UNIVERSITÄT GREIFSWALD
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Partner in the
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MIRE
CENTRE

Paludiculture on bogs

Greta Gaudig & Matthias Krebs

Foto: Uni Greifswald

Paludiculture on bogs

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- peat mosses
- sundew/ Drosera

…

What are peat mosses?

peat moss, Turba sammal, Kūdras sūnas, Durpių samanos (*Sphagnum* spp.)

- 150 – 450 species (depending on species concept) (Michaelis 2011)
- storage of 20 – 30 times their own weight in **water** possible
- efficient uptake of **nutrients** through cation exchange (H+ release) → peat mosses acidify their environment
- high **regeneration** ability
- natural, global **productivity** Ø 260 g m^{-2} a^{-1} (Gunnarsson 2005)

utilisation of peat mosses

→ Collection in natural stocks, e.g. in Chile

Foto: http://www.teara.govt.nz/en/mosses/2/3, Nov 2010

utilisation of peat mosses

→ Application in special cultures: production of *Phalaenopsis* in Taiwan

utilisation of peat mosses

Terrarium litter

Baby nappies

Hanging basket

Wound dressing

Insulation material

Jiffy pots

Cleaning of swimmingpools

Substrate for green walls

utilisation of peat moss peat

→ Manual peat cutting in bogs → utilisation as fuel peat

utilisation of peat moss peat

→ industrial peat mining in bogs → utilisation in horticulture

utilisation of peat moss peat

→ Optimal for horticulture

→ 3x “nothing”: nearly only pores + nearly no nutrients + low pH value

annual peat consumption:

globally: 40 Mio. m³, **Germany**: 8 Mio m³, incl. 3 Mio m³ ‚white peat‘

→ BUT: **peat is fossil**. Its use is harmful to the climate.

peat alternatives

Wood fibres

Green compost

Coco fibres and mark

Fotos: www.torffrei.info

→ Proportion in substrates approx. 10%, in potting soils approx. 30%

→ Not available in sufficient quality and quantity

→ Cultivation of peat mosses?

peat alternatives

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Peat moss peat developed from fresh peat moss biomass →

Peat moss biomass has similar properties for high quality raw material

Peat moss - peat

Peat moss - biomass

What is paludiculture?

„palus“ - swamp + *„cultura“* - cultivation

→ **productive use of wet and rewetted peatlands**

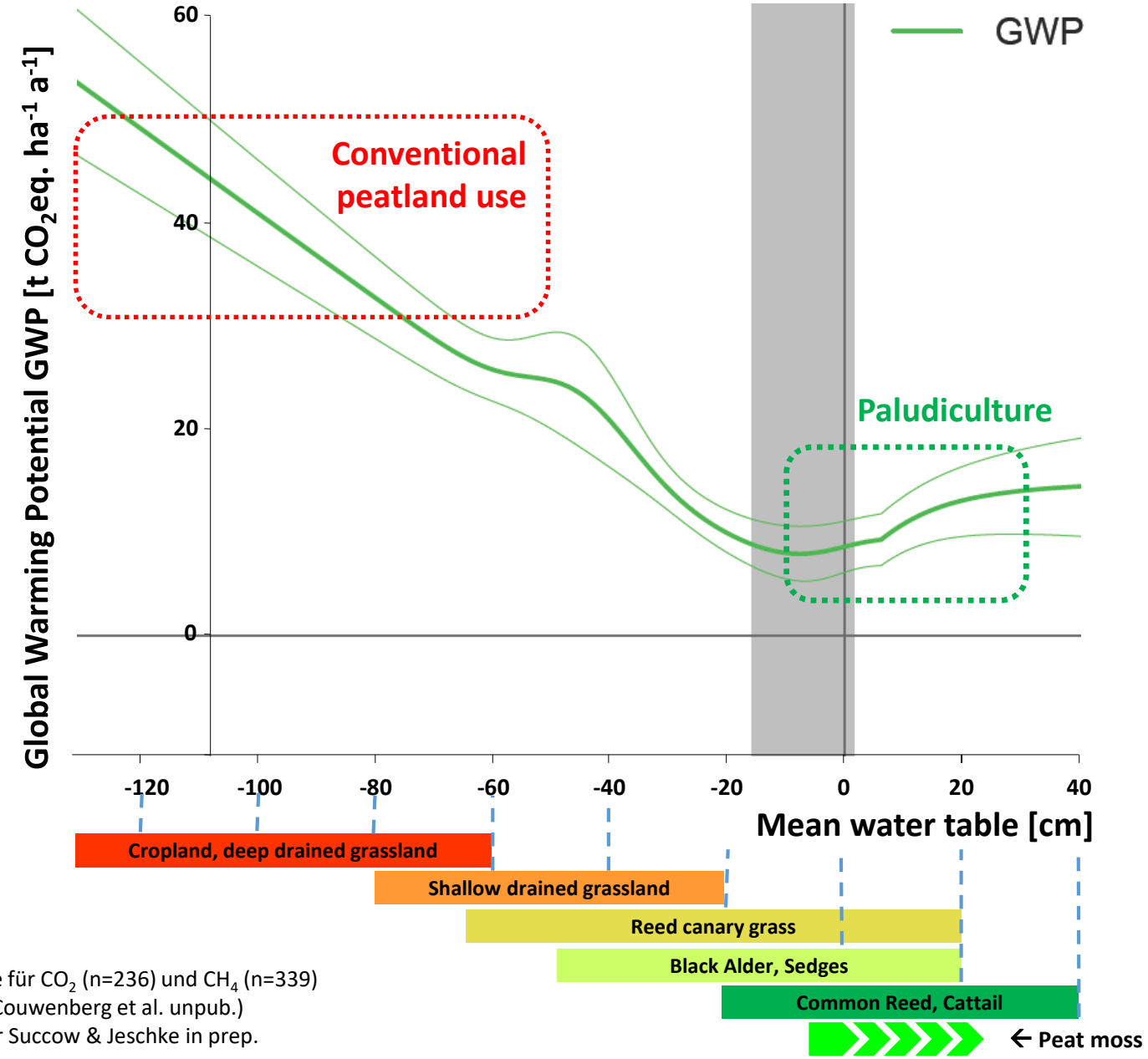
Objectives

- Production → agricultural or silvicultural utilisation
- Maintain peat → stop subsidence and soil degradation
  → reduce GHG emissions
- Optional → peat formation; other ecosystem services

Photo: S. Wichmann

What is paludiculture?

→ peatland use
and GHG emissions



Meta-Analyse für CO_2 (n=236) und CH_4 (n=339)
Emissionen (Couwenberg et al. unpub.)
Adapted after Succow & Jeschke in prep.

history of *Sphagnum* paludiculture

Joosten 1998
“paludiculture”

„peat as a renewable resource“

2001

Literature study
„*Sphagnum* as a renewable resource“
→ *Gaudig 2002, Telma*

2004

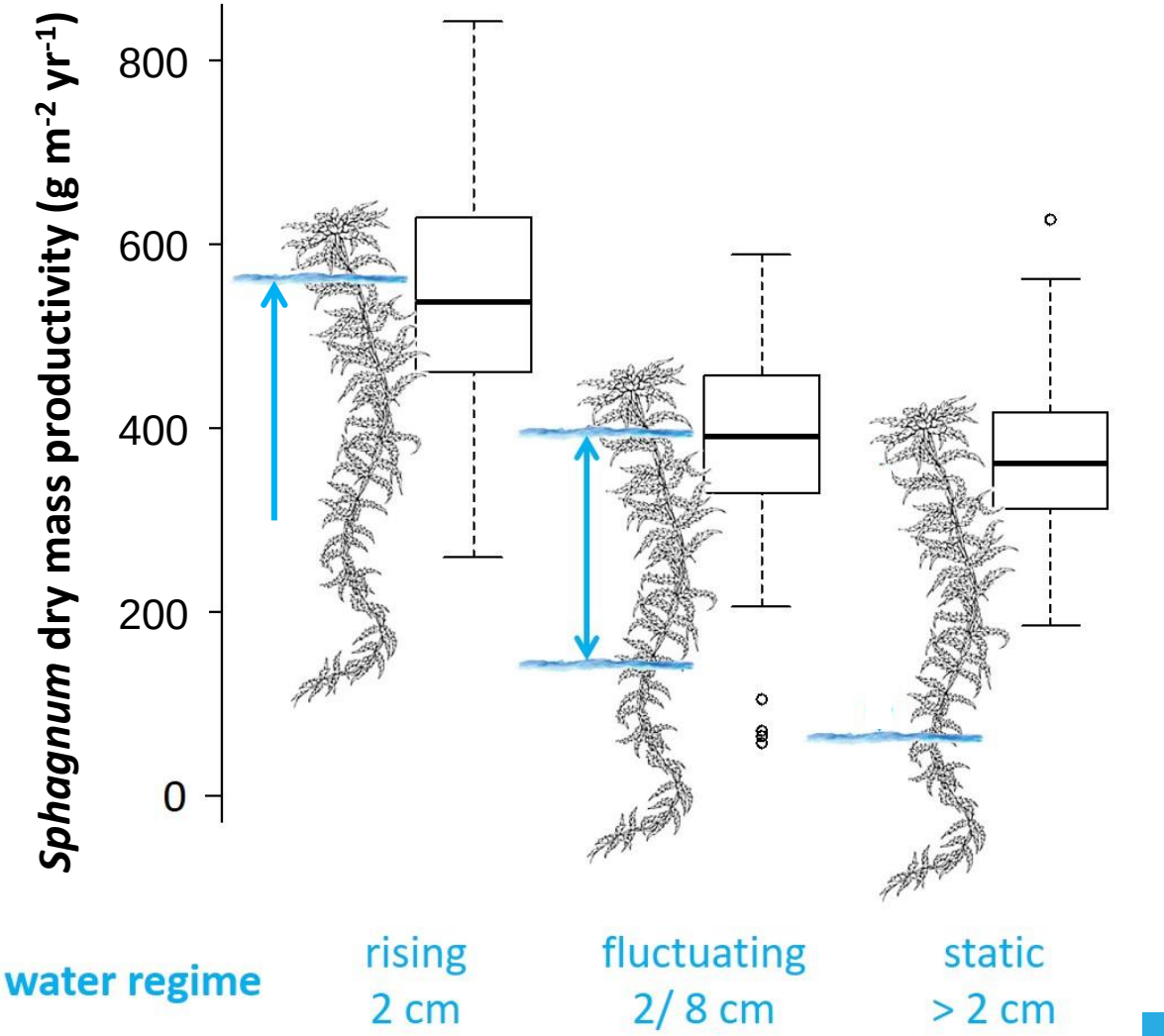
TORFMOOS
Glasshouse experiments +
1. field trial on 1.200 m²
(until 2014) → *Gaudig et al. 2017, 2020*

