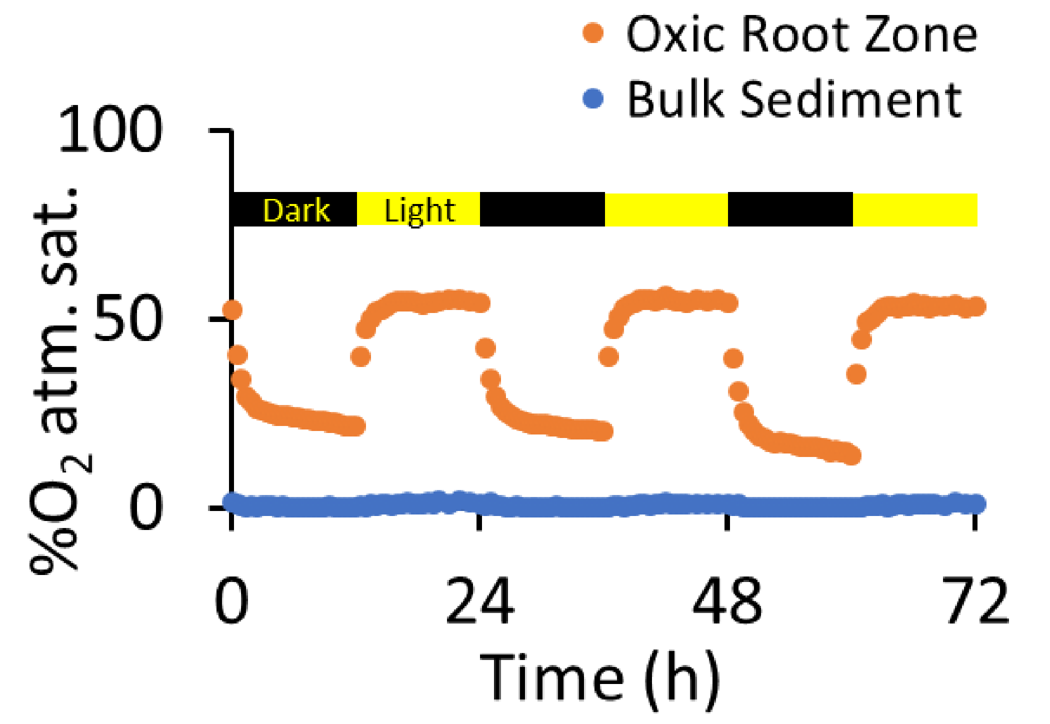


Photo © Koop-Jakobsen

Planar optode imaging is a quantitative technology
- Each pixel in the optode image is assigned an $[O_2]$-value

