Assessment of Macrophytes Seasonal Dynamics Using Dense Time Series of Satellite Data

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Introduction

- Aquatic vegetation (i.e. **macrophytes**) communities are a key component of **shallow inland water ecosystems**, acting on and interacting with:
  - other primary producers (e.g. phytoplankton)
  - biogeochemical cycles (e.g. carbon pools, N and P cycles)
- **New generation** of **EO** platforms (i.e. Sentinel-2), are crucial step forward towards operational monitoring of such dynamic ecosystems.

- We set up a **multitemporal experiment** based on **SPOT5 Take5** data over a fluvial-lake ecosystem with the objective of:
  - investigating the potential of high spatial (10m) and temporal (5 days revisit) resolution satellite data for monitoring macrophyte coverage and their inter-annual morpho-functional dynamics

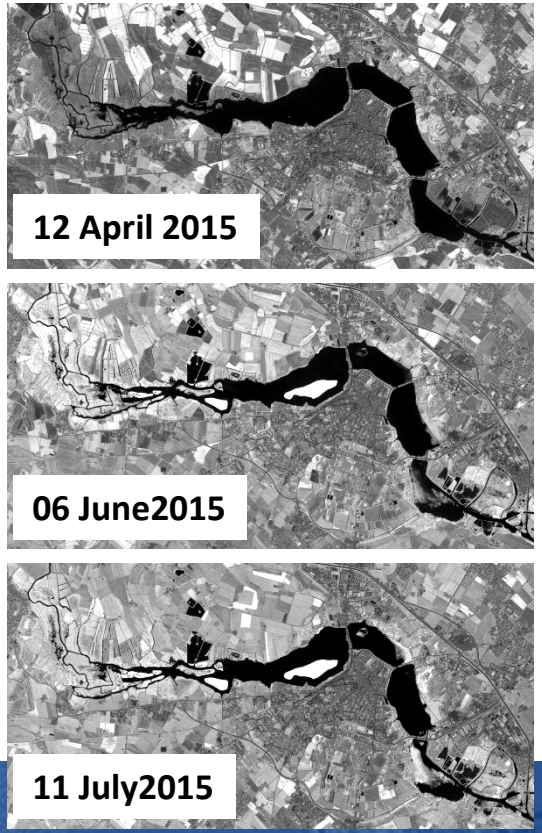
Project context

- **INFORM**: Improved monitoring and forecasting of ecological status of European INland waters by combining Future earth ObseRvation data and Models

- **Macrosentinel**: Macrophytes Phenology Assessment using Sentinel-2

Study area

- **Mantua lakes system**
  - North Italy: 45°10’ N, 10°47’ E
  - **Fluvial-lake** system with connected **wetlands**
  - Water body area: **6.1 km²**
  - Average depth: **3.5 m**
  - **Hypertrophic**, different **macrophyte** stands
  - High anthropic pressure over the watershed (agriculture, husbandry, industry)
  - **SPOT5Take5 site: Mantua**



Target species

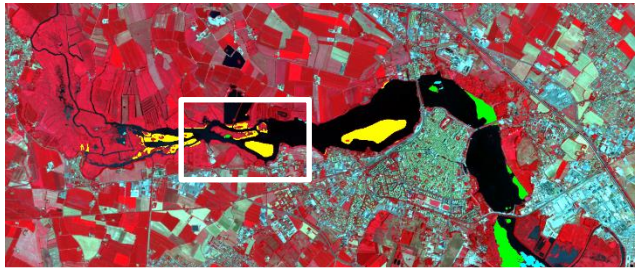
- Main macrophyte species sampled:
  - ***Nuphar lutea*** (floating-leaved rhizophyte)
  - ***Nelumbo nucifera*** (emergent rhizophyte)
  - ***Trapa natans*** (floating pleustophyte)