2007

2010

Optimisation of *Sphagnum* productivity

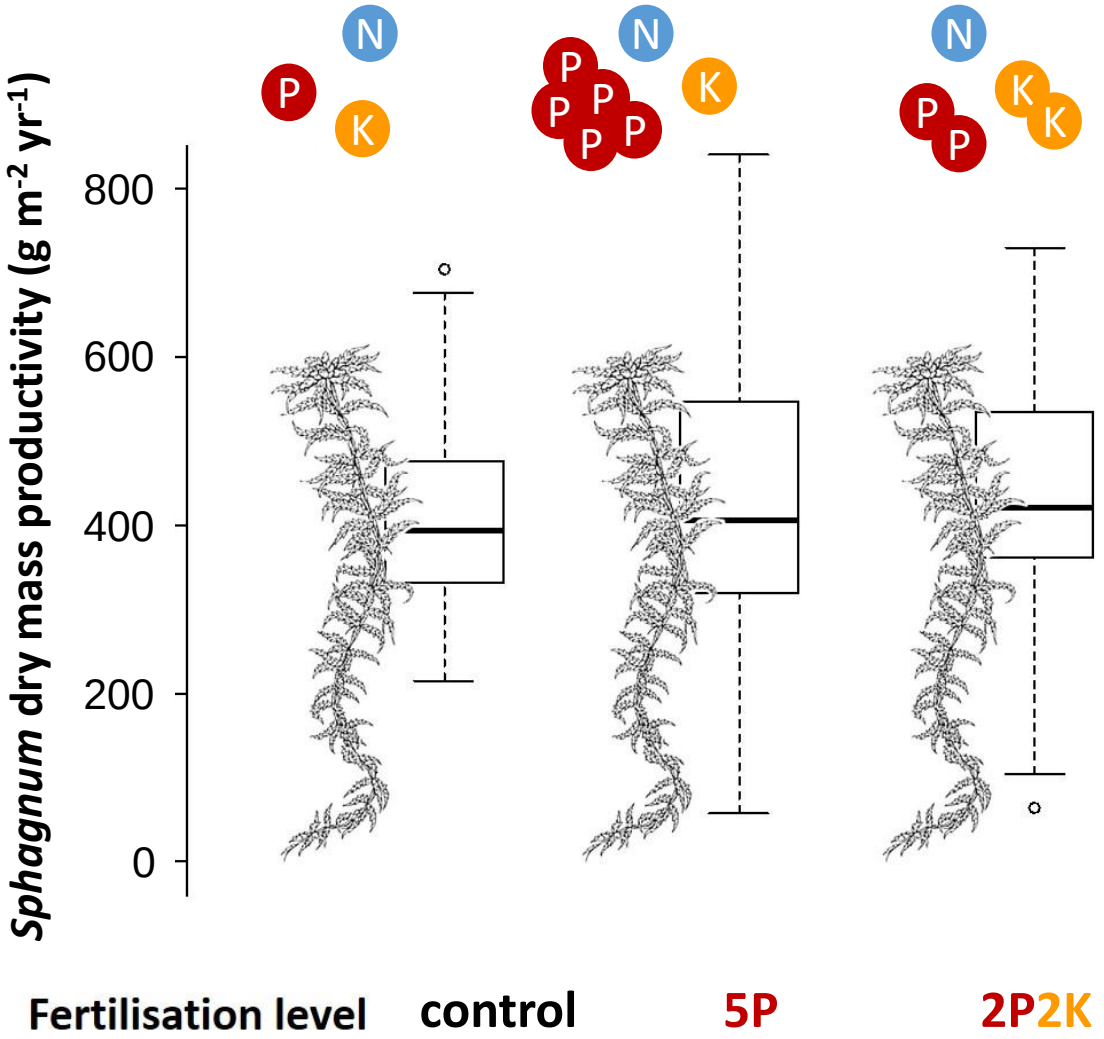
→ test of different water regimes: best growth at rising water table



Gaudig et al. 2020, Plant Biol.

Optimisation of *Sphagnum* productivity

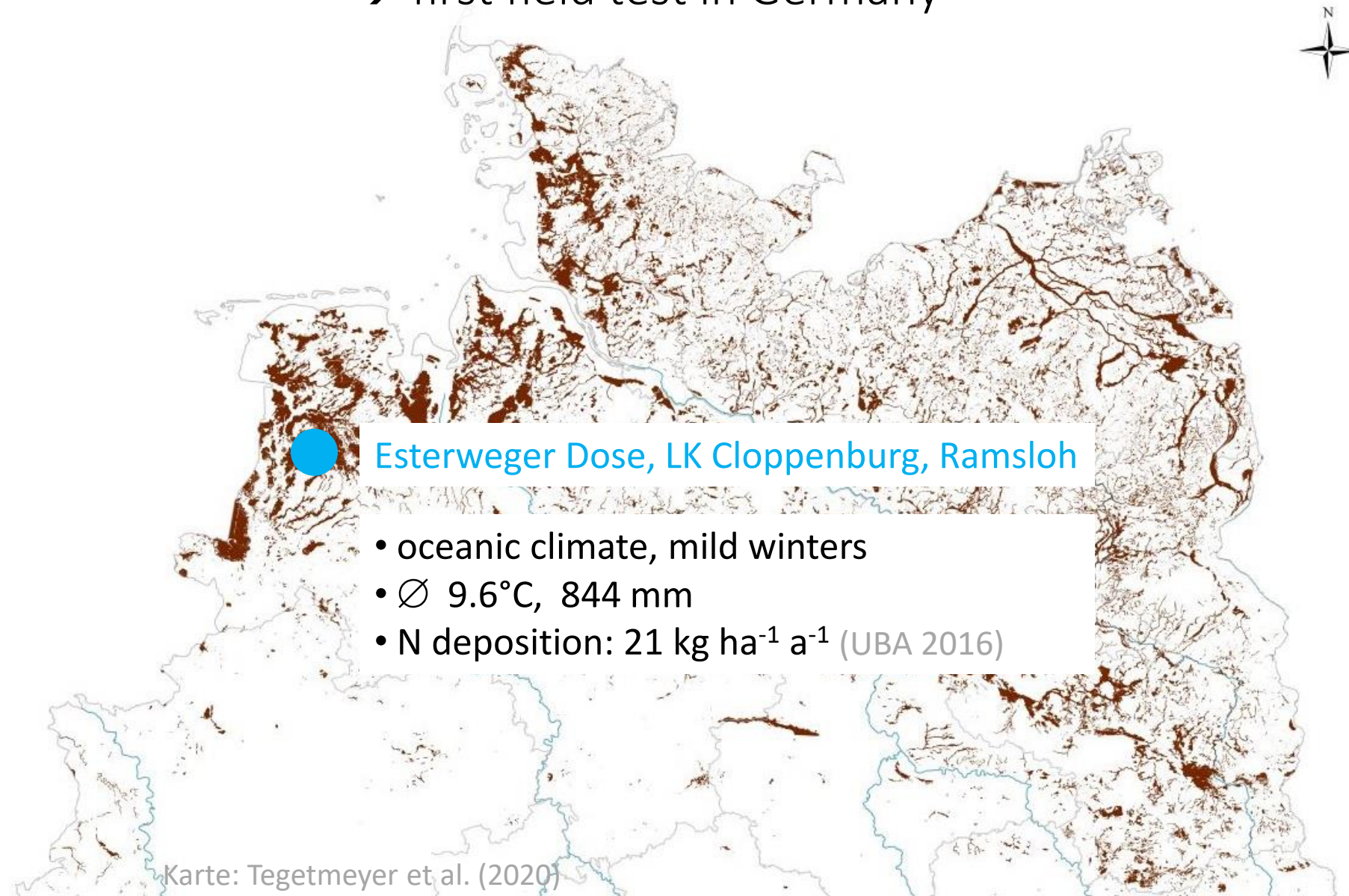
→ test of different fertilisation levels: no effect on peat moss productivity



Gaudig et al. 2020, Plant Biol.

Sphagnum paludiculture on cut-over bog

→ first field test in Germany



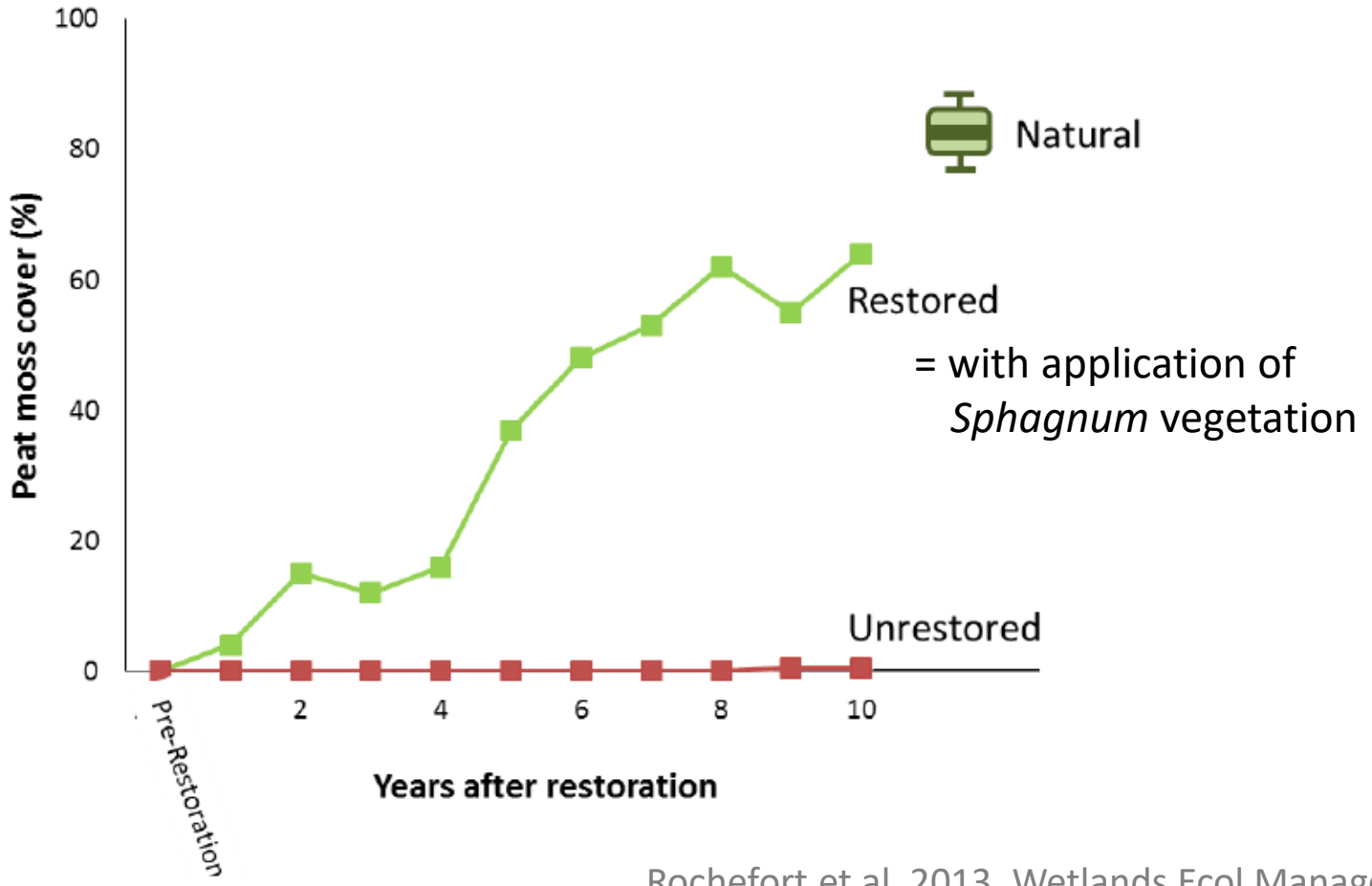
Esterweger Dose, LK Cloppenburg, Ramsloh

- oceanic climate, mild winters
- ∅ 9.6°C, 844 mm
- N deposition: 21 kg ha^{-1} a^{-1} (UBA 2016)

Karte: Tegetmeyer et al. (2020)

Sphagnum paludiculture on cut-over bog

→ Inspired by the Canadian “moss layer transfer technique”



Rochefort et al. 2013, Wetlands Ecol Manage

Sphagnum paludiculture on cut-over bog: initial situation

Foto: D. Kamermann

Sphagnum paludiculture on cut-over bog: site preparation

November 2004

Foto: D. Kamermann

Sphagnum paludiculture on cut-over bog: site installation

- *Sphagnum papillosum*
- Initial cover ~95% (brownish peat mosses)