2. Key Feature: Quantification of Temporal Variation





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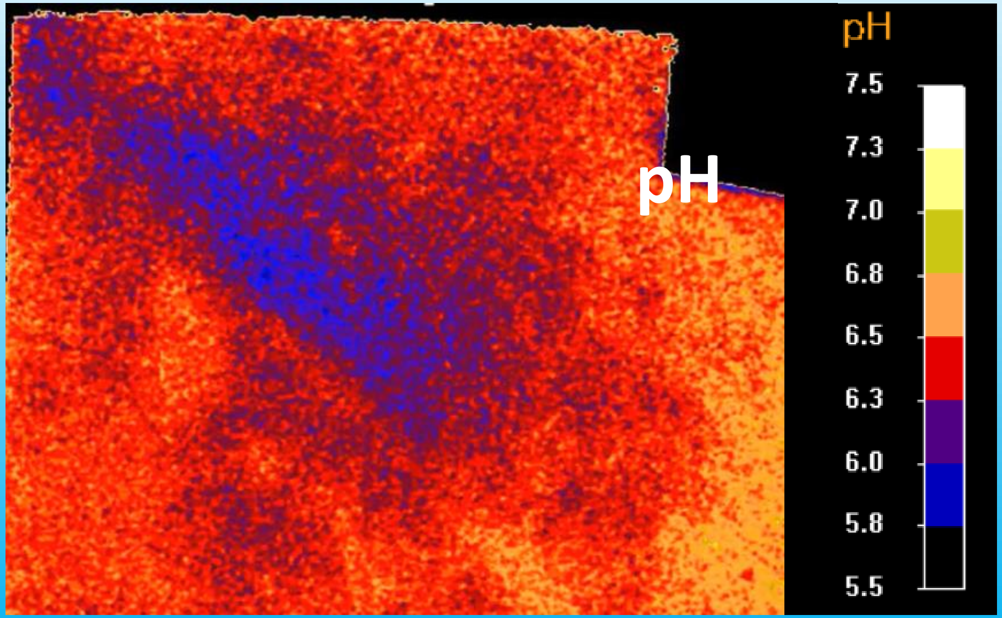
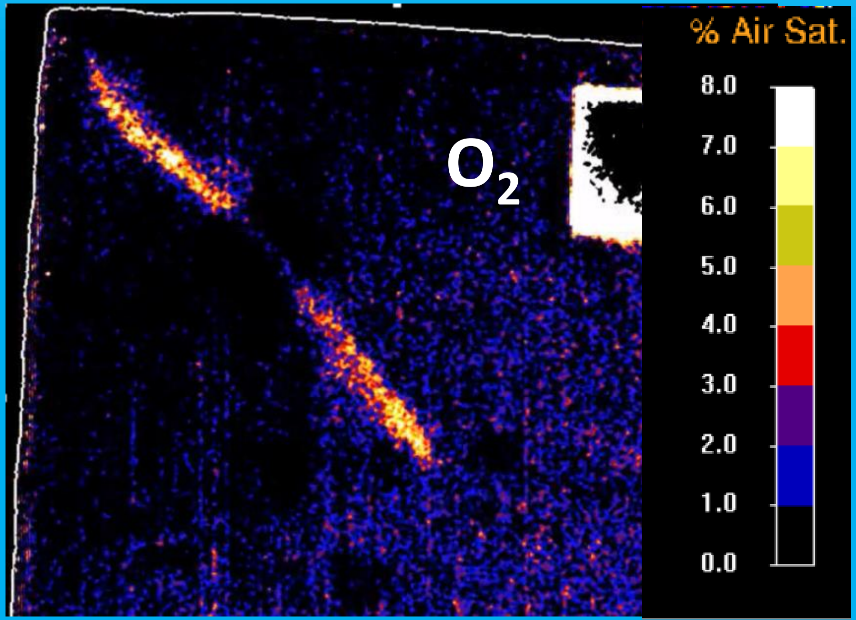
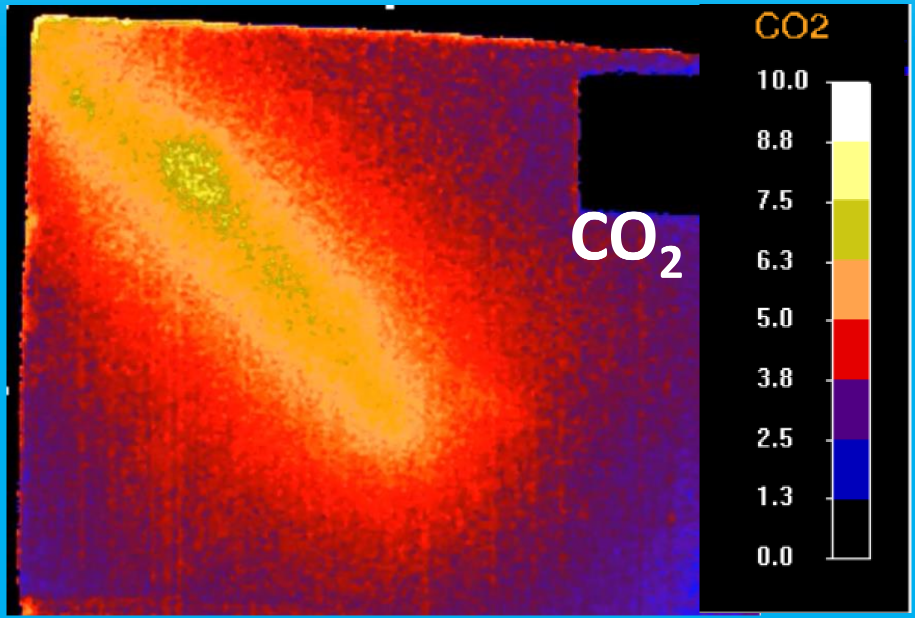
Dynamics of O_2, pH and CO_2 in marsh rhizospheres