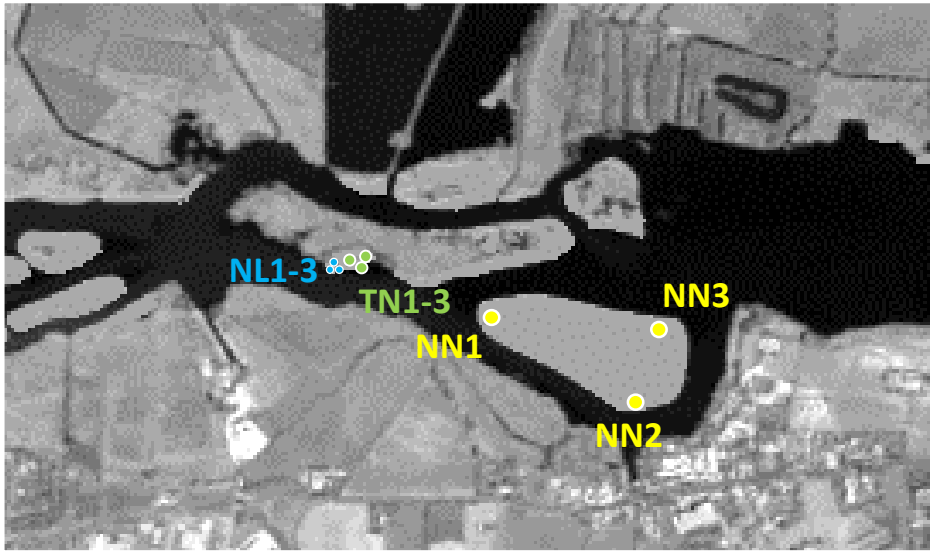



Macrophyte parameters data

- **45 samples**:
  - 3 sampling points per species (9 per date)
  - 5 sampling dates in 2015 (12 May, 11 June, 16 July, 31 July, 4 September)

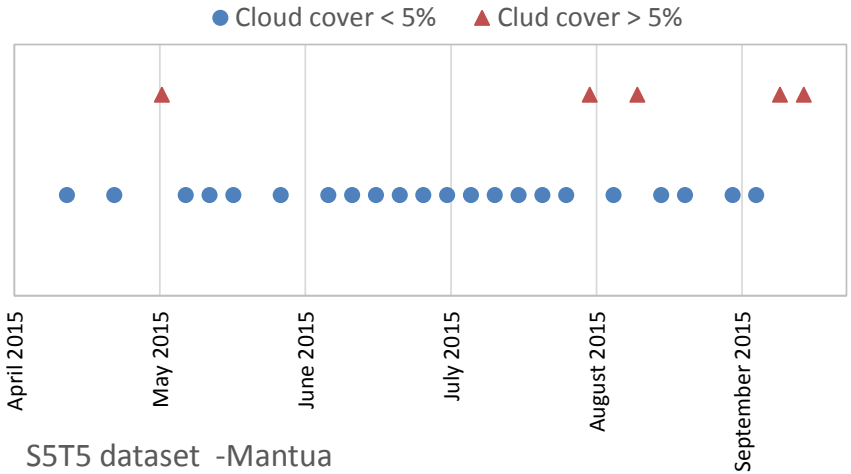


- **Collected data**:
  - Fractional cover (fC)
  - Leaf Area Index (LAI)
  - Above-water biomass (Biom)
  - Chlorophyll-a leaf content (Chl-a)



Satellite data

- **SPOT 5 HRG data**
  - **4 spectral bands**:
    - Green (0.50-0.59 µm)
    - Red (0.61-0.68 µm)
    - NIR (0.78-0.89 µm)
    - SWIR (1.58-1.75 µm)



  - **5 day** revisit (Take 5 experiment):
    - 27 scenes processed to L2A (surface reflectance)