November 2004

Foto: D. Kamermann

Sphagnum paludiculture on cut-over bog: after site installation

November 2004

Foto: D. Kamermann

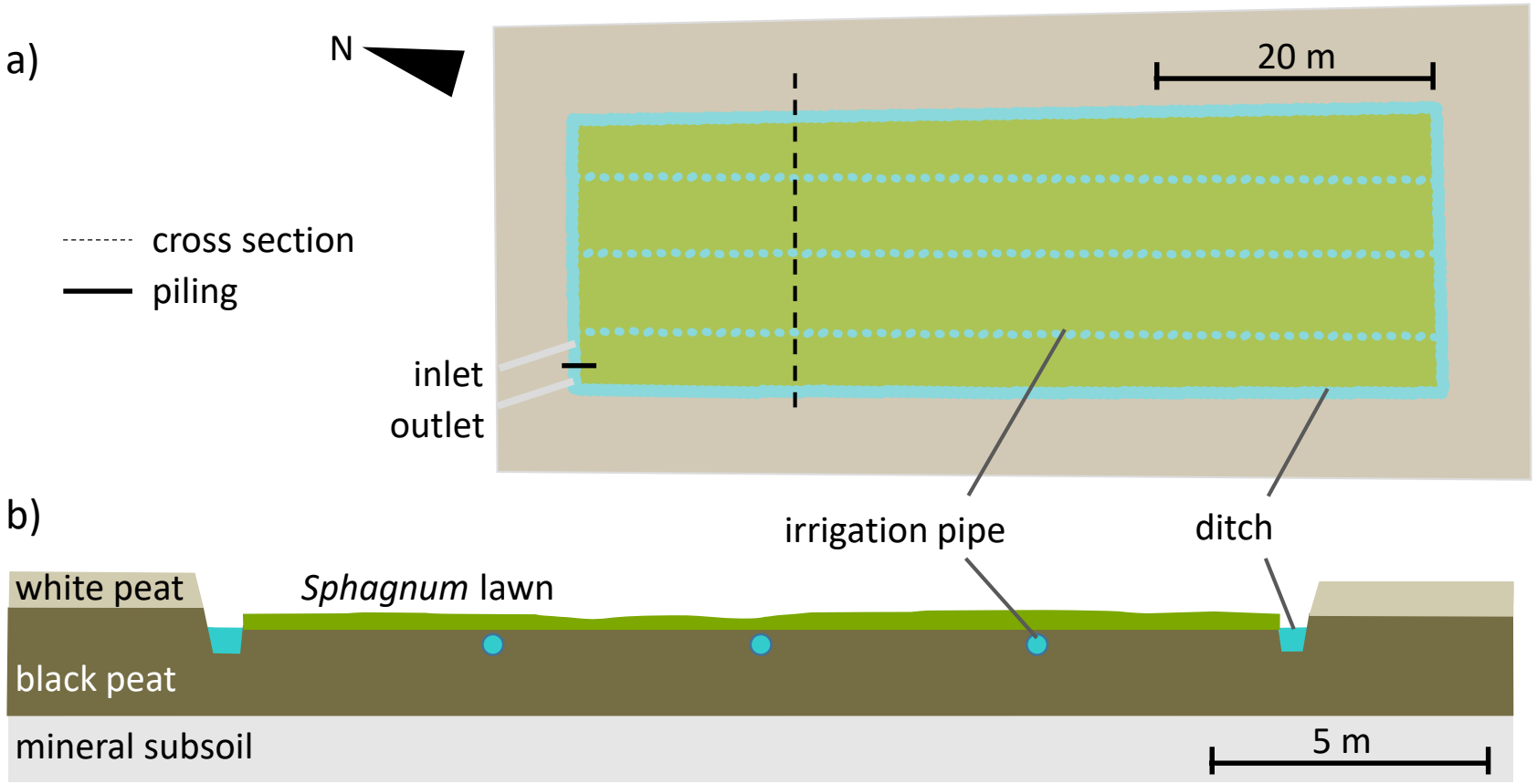
Sphagnum paludiculture on cut-over bog: 5.5 years old

Mai 2010

Sphagnum paludiculture on cut-over bog: green oasis

Foto: Google Earth 2010

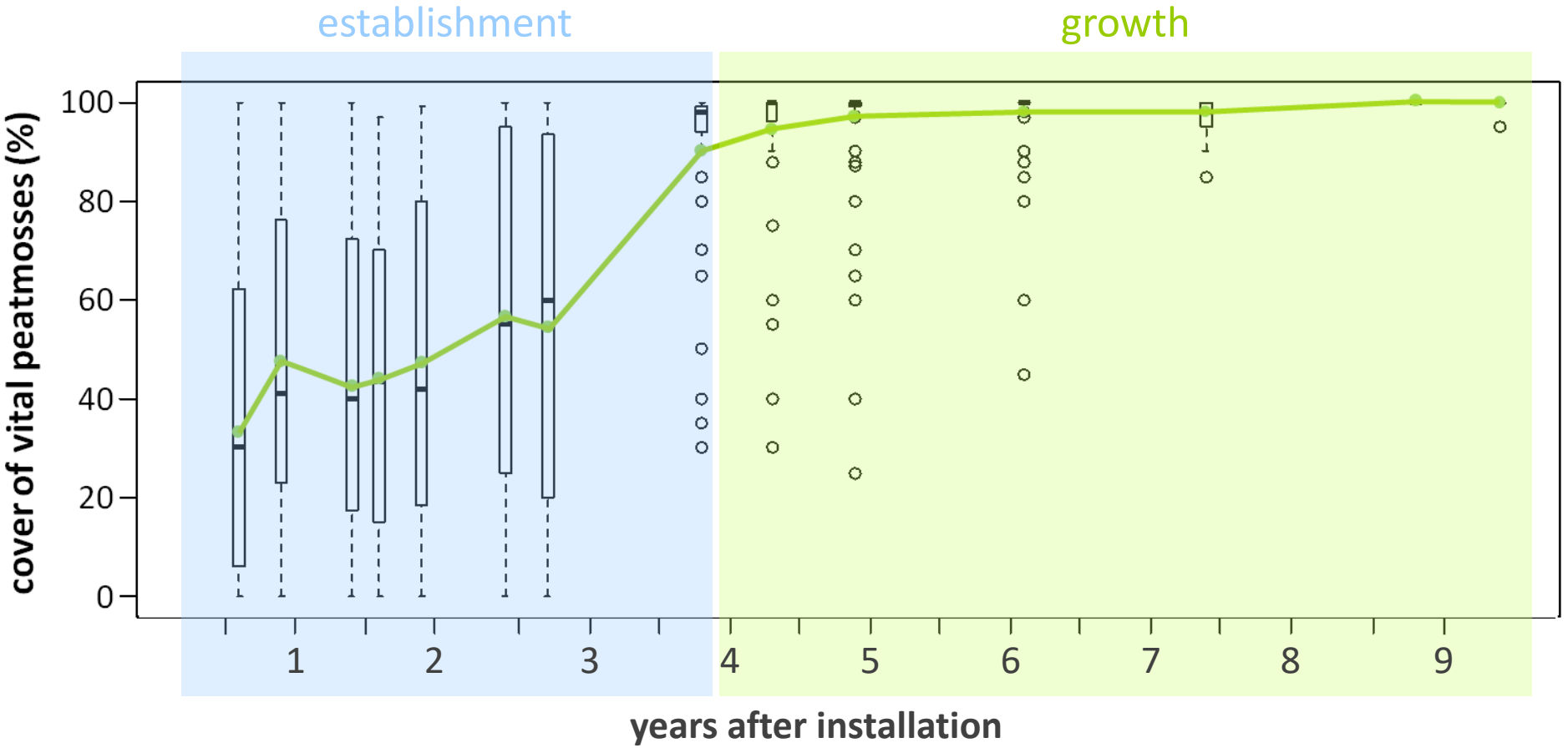
Sphagnum paludiculture on cut-over bog: setup



- size: ca. 60 x 20 m
- irrigation: (drain)pipes every 5 m + surrounding ditch
- on black peat (H7), ca. 1,8 m thick

Gaudig et al. 2017, Mires and Peat

Sphagnum paludiculture on cut-over bog: results



- Continuous increase of vital (green) *Sphagnum papillosum* cover
- Established after 45 months (3.75 years)

Gaudig et al. 2017, Mires and Peat

Sphagnum paludiculture on cut-over bog: results

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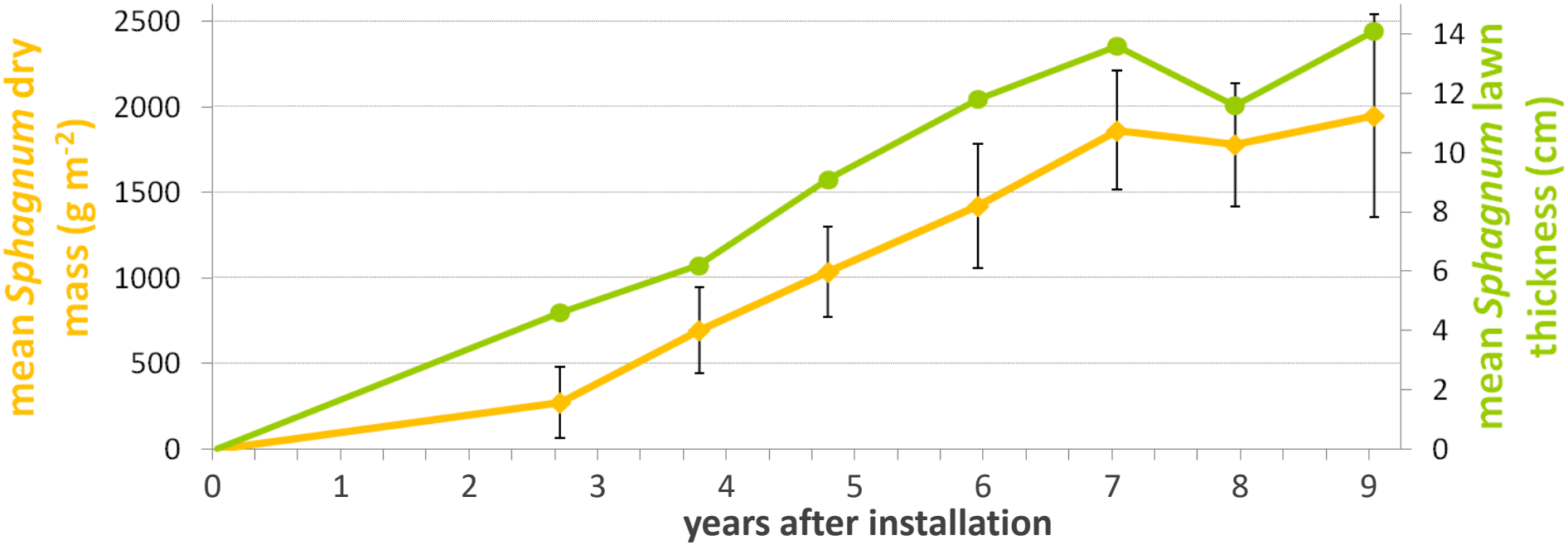

- Growth in biomass and lawn thickness is related
- Low productivity during establishment phase + stagnation at dry conditions
- Biomass after 9 years: 19.5 t ha^{-1} = 2.2 t ha^{-1} yr^{-1}
- Max. biomass productivity 690 g m^{-2} a^{-1}

Gaudig et al. 2017, Mires and Peat

history of *Sphagnum* paludiculture

GREIFSWALD MIRE CENTRE

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TORFMOOS
Glasshouse experiments +
1. field trial on 1.200 m²
(until 2014) → *Gaudig et al. 2017, 2020*

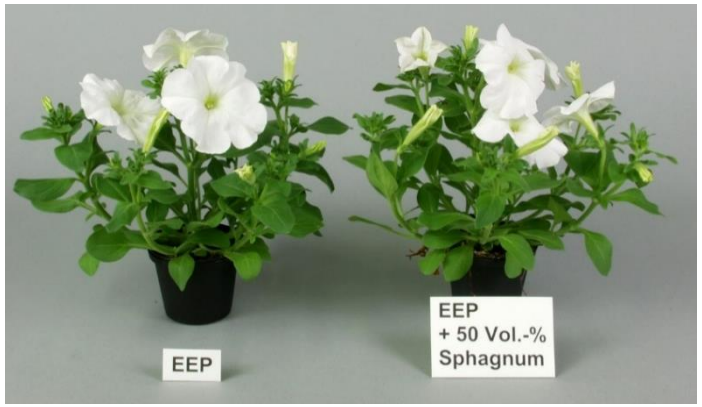
+ plant cultivation experiments
→ *Grantzau & Gaudig 2005*

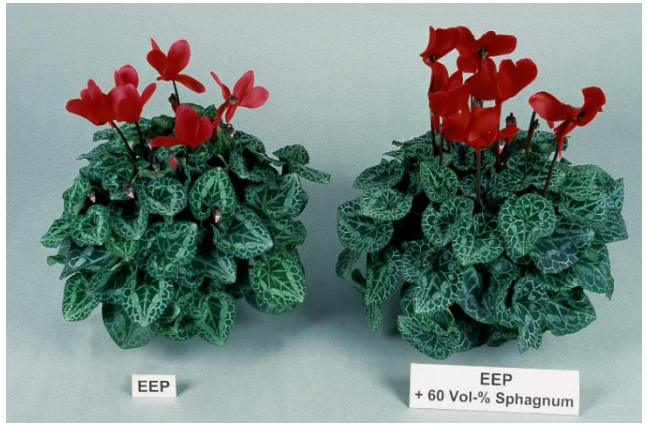
2007

2010

Sphagnum biomass is a well suitable peat substitute

GREIFSWALD MIRE CENTRE





Fotos: E. Grantzau, E. Ueber, M. Emmel

Sphagnum biomass is a well suitable peat substitute

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Poinsettia in 80% Sphagnum biomass