Planar optode technology

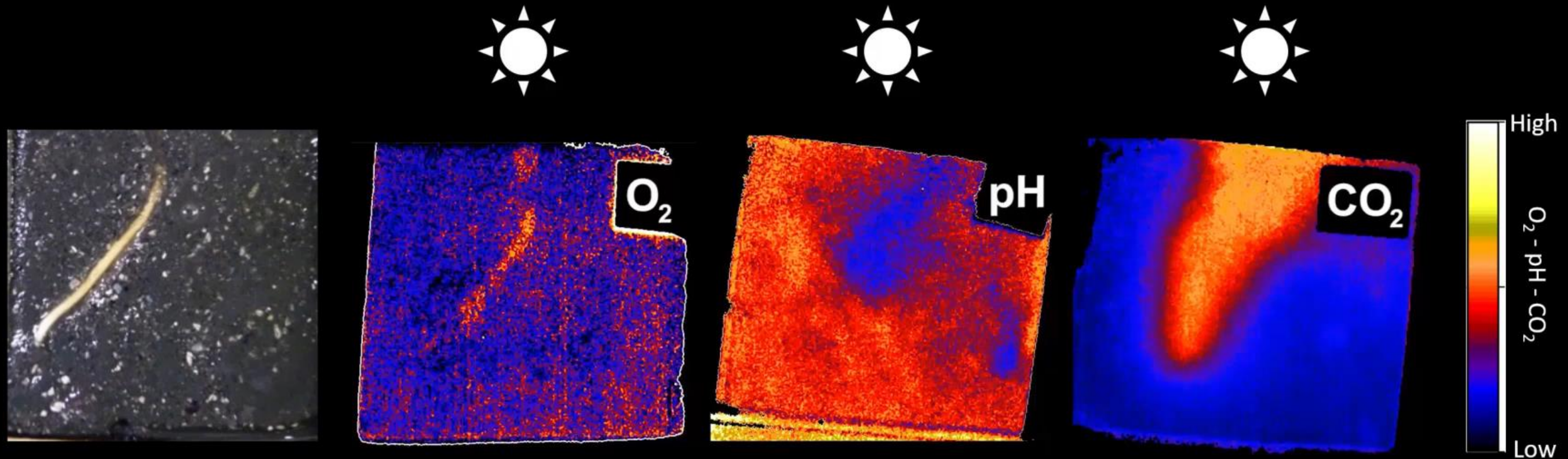






Koop-Jakobsen et al 2018 Frontiers in Plant science

Dynamics of O_2, pH and CO_2 in marsh rhizospheres



Daily variation in O_2, pH and CO_2 around Spartina root. (periods: 12h light/ 12h dark)