Methodological approach

- **Cloud cover screening** (<5% over study area, 22 S5T5 scenes used)
- Extraction of **time series** of relevant **SIs** (14, see table)
- Selection of **best linear predictors** (3 SIs) for each macrophyte parameter
- SI-based **semi-empirical linear modelling** of each parameter (fC, LAI, Biom, Chl-a)
  - Collected samples split: **2/3 for training**, **1/3 for validation**

SI	Formula	References	Vegetation parameters
AFRI1600	$NIR - 0.66\frac{SWIR_1}{NIR + 0.66SWIR_1}$	Karnieli et al., 2001	Fractional cover, LAI
Chl_{green}	$\frac{Green}{NIR}$	Gitelson et al., 2006	Chlorophyll content
CI_{green}	$\frac{NIR}{Green} - 1$	Hunt et al., 2011	Chlorophyll content
CVI	$NIR\frac{Red}{Green^2}$	Hunt et al., 2011	Chlorophyll content
EVI2	$2.4\frac{NIR - Red}{NIR + Red + 1}$	Jiang et al., 2008	Fractional cover, LAI, Biomass
GNDVI	$\frac{NIR - Green}{NIR + Green}$	Gitelson and Merzlyak, 1994 Lymburner et al., 2000	Fractional cover, LAI, Biomass
gWAVI	$1.5\frac{NIR - Green}{NIR + Green + 0.5}$	Tian et al., 2005	Fractional cover, LAI, Biomass
MCARI1	$1.2(2.5(NIR - Red) - 1.3(NIR - Green))$	Haboudane et al, 2004	Chlorophyll content, LAI
MTVI1	$1.2(1.2(NIR - Green) - 2.5(Red - Green))$	Haboudane et al, 2004	Chlorophyll content, LAI
NDVI	$\frac{NIR - Red}{NIR - Red}$	Rouse et al., 1974	Fractional cover, LAI, Biomass
RI	$\frac{Red - Green}{Red + Green}$	Escadafal and Huete, 1991 Bannari et al., 1995	Chlorophyll content
SAVI	$1.5\frac{NIR - Red}{NIR + Red + 0.5}$	Huete, 1988	Fractional cover, LAI, Biomass
SLAVI	$\frac{NIR}{Red + SWIR_1}$	Lymburner et al., 2000	LAI
TrVI	$\sqrt{\left(\left(\frac{NIR - Red}{NIR + Red}\right)\right) + 0.5}$	Bannari et al., 1995 Hunt et al., 2011	Chlorophyll content