Foto: A. Prager

history of *Sphagnum* paludiculture

GREIFSWALD MIRE CENTRE

Joosten 1998
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2010

„peat as a renewable resource"

Literature study „*Sphagnum* as a renewable resource"
→ *Gaudig 2002, Telma*

TORFMOOS

MOOSFARM
on floating mats
→ *Gaudig et al. 2014*

PROSUGA

history of *Sphagnum* paludiculture

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2010

PROSUGA

MOOSGRÜN

→ on 4 ha bog grassland

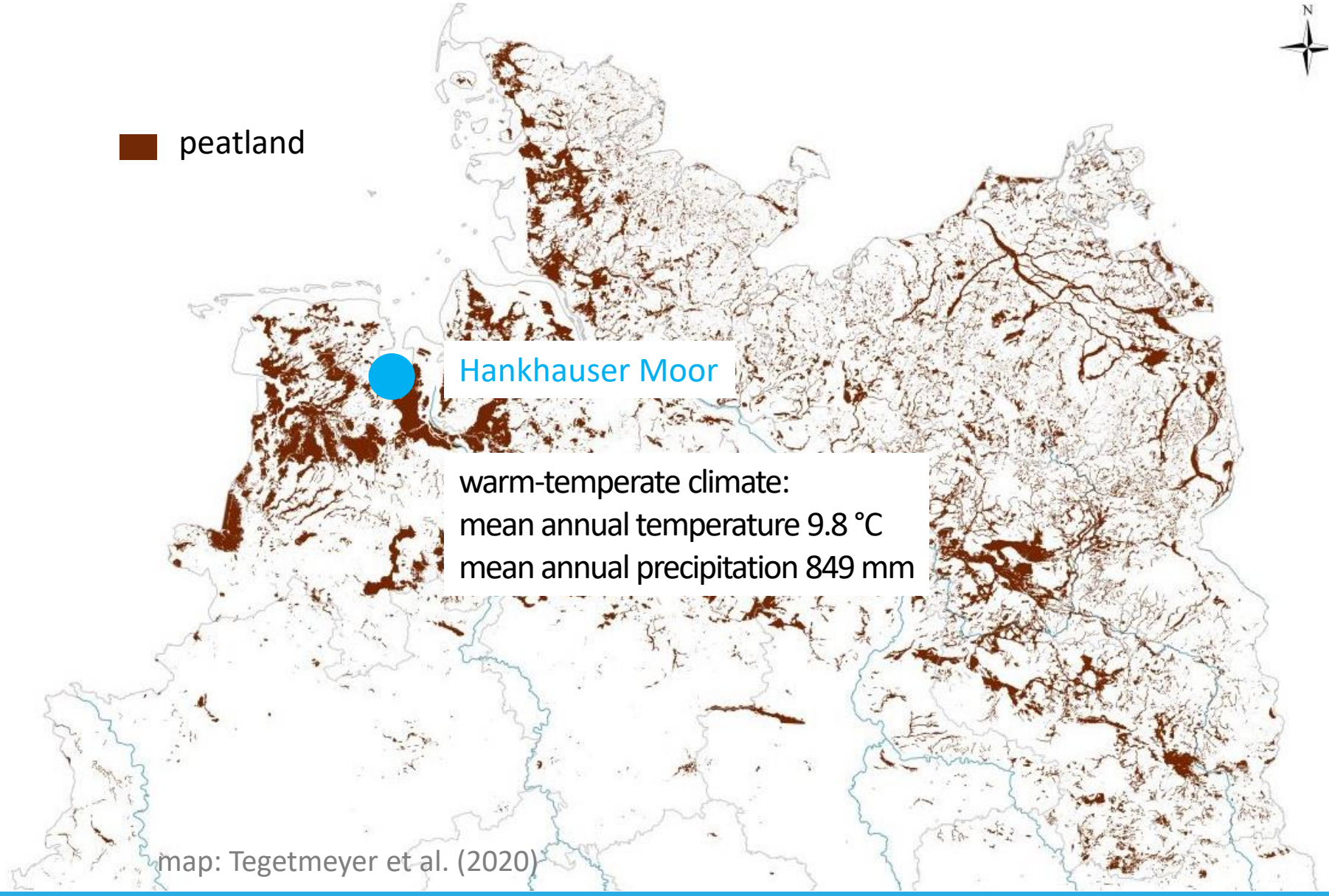
2015

MOOSWEIT

→ on 14 ha bog grassland, 1. mechanical harvest

Sphagnum paludiculture on bog grassland

GREIFSWALD MIRE CENTRE



map: Tegetmeyer et al. (2020)

Sphagnum paludiculture on bog grassland: initial situation

October 2010

Foto: Uni Greifswald

Sphagnum paludiculture on bog grassland: site preparation

→ topsoil removal + irrigation ditches

April 2011

Foto: G. Block

Sphagnum paludiculture on bog grassland: site preparation

→ topsoil removal + irrigation ditches

April 2011

Foto: Uni Greifswald

Sphagnum paludiculture on bog grassland: site installation

→ application of *Sphagnum* fragments as founder material + straw mulch

June 2011

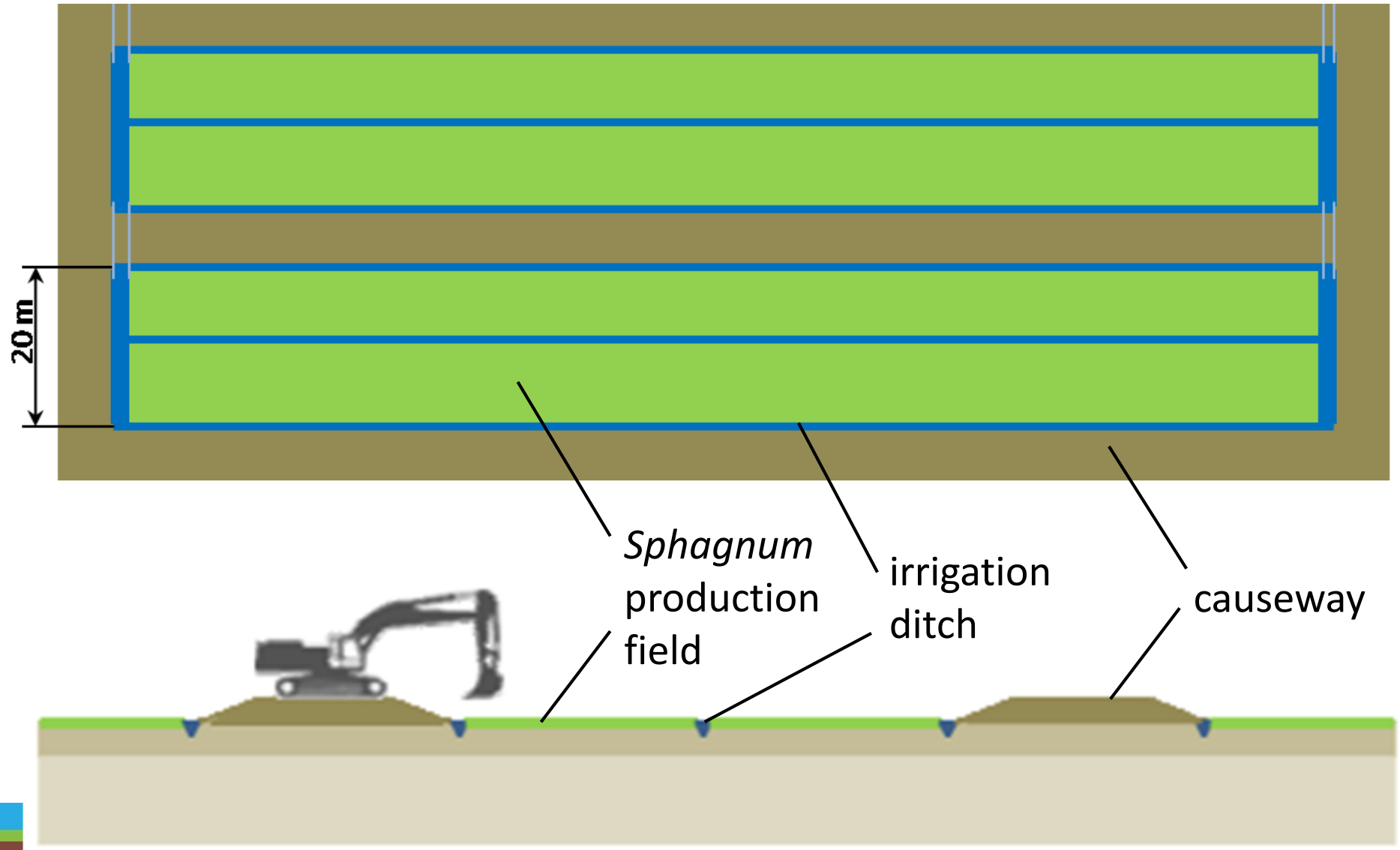
Foto: Uni Greifswald

Sphagnum paludiculture on bog grassland: after installation

June 2011

Foto: Uni Greifswald

Sphagnum paludiculture on bog grassland: production system



Sphagnum paludiculture on bog grassland: production system in the peatland Hankhauser Moor

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Foto: ASEA aerial 2017

Sphagnum paludiculture on bog grassland: establishment

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after 3 years

Sphagnum paludiculture on bog grassland: establishment

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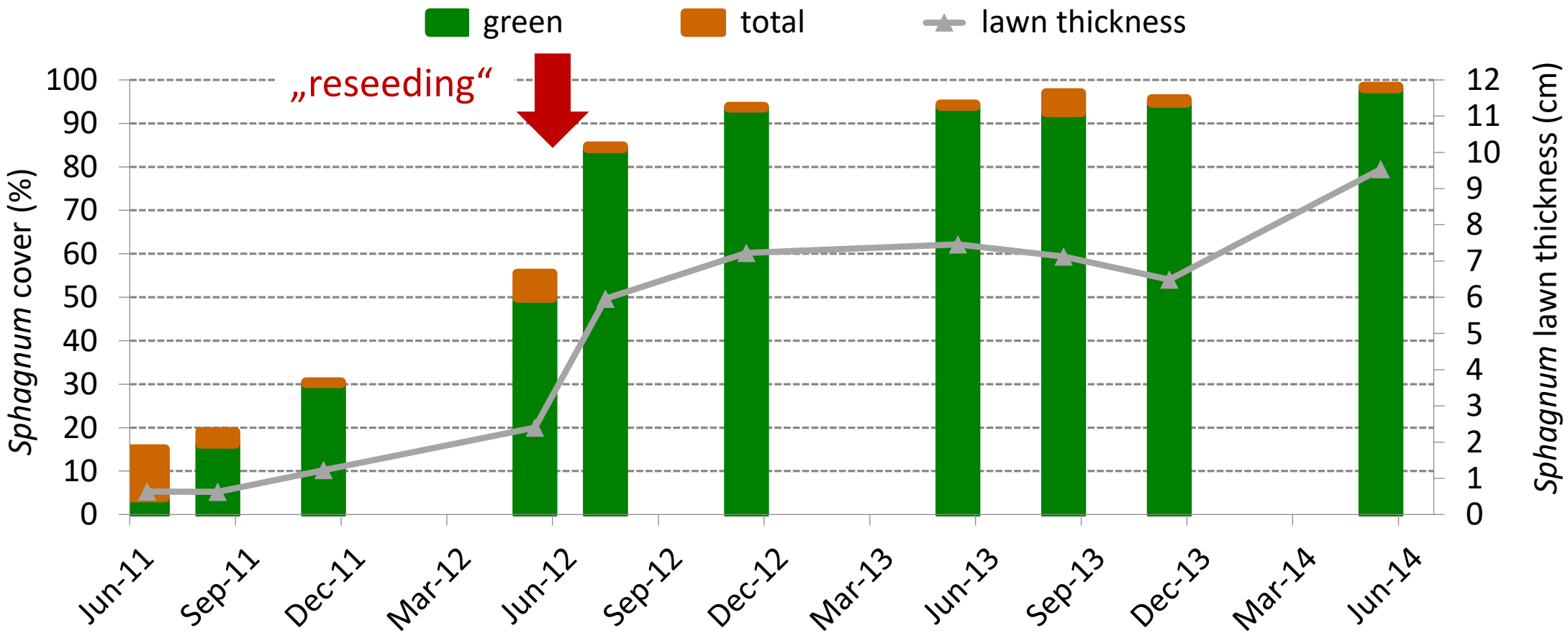
- establishment of the *Sphagnum* lawn within 1.5 years