https://www.researchgate.net/publication/326033658_Video_following_O2_pH_and_CO2_distribution_around_a_root_of_the_wetland_grass_Spartina_anglica

Plant-mediated sediment oxygenation - *in Elymus athericus*

Research example 1:
Plant-mediated sediment oxygenation facilitate the spread of *Elymus athericus* in European marshes

Ketil Koop-Jakobsen, Alfred-Wegener-Institute - Wadden Sea station, Germany
Robert Meier, PreSens Precision Sensing GmbH, Regensburg, Germany
Peter Müller, Institute of Soil Science, Center for Earth System Research and Sustainability, Universität Hamburg, Hamburg, Germany

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Photo: Dirk Granse UniHH

Oxygen dynamics in *Elymus athericus* rhizosphere

Photo © Koop-Jakobsen

Characteristics:

Name: *Elymus athericus*
Distribution: Native to *Europe*
Habitat: *High marsh*
Length: 20-120 cm
Roots: long rhizomes,
Most root biomass in 0-10cm

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Geographical distribution and study area:

Oxygen dynamics in *Elymus athericus*

Geographical distribution:
Europe Atlantic coast and Mediterranean coast

Study area:
Wadden sea: Tidal dominated describe

Green: distribution of Elymus
http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:912429-1

Wadden Sea salt marsh
Photo: Koop-Jakobsen, AWI

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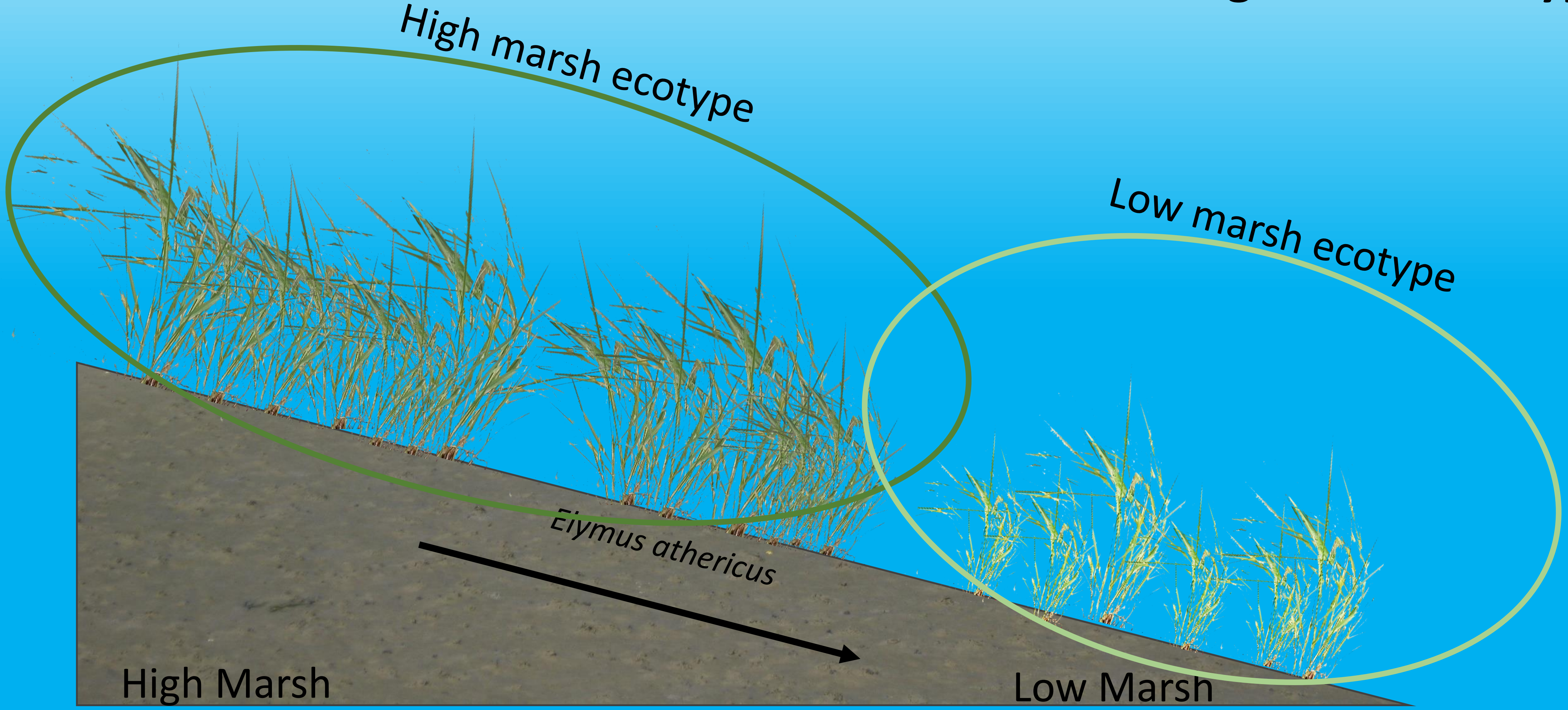
Elymus is spreading significantly altering the plant composition

Does Elymus possess traits that enables its spread into waterlogged areas ?