Results

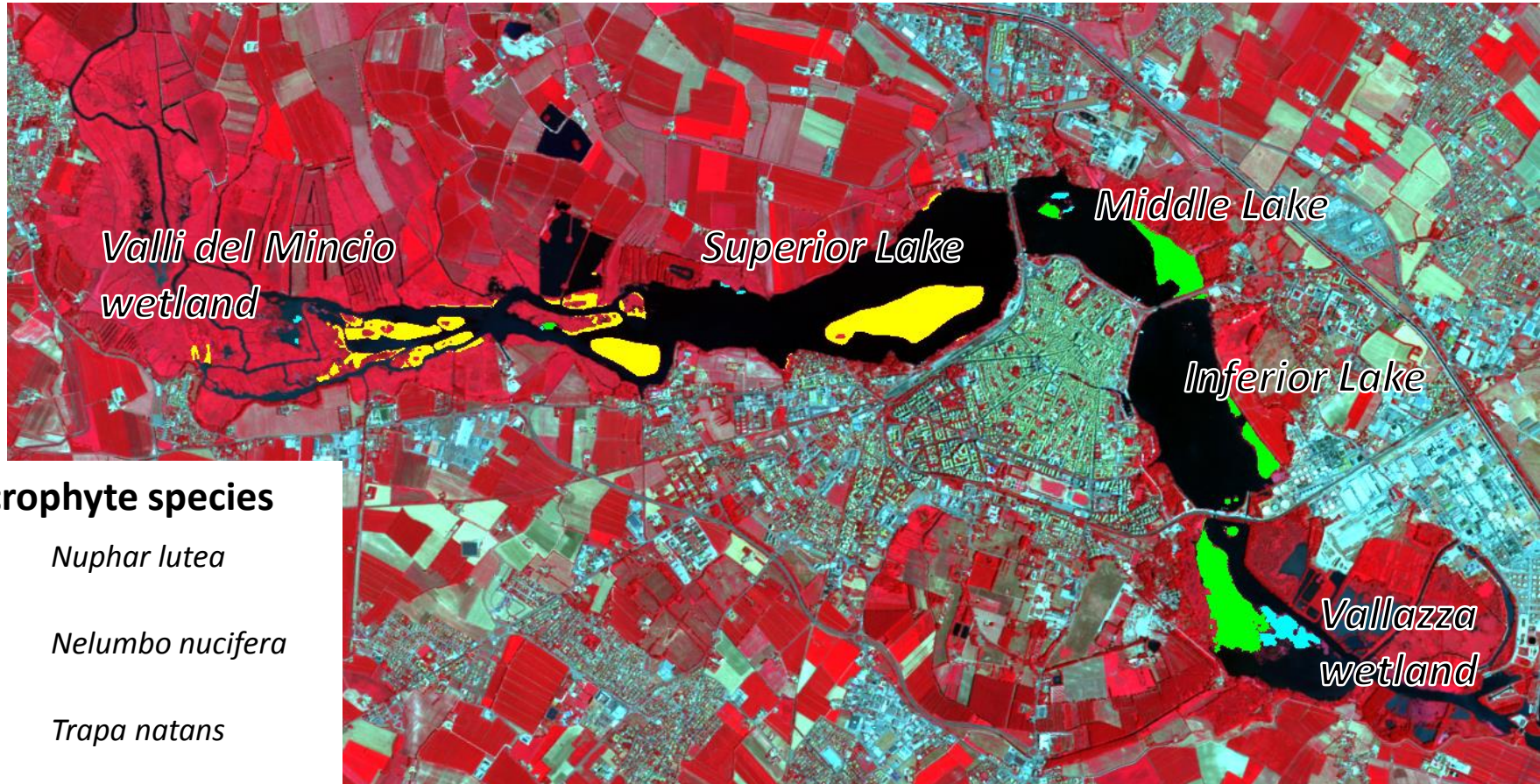
- Macrophyte functional types **map**
  - rule-based algorithm fed with multi-temporal spectral features
    - adapted from Villa et al., 2015
- Macrophyte **morpho-functional traits maps**
  - Semi-empirical linear modelling based on best SI predictors:
    - fC
    - LAI
    - Biom (above-water biomass)
    - Chl-a (canopy density)

Validation
N=14 (1/3 samples)

Macrophyte parameter	Spectral Index	R^2	MAE	rRMSE
fC (%)	AFRI1600	0.85	6.3%	0.11
	TrVI	**0.86**	**6.0%**	**0.11**
	NDVI	0.86	6.0%	0.11
LAI (m^2 m^{-2})	**MCARI1**	**0.88**	**0.14**	**0.16**
	EVI2	0.88	0.13	0.17
	SAVI	0.87	0.13	0.17
Biom (kg m^{-2})	**CVI**	**0.63**	**0.09**	**0.41**
	CI_{green}	0.56	0.10	0.47
	GNDVI	0.51	0.11	0.49
Chl-a (g m^{-2})	**CI_{green}**	**0.65**	**0.31**	**0.54**
	CVI	0.60	0.29	0.58
	gWAVI	0.55	0.35	0.61

Villa, P., Bresciani, M., Bolpagni, R., Pinardi, M., and Giardino, C. (2015). Remote Sensing of Environment, 171, 218-233.