Sphagnum paludiculture on bog grassland: development

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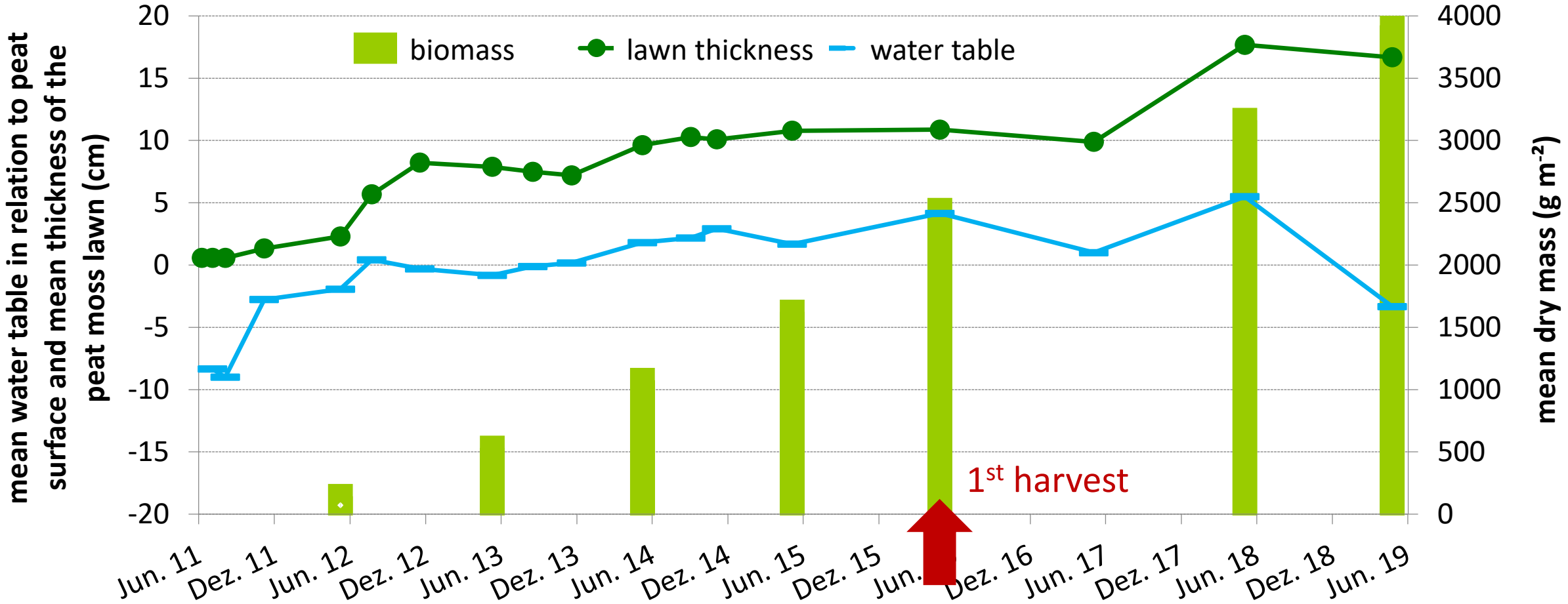
- continuous increase in lawn thickness and biomass over 8 years
- after 8 years: 40 tons *Sphagnum* dry mass per hectare (= 5 tons ha^{-1} yr^{-1} → ~200 m^3)
- water table is raised with *Sphagnum* growth



Sphagnum paludiculture on bog grassland: harvest after 5 years

- Excavator + mowing basket
- cutting of the top part (good experiences from small-scale experiments)

Foto: G. Block

Sphagnum paludiculture on bog grassland: harvest after 5 years

https://www.youtube.com/watch?v=jng6sTf0rwg&t=126s

Tests of other harvest machines

- 07.12.2021 successful test of *Sphagnum* harvest in Hankhauser Moor with Robert Wellink and the company loglogic


Company Hanze Wetlands with a scarifier
https://www.paludikultur-niedersachsen.de/kompetenzstelle-paludikultur/filme.html

19.05.2022 test of a new mowing machine from mera rabeler in the Hankhauser Moor

https://www.ardmediathek.de/video/die-maus/die-landwirtschaft-und-das-klima/wdr/Y3JpZDovL3dkci5kZS9CZWl0cmFnLWEyMzcyNzMzLWUzYTMtNDhhYy04ZDUzLTA0ZmZhYWYyNjYyOA?isChildContent

test of another mowing machine from Brielmeyer with mowing bar

history of *Sphagnum* paludiculture

GREIFSWALD MIRE CENTRE

2010

PROSUGA

MOOSGRÜN
→ on 4 ha bog grassland

2015

MOOSWEIT
→ on 14 ha bog grassland, 1. mechanical harvest

2019

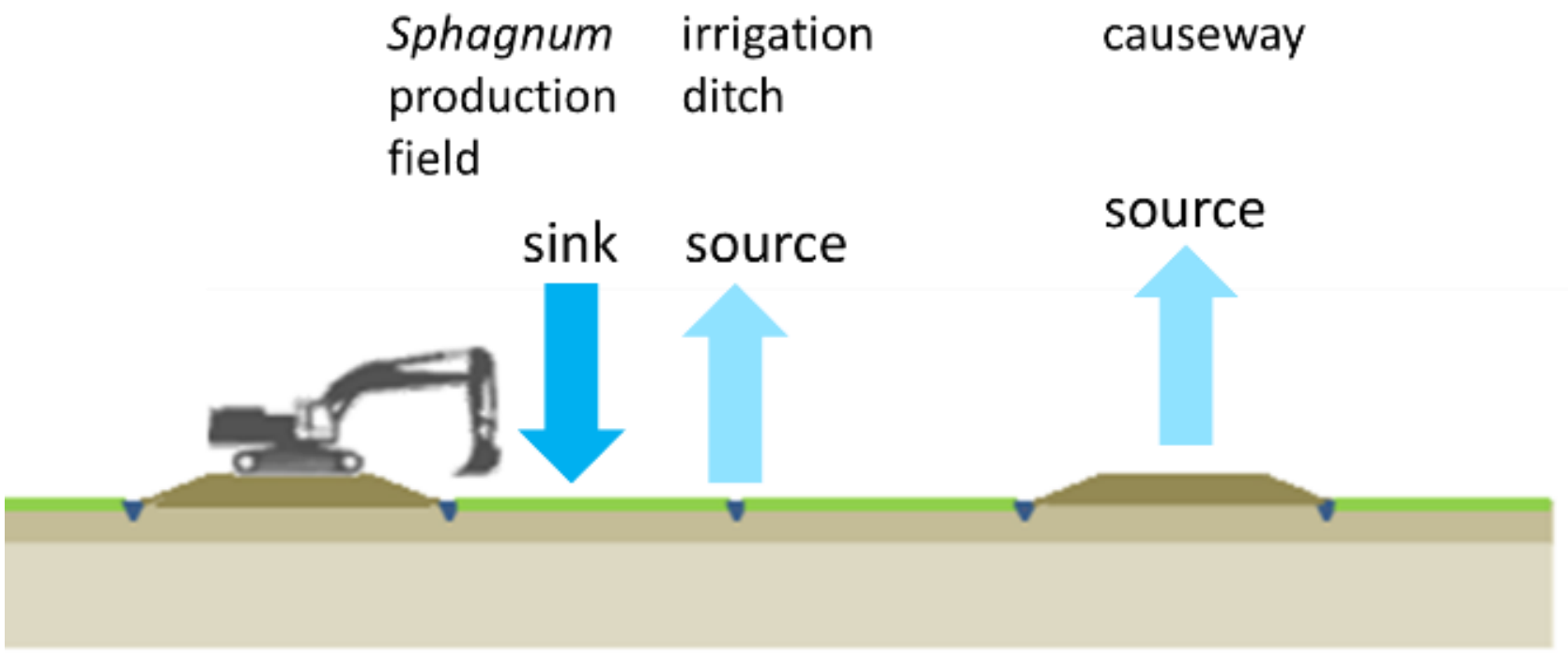
OptiMOOS:
→ on 17 ha bog grassland

Optimisation of *Sphagnum* paludiculture on bog grassland

GREIFSWALD MIRE CENTRE

→ Minimisation of GHG emissions by:

1. Minimisation of the share of irrigation ditches
2. Minimisation of the topsoil removal

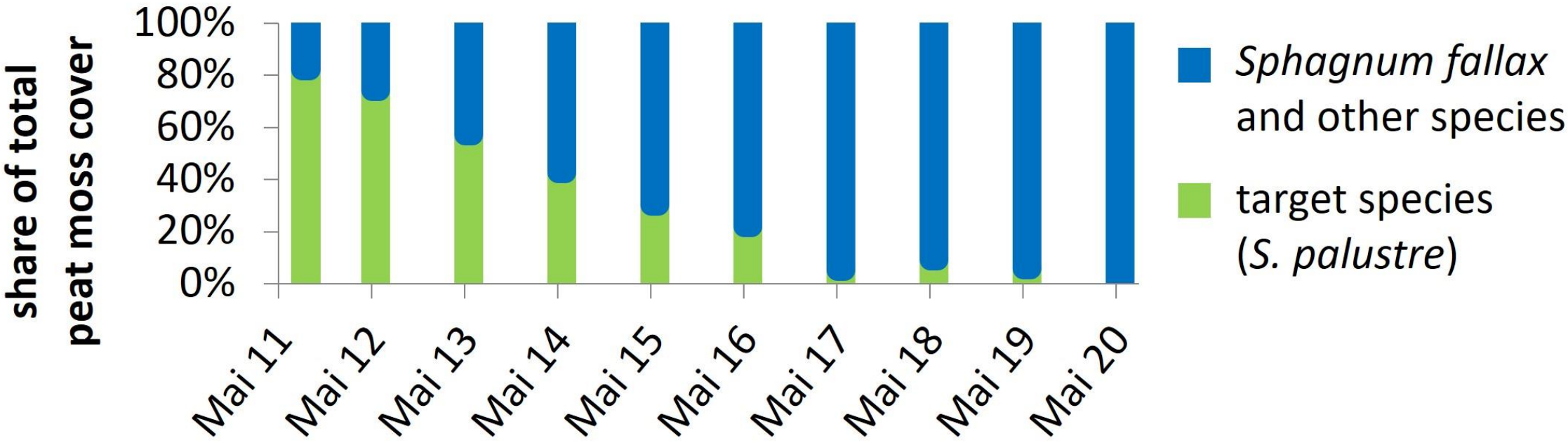


Optimisation of *Sphagnum* paludiculture on bog grassland

GREIFSWALD MIRE CENTRE

→ promotion of target species

- decrease of target species, increase of *Sphagnum fallax*
- main reason: high nutrient input



Optimisation of *Sphagnum* paludiculture on bog grassland

GREIFSWALD MIRE CENTRE

→ promotion of target species

- decrease of target species, increase of *Sphagnum fallax*
- main reason: high nutrient input