Is Elymus capable of plant-mediated sediment oxygenation?

Are there differences between between the low and high marsh ecotype?



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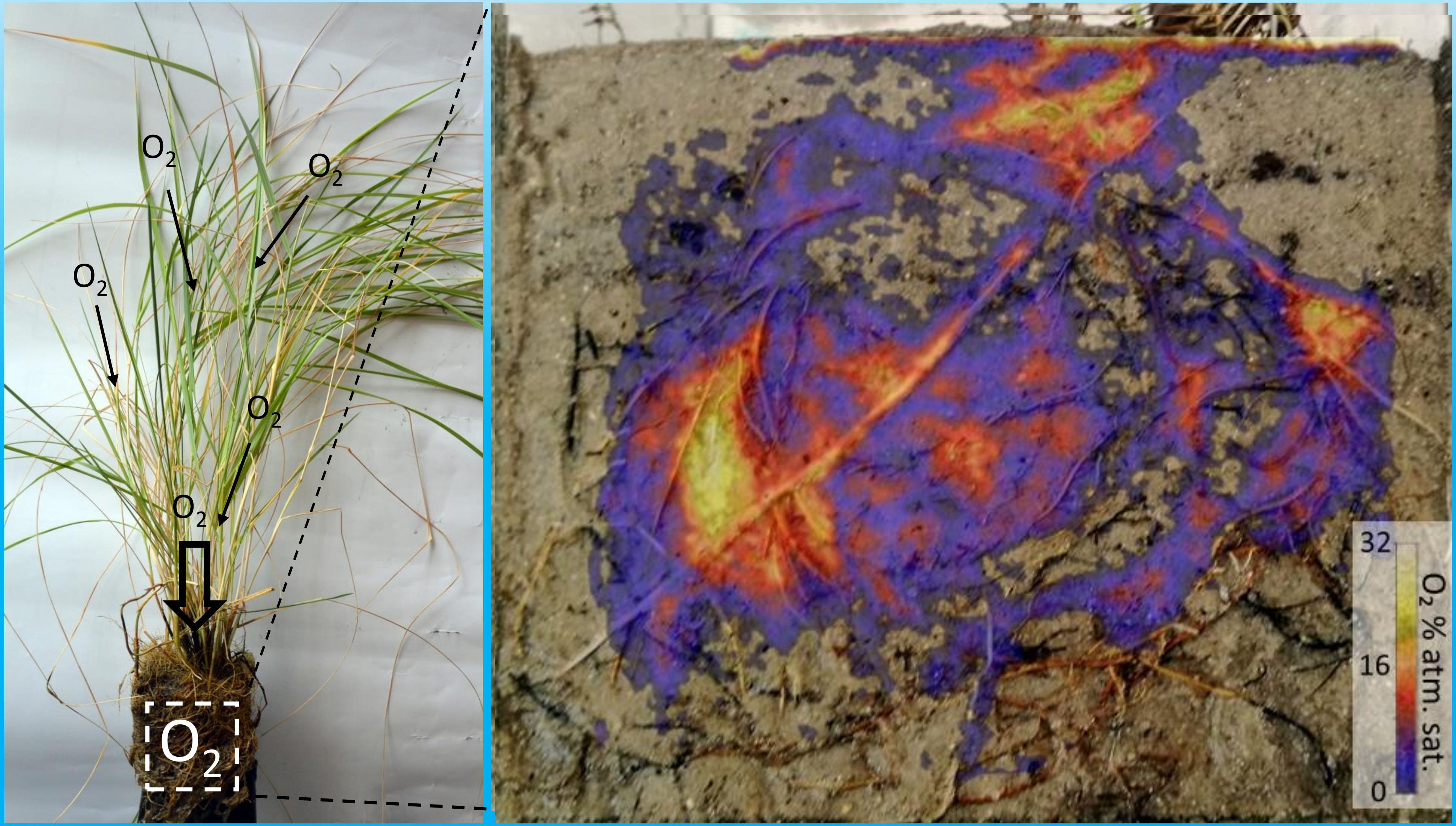
Plant-mediated sediment oxygenation release oxygen into the rhizosphere

Elymus athericus - Wadden sea marshes, Germany



Oxygen dynamics in *Elymus athericus*

Koop-Jakobsen and Mueller 2021 Frontiers in plant science

Study design

Plant mediated sediment oxygenation in Elymus was investigated using planar optode, which images oxygen in the rhizopshere.