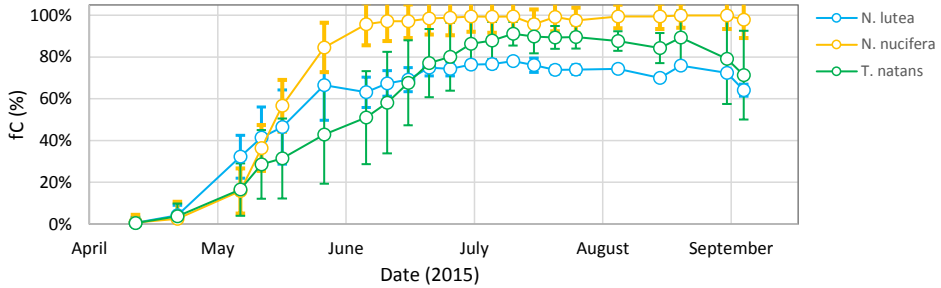
Macrophyte map



Macrophyte species

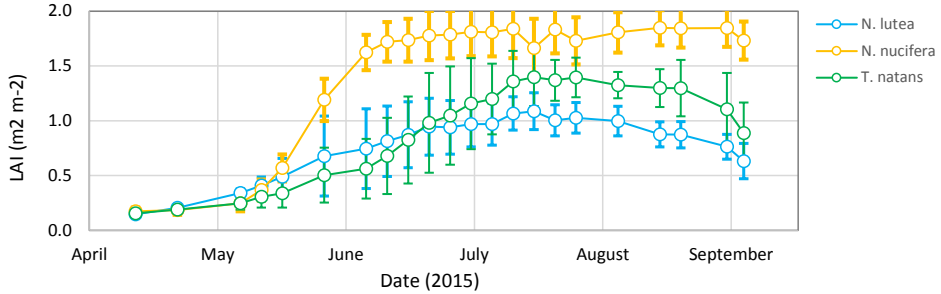
- *Nuphar lutea*
- *Nelumbo nucifera*
- *Trapa natans*