→ basins with *Typha* and *Phragmites*: filtration of water before using it for the irrigation of *Sphagnum*

history of *Sphagnum* paludiculture

GREIFSWALD MIRE CENTRE

2010

PROSUGA

MOOSGRÜN
→ on 4 ha bog grassland

Foto: M. Heck

2015

MOOSWEIT
→ on 14 ha bog grassland, 1. mechanical harvest

MOOSzucht
→ selection and mass propagation of *Sphagnum* founder material

2019

OptiMOOS:
→ on 17 ha bog grassland

selection of high productive *Sphagnum* provenances

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- *Sphagnum* paludiculture is a new kind of agriculture with no variety of cultivars
- So far available wild provenances of *Sphagnum* species have been used for large scale experiments
- Selection of highly productive *Sphagnum* to enhance the yield of *Sphagnum* paludiculture

selection of high productive *Sphagnum* provenances

→ Selection steps…

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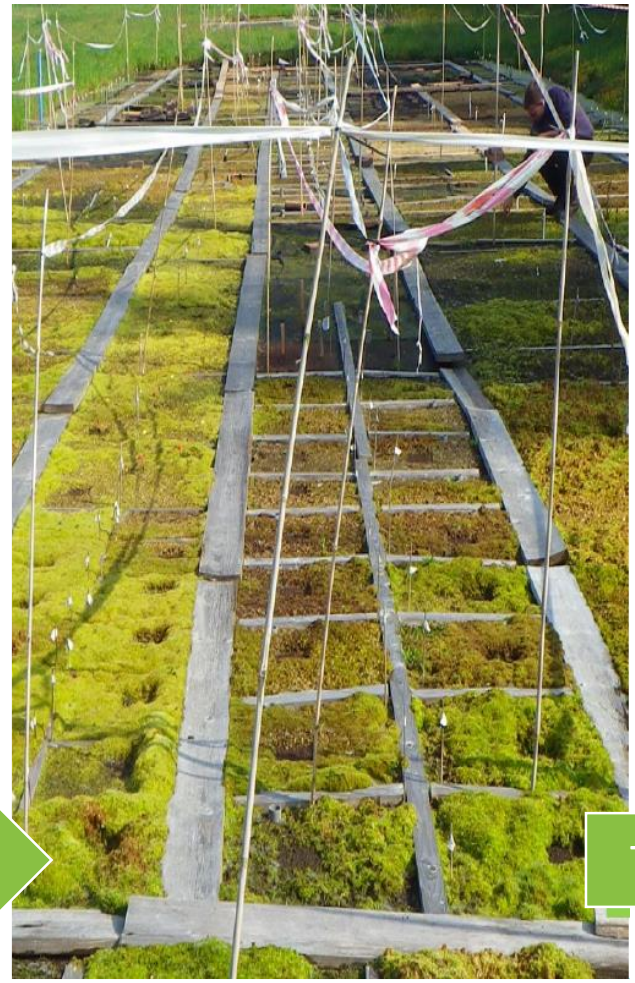
1. Common garden

15 best

2. Climate chamber

2 best

3. Field test

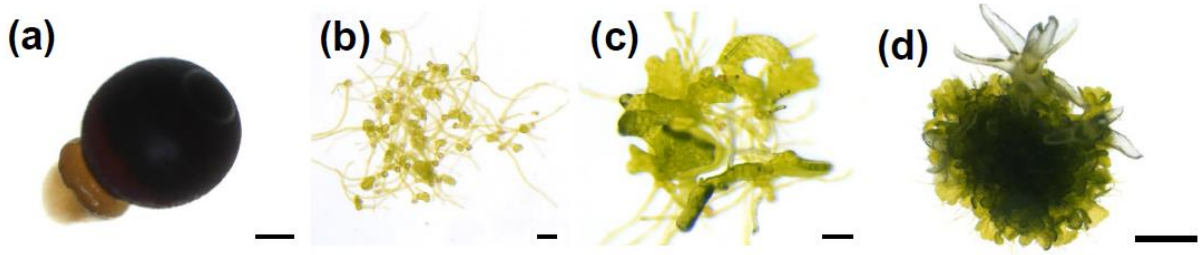


THE best

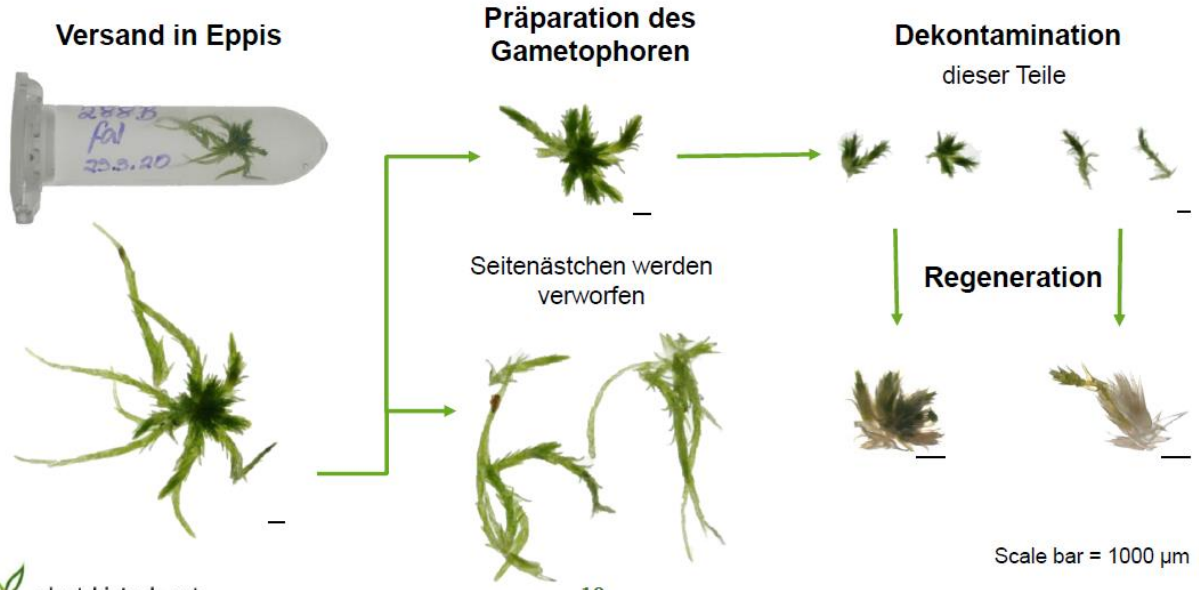
Mass propagation of *Sphagnum*

→ axenic *Sphagnum* culture from spores or vegetative plant material

1. Decontamination & germination



1. Decontamination



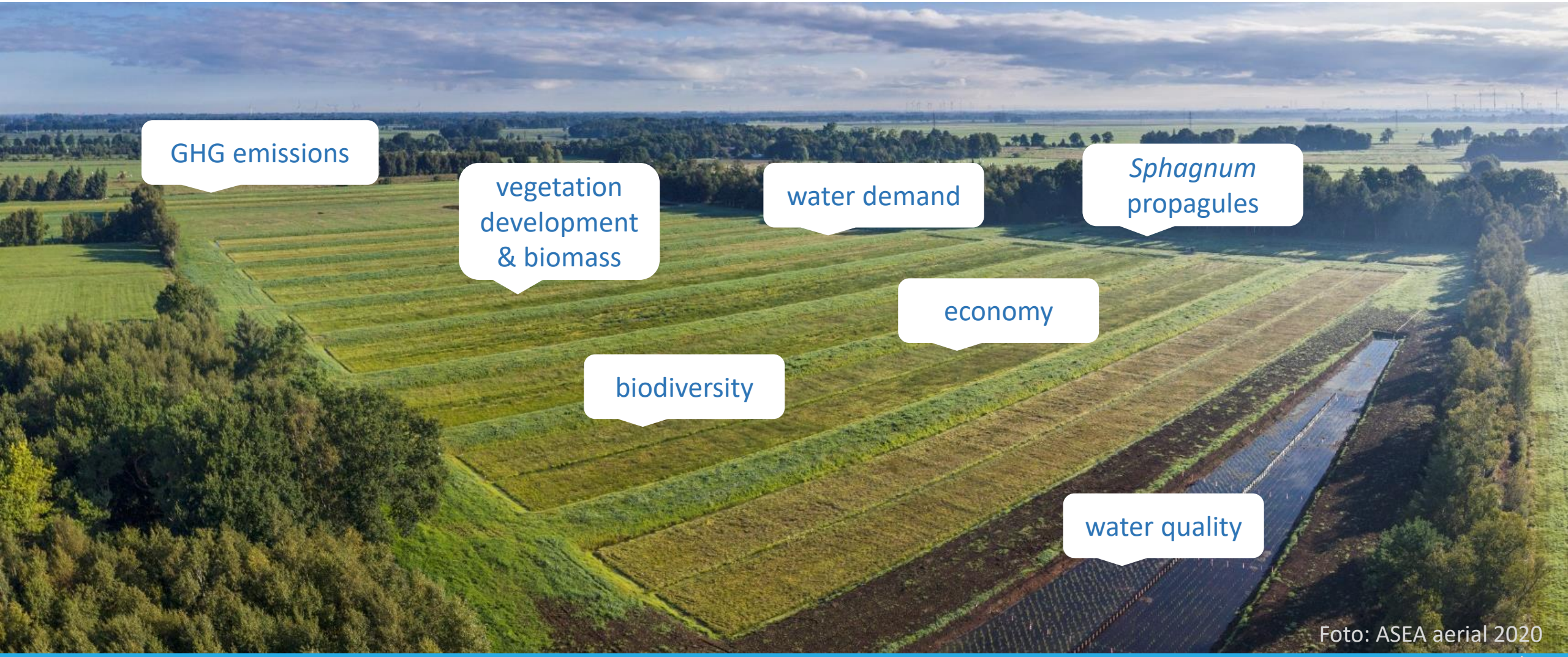
2. Axenic mass propagation in a bioreactor

Heck et al. 2021, New Phytologist

17 ha *Sphagnum* paludiculture site in the Hankhauser Moor

GREIFSWALD MIRE CENTRE

→ versatile investigations since 2010



benefits of *Sphagnum* paludiculture for…

GREIFSWALD MIRE CENTRE

…climate protection

- substantial reduction of greenhouse gas (GHG) emissions
- site in the Hankhauser Moor: net GHG release of ~2.5 t CO_{2e} ha^{-1} yr^{-1} (establishment phase) (Günther et al. 2017)
- potential for further reduction

benefits of *Sphagnum* paludiculture for…

…water filtration

substantial reduction of nutrient loads to surface waters through nutrient fixation in *Sphagnum* biomass: 34 kg N + 4 kg P ha^{-1} yr^{-1}
(Temmik et al. 2017, Vroom et al. 2020)

…mesoclimate

improvement of landscape water balance and mesoclimate: water retention, cooling

benefits of *Sphagnum* paludiculture for…

GREIFSWALD MIRE CENTRE

…biodiversity

→ surrogate habitats for rare bog species

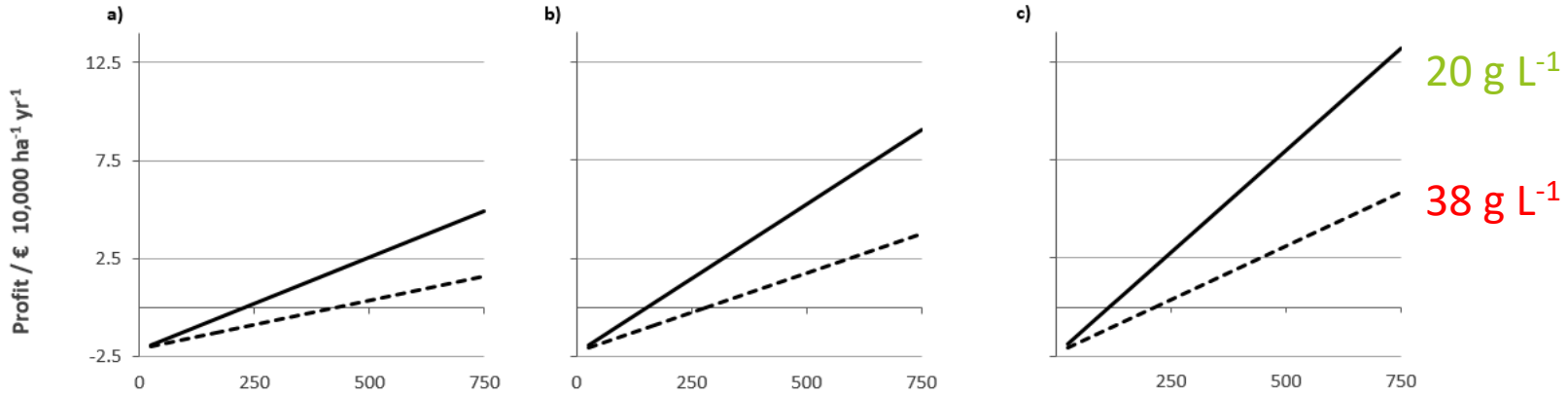
- dragon flys like *Aeshna subarctica*, *Leucorrhinia rubicunda*
- spiders like *Bathyphantes setiger*, *Pardosa sphagnicola* (cf. Muster et al. 2015, 2020)
- plants like *Drosera rotundifolia*, *D. intermedia*, *Rhynchospora alba*, *Andromeda polifolia*, *Vaccinum oxycoccus* (Gaudig & Krebs 2016)

Tabelle mit konkreten Zahlen einfügen

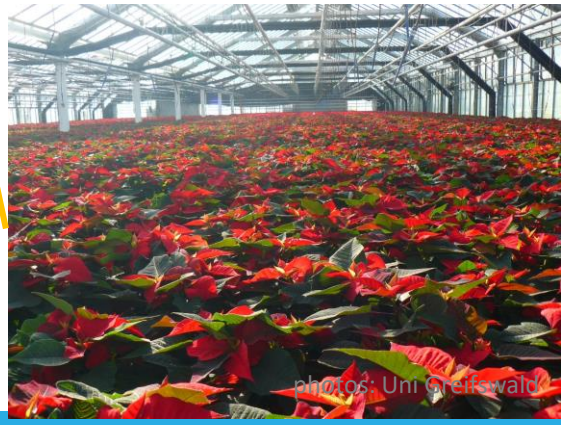
recent profitability of *Sphagnum* paludiculture

Wichmann et al. 2020, Mires and Peat

Productivity:	low	medium	high
Harvest yield [t ha^{-1} a^{-1}]	**2.0**	**3.2**	**4.4**
Bulk density [g L^{-1}]	38 /20	38 20	38 20
“founder material”	✓	✓	✓
Orchid cultivation	✗	✗ ✓	✗ ✓
Peat substitute	✗	✗	✗



Price for Sphagnum biomass/ € m^{-3}



recent profitability of *Sphagnum* paludiculture

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How to increase profitability?