VS

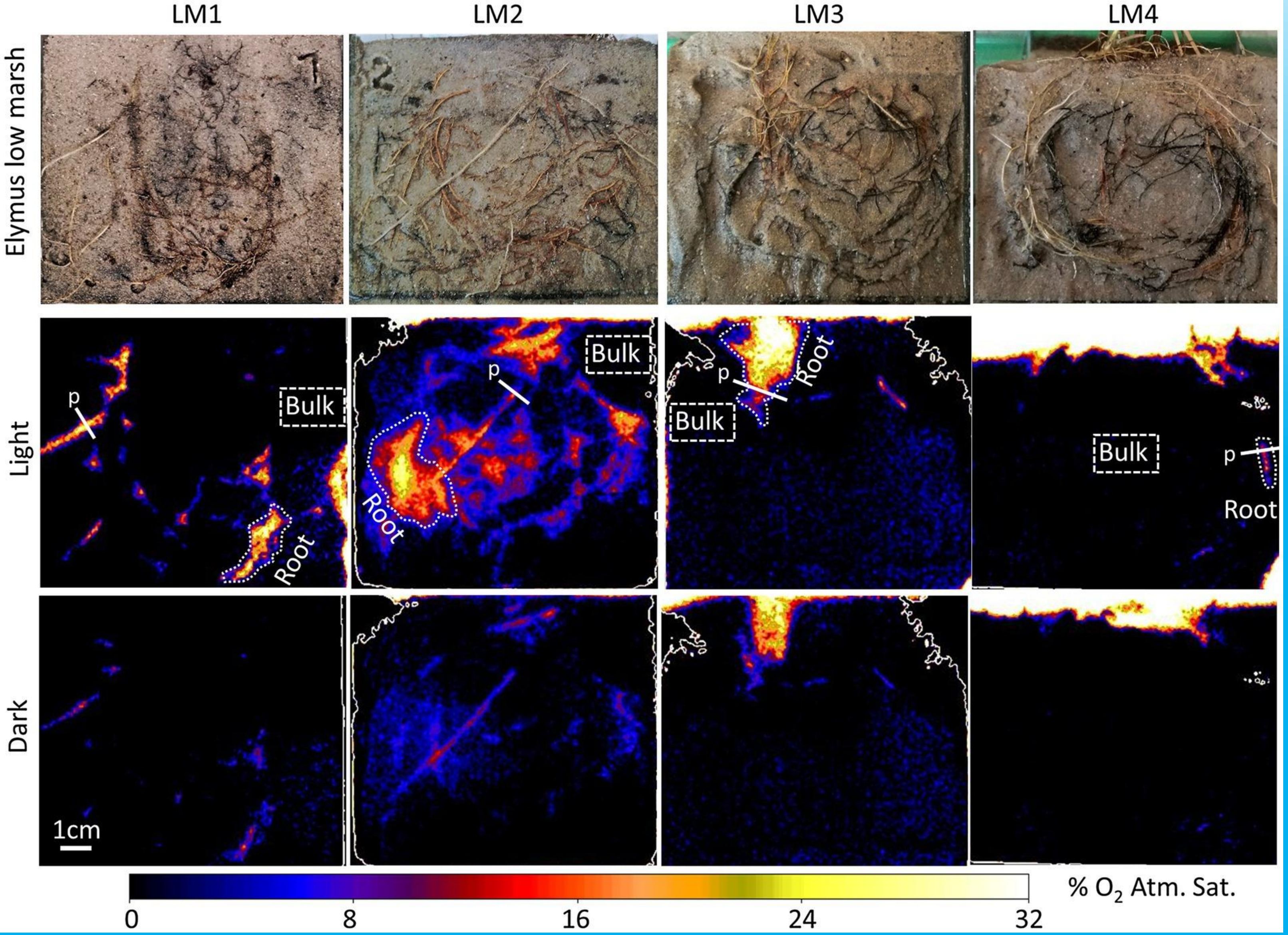



4 **Low-marsh** ecotype samples

4 high marsh ecotype samples

Spatial oxygen distribution in *Elymus* rhizosphere

Low marsh ecotype



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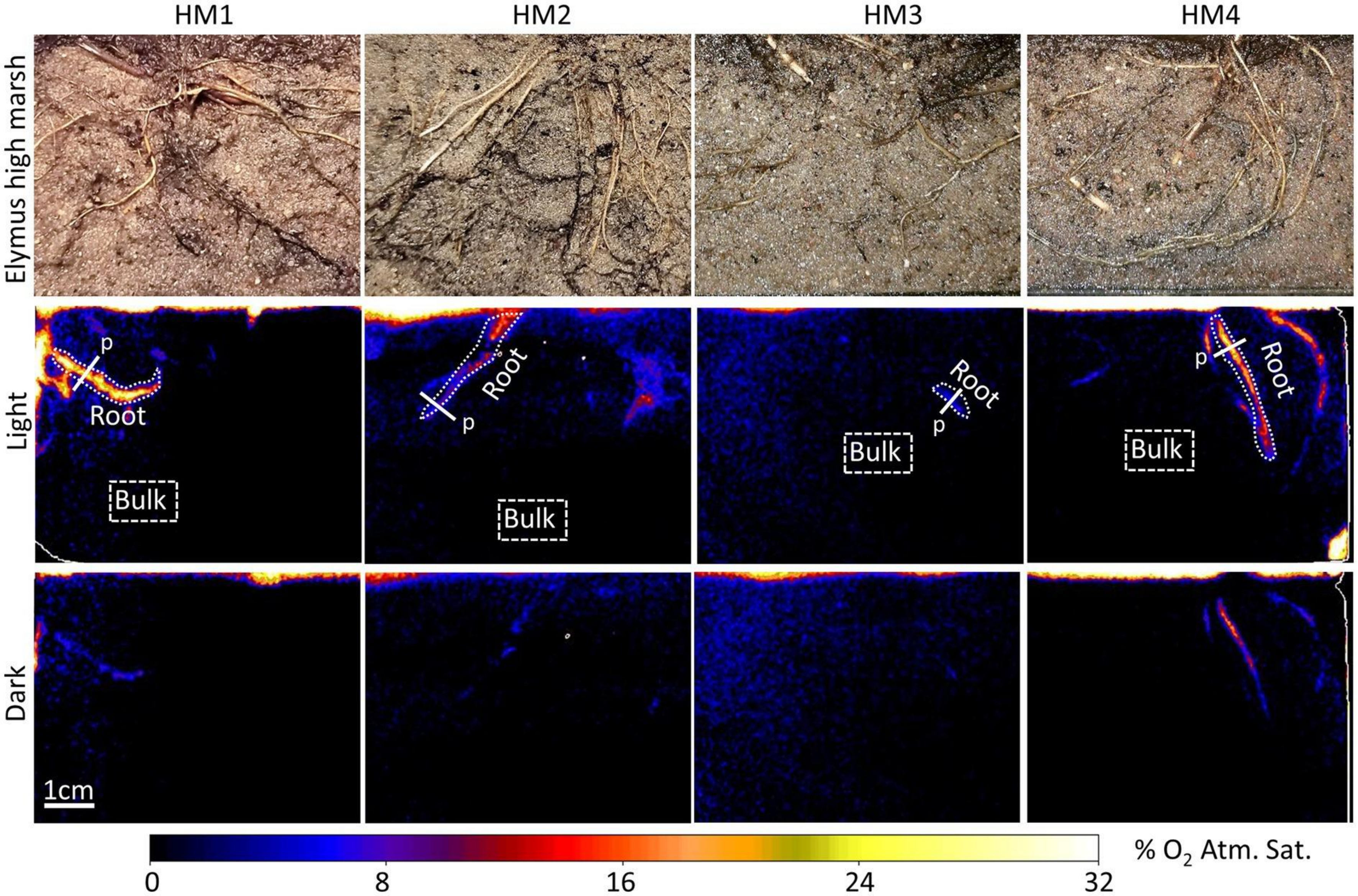
Spatial oxygen distribution in *Elymus* rhizosphere