- High potential for cost reduction by optimisation of the production chain
- non-market income
- Surcharche for peat free products: + 10%

Sphagnum paludiculture – lesson learnt

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Best practice with regard to optimal *Sphagnum* growth and GHG reduction:

- 80 % *Sphagnum* production fields, 20 % infrastructure (causeways, ditches)
- Conversion of bog grassland: 5-10 cm topsoil removal
- *Sphagnum* founder material: high initial *Sphagnum* cover at least 40 m^3 ha^{-1} green *Sphagnum* fragments (mainly Capitula)
- Low initial mulch cover
- Constant water supply: water table few centimeters below capitula, increasing with *Sphagnum* growth
- Low vascular plant cover → regular mowing
- Balanced NPK stochiometry

Gaudig et al. 2017, Mires and Peat

Sphagnum paludiculture in Germany

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→ 35,000 ha necessary to substitute 3 Mio. m³ ‘white peat’ in growing media

Foto: ASEA aerial 2020

Sphagnum paludiculture in Germany: current situation

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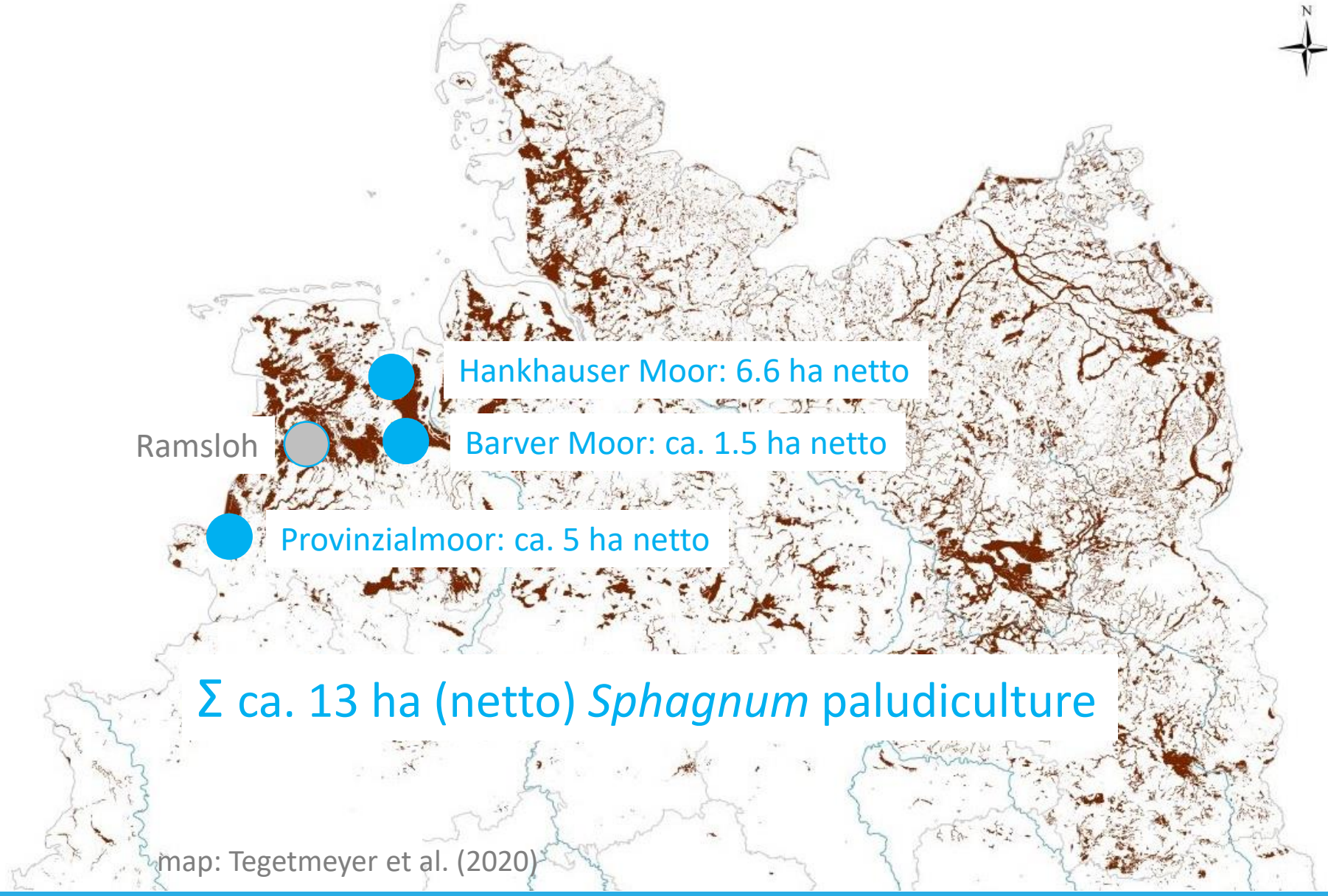

map: Tegetmeyer et al. (2020)

Sphagnum paludiculture in Germany: potential areas

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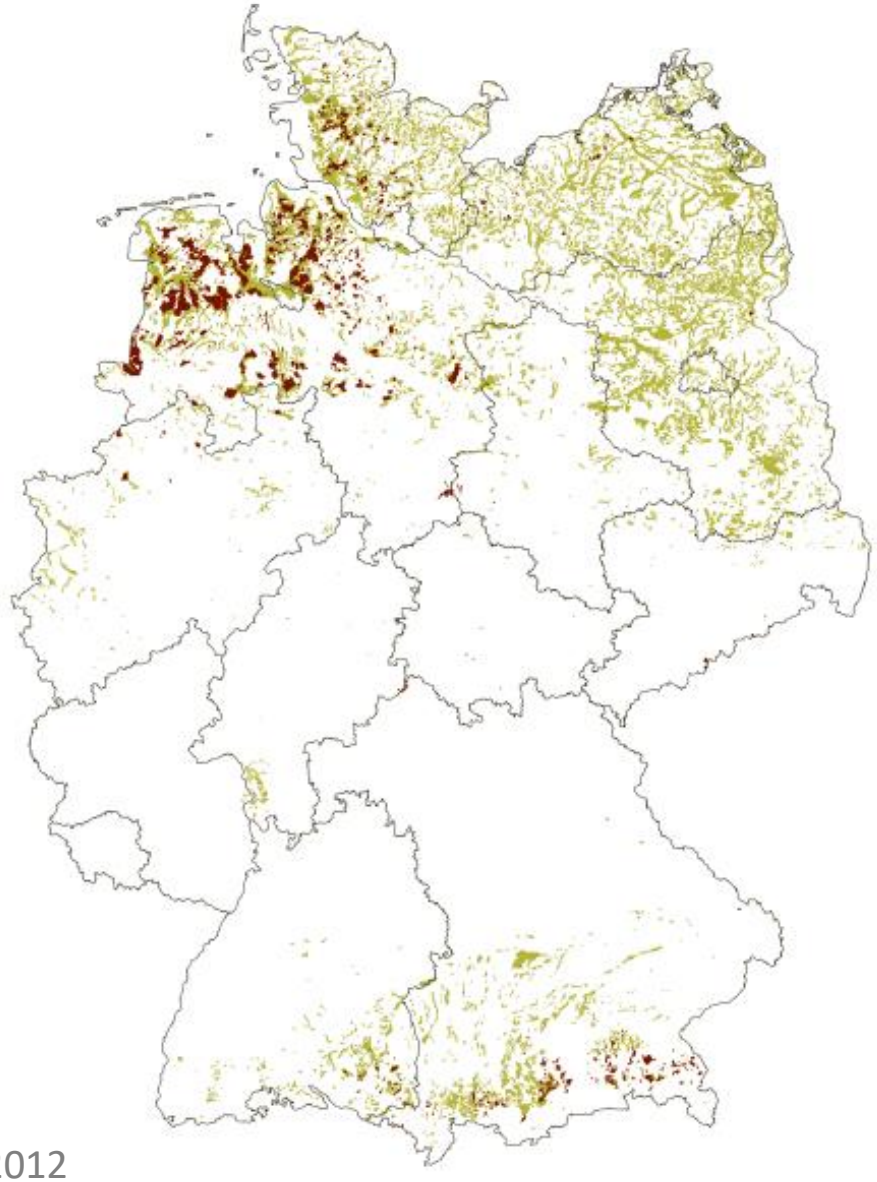
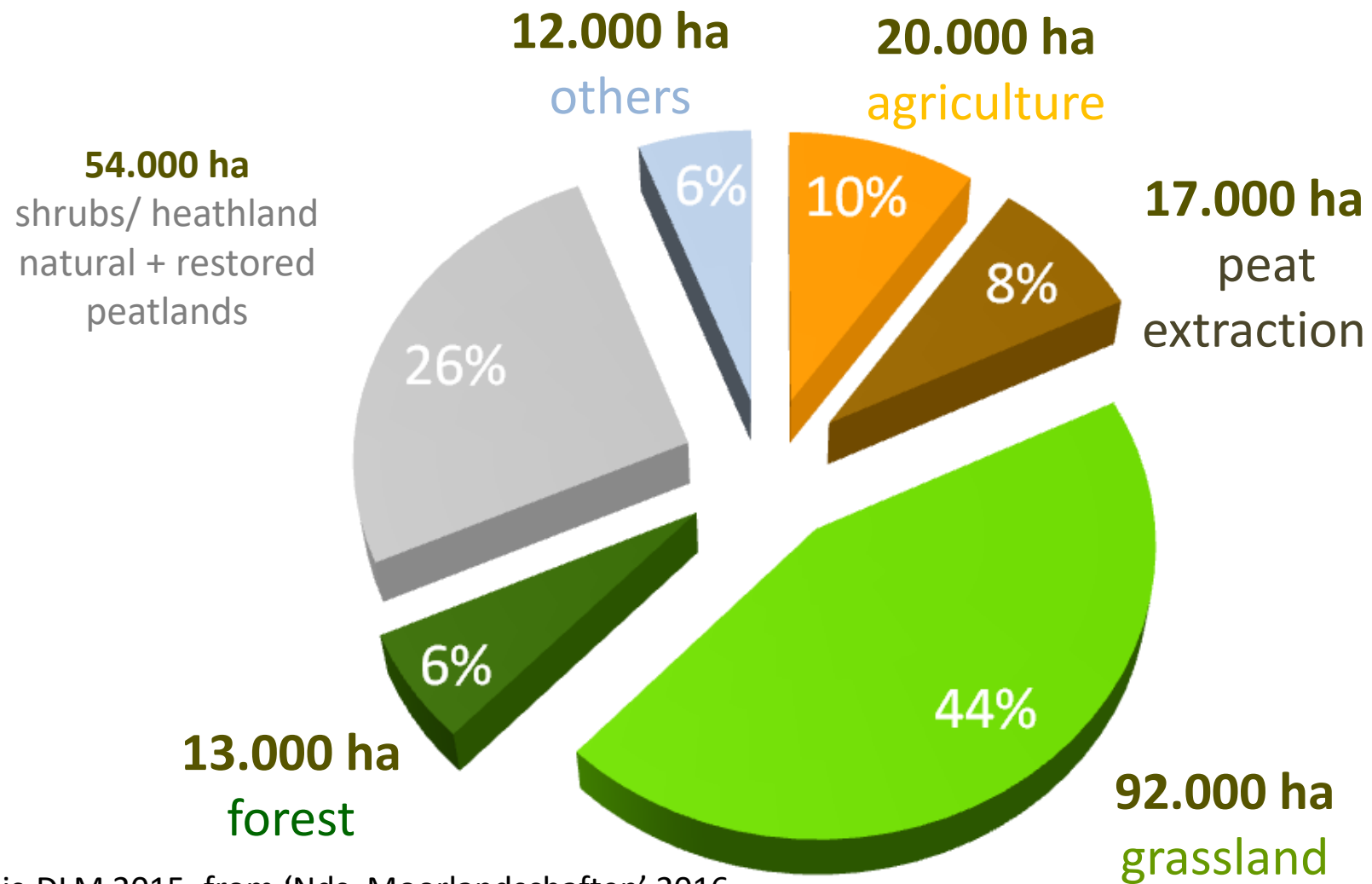
→ main bog distribution:
NW Germany
(Lower Saxony)