High marsh ecotype



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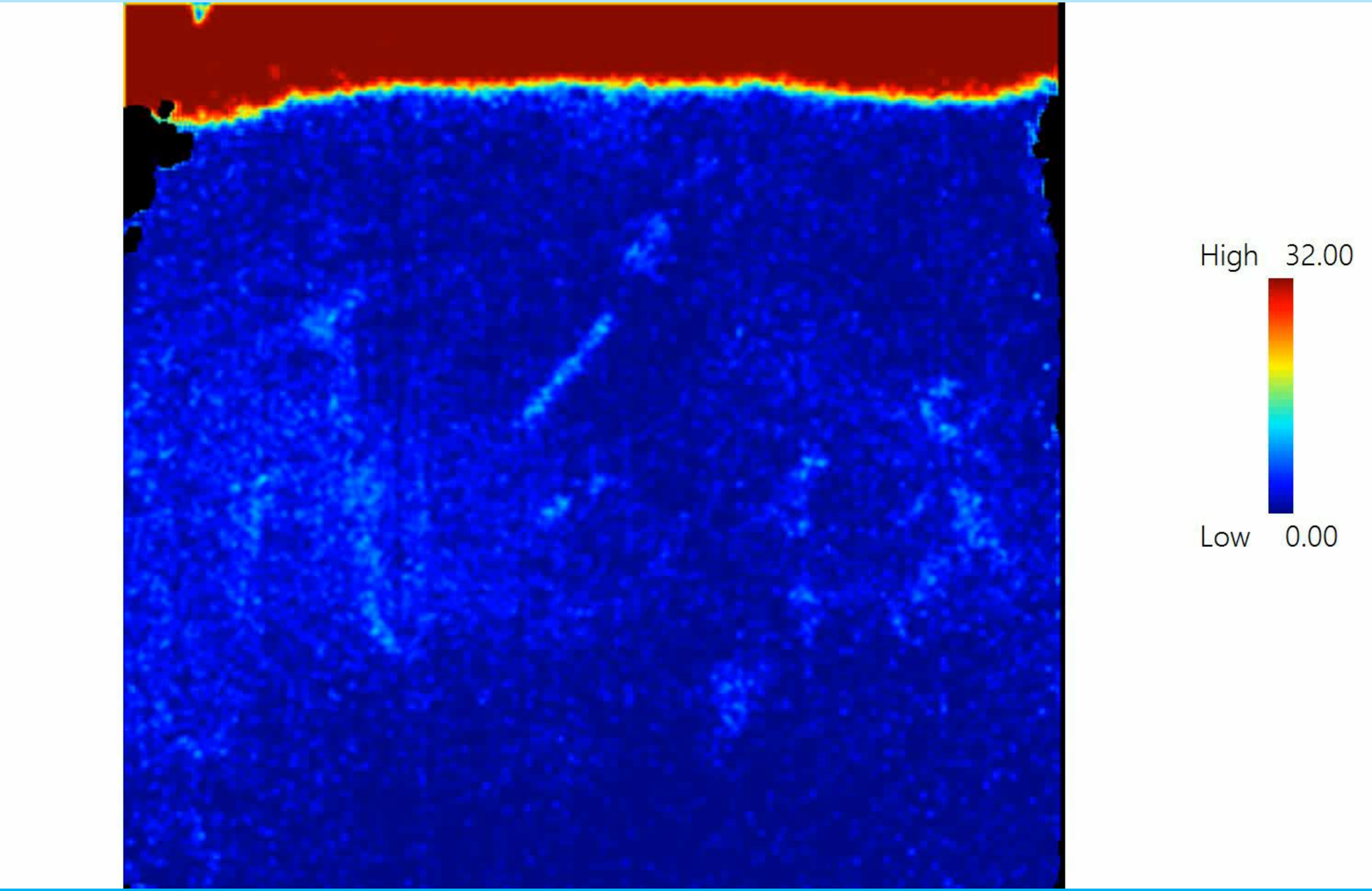
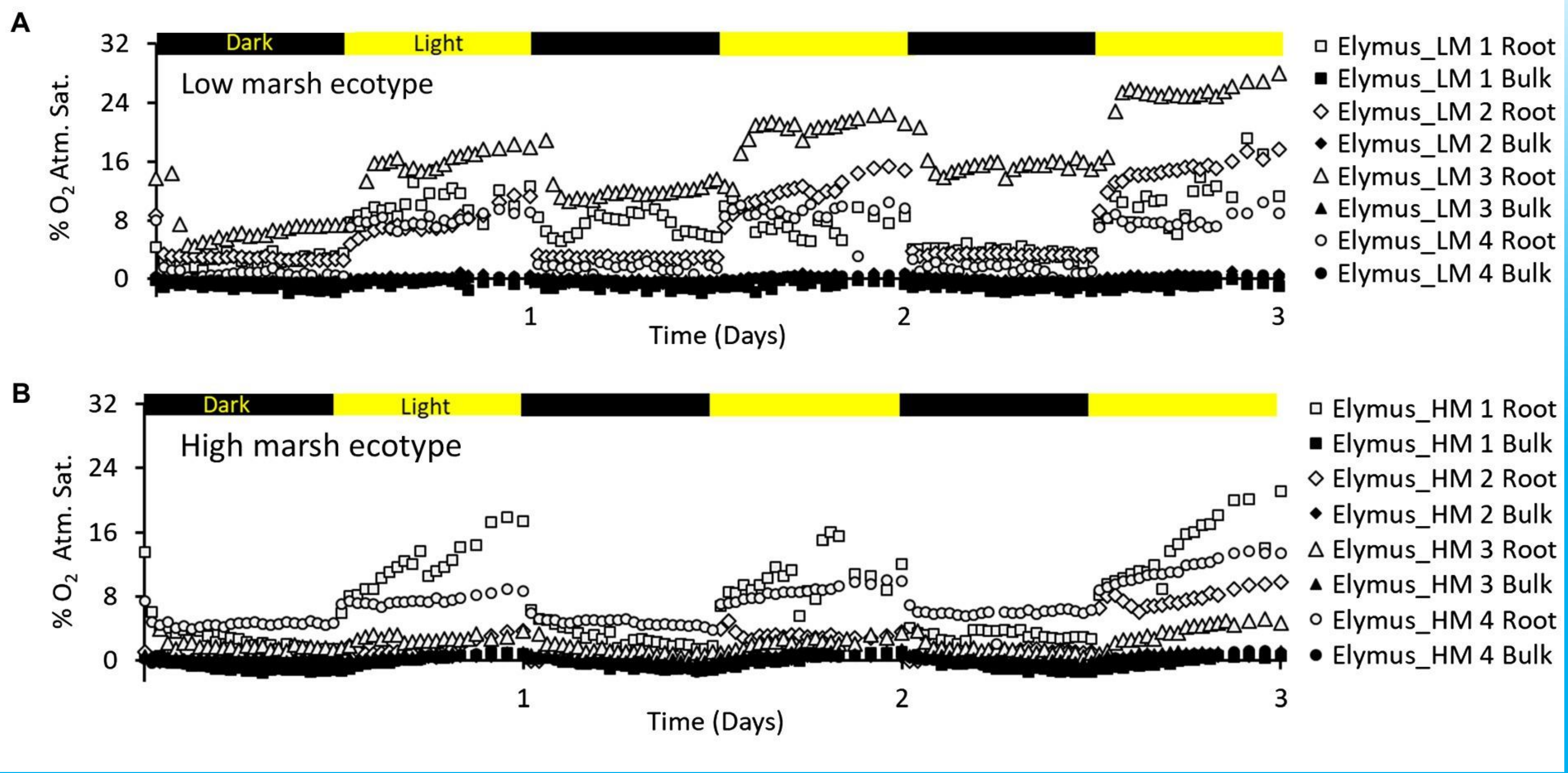
Spatial oxygen distribution in *Elymus* rhizosphere

Low marsh ecotype



Koop-Jakobsen unpublsihed

Temporal oxygen distribution in Elymus



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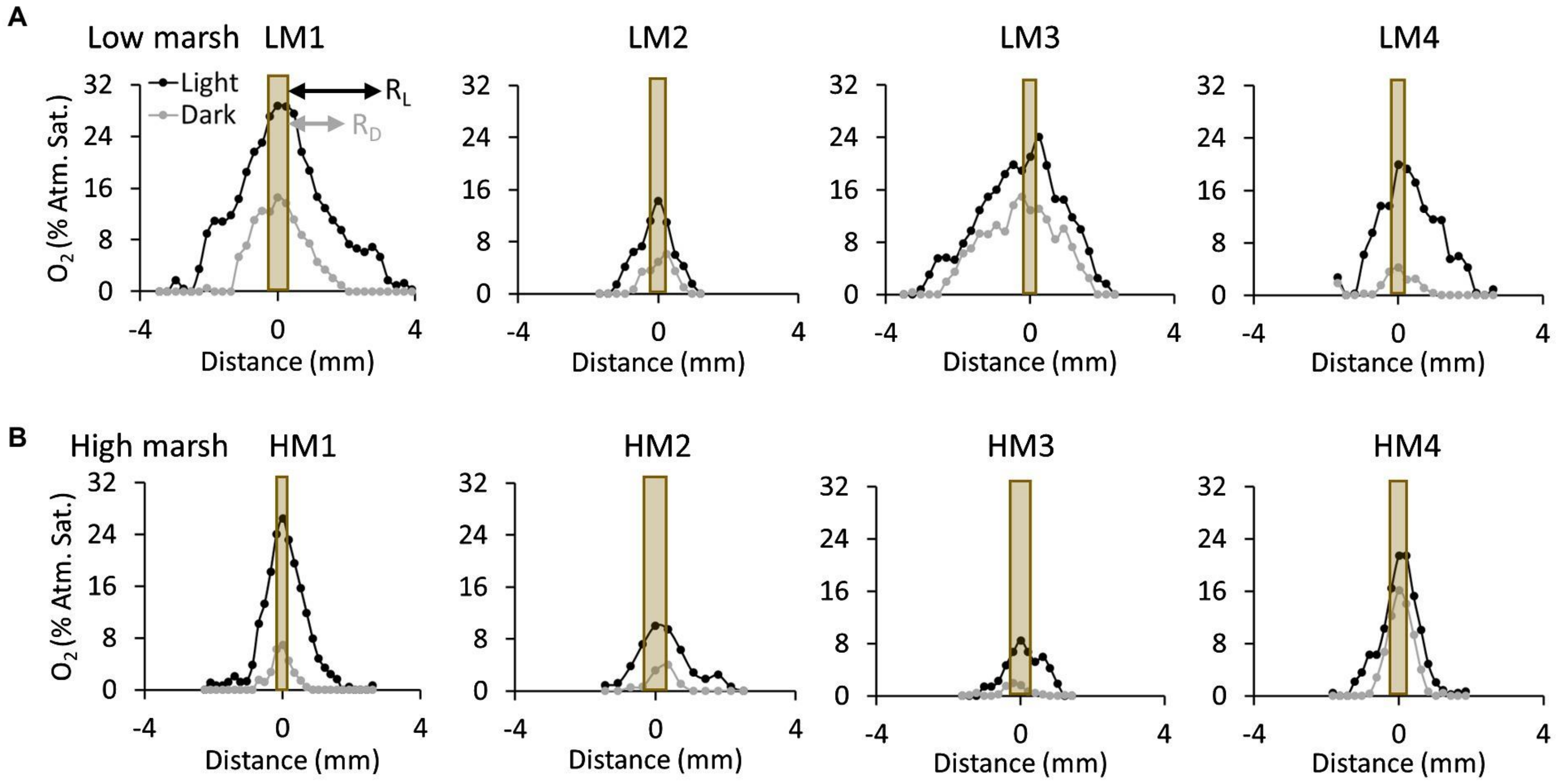
Spatial oxygen distribution in Elymus



C

	Radius Light R_L (mm)	Radius Dark R_D (mm)	Radius reduction
Elymus LM 1	2.62	1.36	-48%
Elymus LM 2	1.04	0.69	-33%
Elymus LM 3	2.59	2.01	-23%
Elymus LM 4	1.68	0.72	-57%
Low Marsh			

	Radius Light R_L (mm)	Radius Dark R_D (mm)	Radius reduction
Elymus HM 1	1.82	0.69	-62%
Elymus HM 2	1.04	0.68	-35%
Elymus HM 3	0.87	0.46	-47%
Elymus HM 4	1.13	0.72	-36%
High Marsh			

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***Conclusion*:**

- *Elymus athericus* is capable of plant-mediated sediment oxygen
- Plant-mediated Sediment oxygenation can have significant impact on Elymus' rhizosphere chemistry via sediment oxygenation
- This specific trait enables Elymus to spread in to the more waterlogged parts of the low marsh
- This spread of Elymus and its alteration of sediment chemistry may affect carbon storage capacity

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https://doi.org/10.3389/fpls.2021.669751

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