source: GÜK 200, NABU 2012

Current bog utilisation types in NW Germany in Lower Saxony

Total area: ca. 208.000 ha



source: after ATKIS-Basis-DLM 2015, from 'Nds. Moorlandschaften' 2016

Sphagnum paludiculture in Germany: potential areas

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cut-over bogs

→ first field trial 2004 – 2014

→ area potential in Germany: ~500 ha

bog grassland

→ field trial since 2010

→ area potential in Germany: ~90.000 ha

Sphagnum paludiculture in Germany: milestones

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- **Production** of *Sphagnum* biomass on cut-over bogs and bog grasslands works; water is the decisive parameter → ready for implementation
- Many **positive effects** proved: reduction of GHG emissions, cooling by evapotranspiration, water filtration, surrogate habitat for rare species
- **Economy**: profitable for special cultures, still too expensive as a peat substitute (or peat is too cheap), with 10% surcharche for peat free products already profitable; high potential for cost reduction
- **Production of founder material** (for the installation of new *Sphagnum* paludiculture sites): mass propagation from axenic material (generative and vegetative) possible in a bioreactor

Sphagnum paludiculture in Germany

GREIFSWALD MIRE CENTRE

→ Accelerate development & implementation:

- Incentives for peatland rewetting & paludiculture
- Commercial-scale implementation
- Increasing market demand for renewables
- Setting climate targets for the agricultural and horticultural sectors

photo: ASEA aerial 2020

Paludiculture on bogs

GREIFSWALD MIRE CENTRE

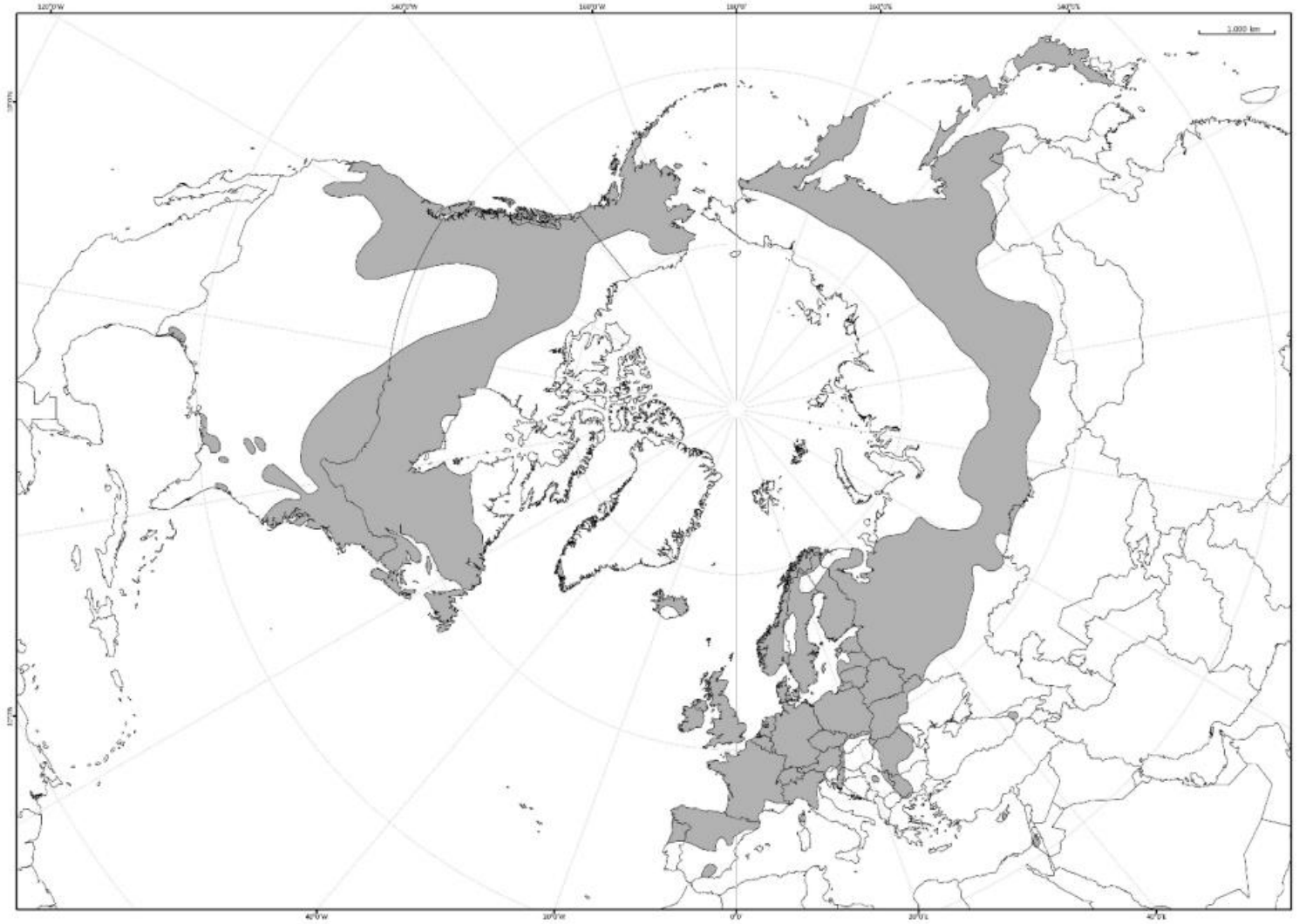
- peat mosses
- sundew/ Drosera
- …

Drosera

Drosera

- perennial insectivorous herb
- habitats: open, wet, oligotrophic
  → bogs and poor fens in particular in *Sphagnum-dominated* communities (or Sphagnum paludiculture ;))

Drosera



distribution of

D. rotundifolia in the Holarctic

(Baranyai & Joosten 2018)

Drosera

- since mediaeval times collected from natural habitats
- used as a medicine for coughs and pulmonary diseases
- commercial collection when plants flowering → greatest contents
- protected in most European countries since the 1980s due to decline of habitats
- recently mainly *Drosera madagascariensis* is used, but has lower content of pharmacologically active compounds

→ solution: cultivation of *Drosera*

Drosera cultivation

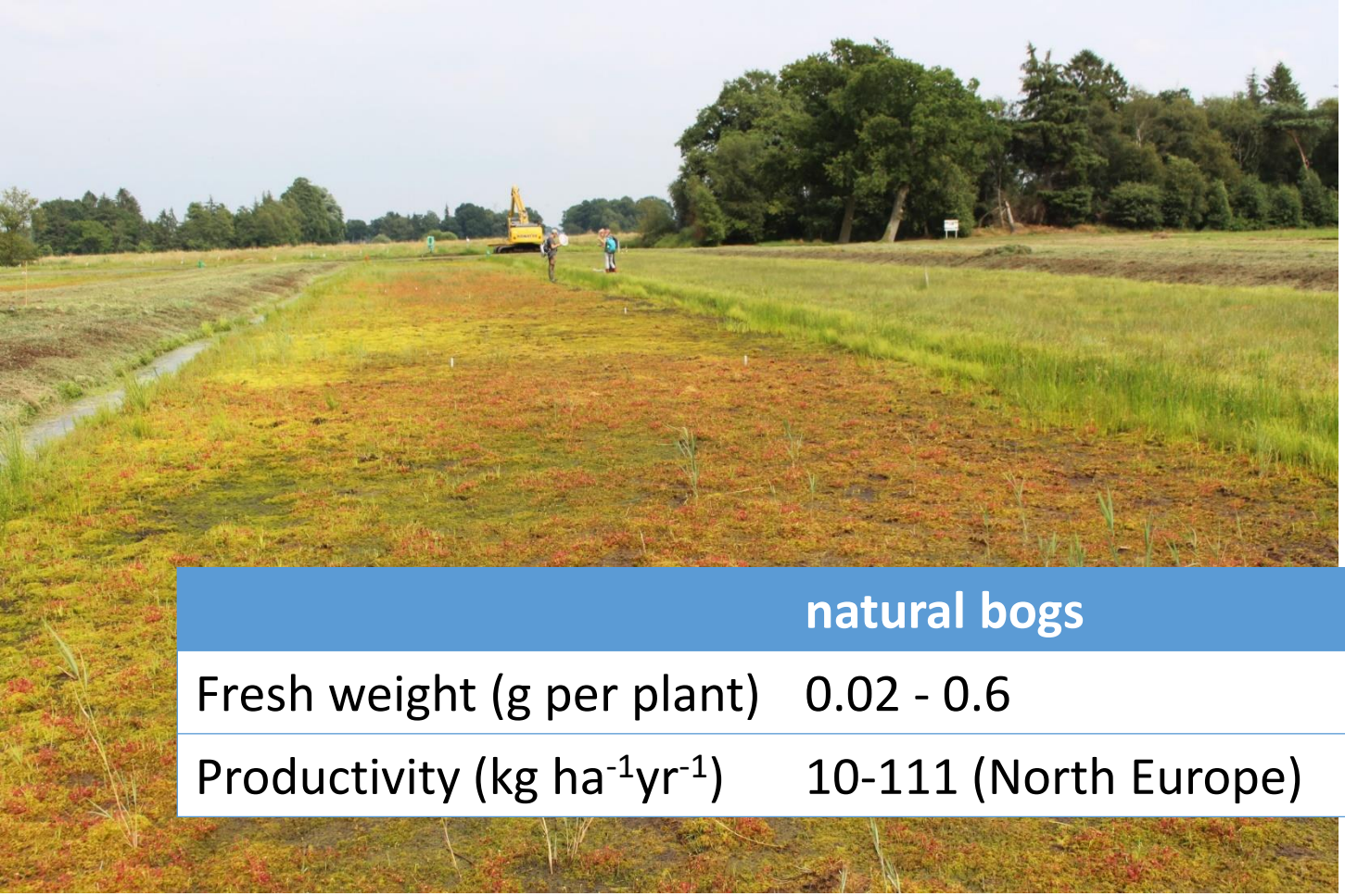
→ In co-cultivation with *Sphagnum* paludiculture

- seeds and plant pieces introduced with the *Sphagnum* founder material

Drosera cultivation

→ In co-cultivation with *Sphagnum* paludiculture

- seeds and plant pieces introduced with the *Sphagnum* founder material



	natural bogs	*Sphagnum* paludiculture site Hankhausen
Fresh weight (g per plant)	0.02 - 0.6	Ø 0.32
Productivity (kg $ha^{-1}yr^{-1}$)	10-111 (North Europe)	400 (highest in July and August)

Thanks for your attention!

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photo: ASEA aerial 2020

Sphagnum paludiculture on bog grassland

→ Summary in a video

https://www.youtube.com/watch?v=jng6sTf0rwg&t=21s