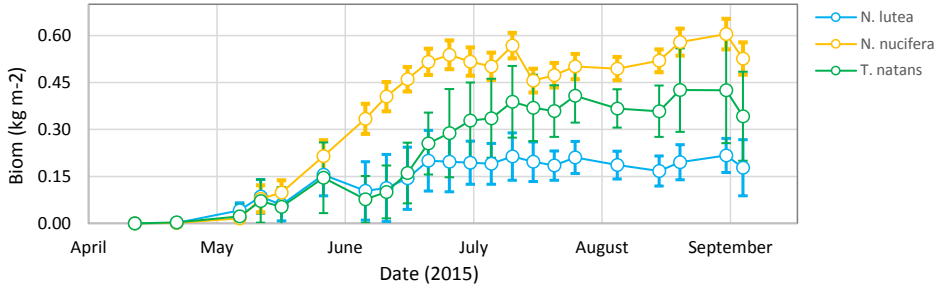
Morpho-functional traits evolution

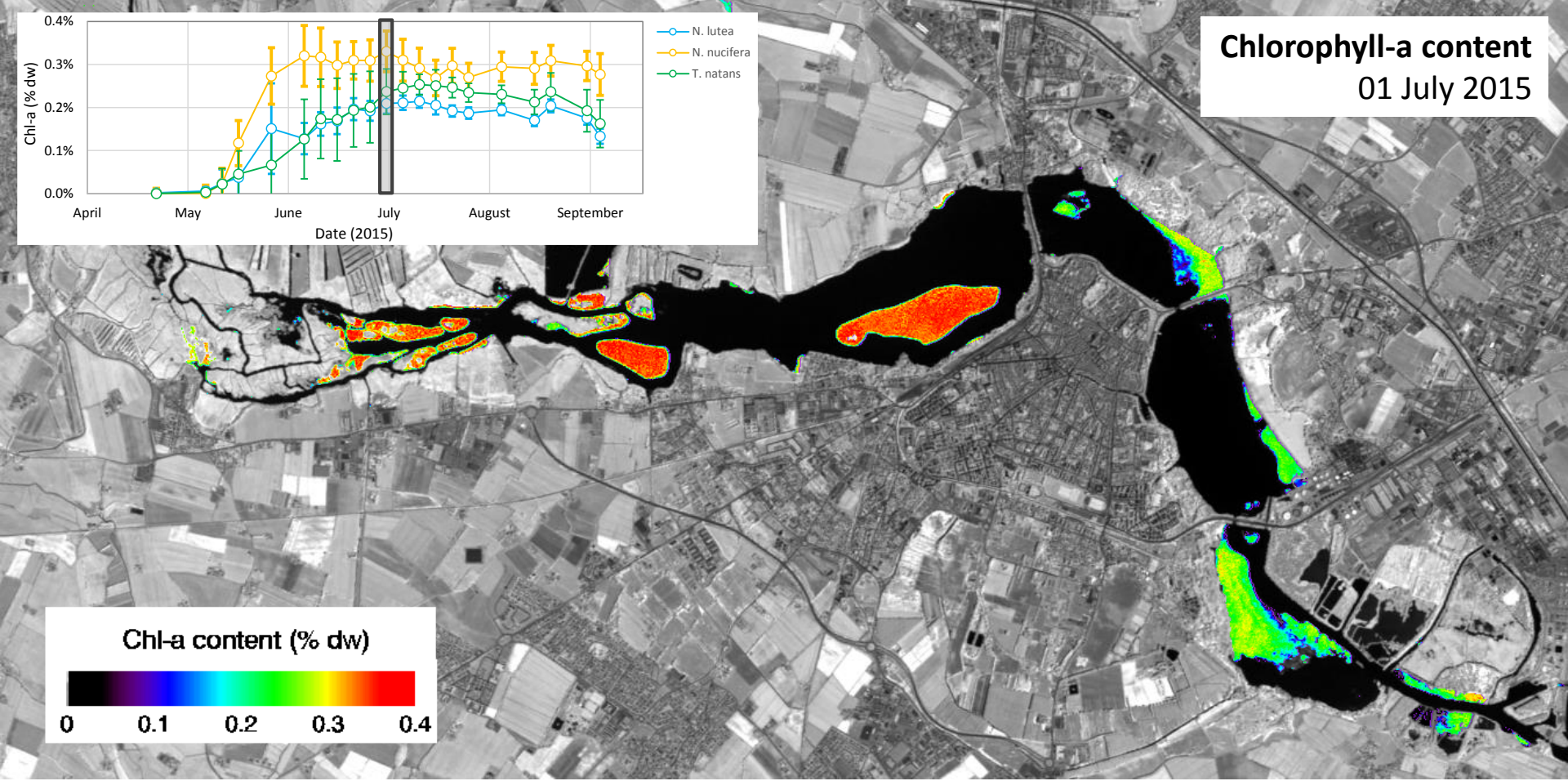


	N. lutea	*N. nucifera*	*T. natans*
Emergence timing	12 Apr	07 May	07 May
Growing phase lenght	60 days	40 days	60 days
Full canopy timing	21 June	11 June	01 July
Peak biomasss timing	26 July	30 August	20 August
Senescence starting	15 August	04 September	20 August
PoS fC	74.7±2.1%	98.6±1.2%	88.4±2.1%
PoS LAI	1.00±0.05 m2 m-2	1.79±0.06 m2 m-2	1.31±0.08 m2 m-2
PoS Biomass	0.20±0.01 kg m-2	0.52±0.05 kg m-2	0.38±0.03 kg m-2

(Pos: Peak of Season)






0.4%
0.3%
0.2%
0.1%
0.0%
Chl-a (% dw)
April
May
June
July
August
September
Date (2015)
N. lutea
N. nucifera
T. natans
Chlorophyll-a content
01 July 2015
Chl-a content (% dw)
0
0.1
0.2
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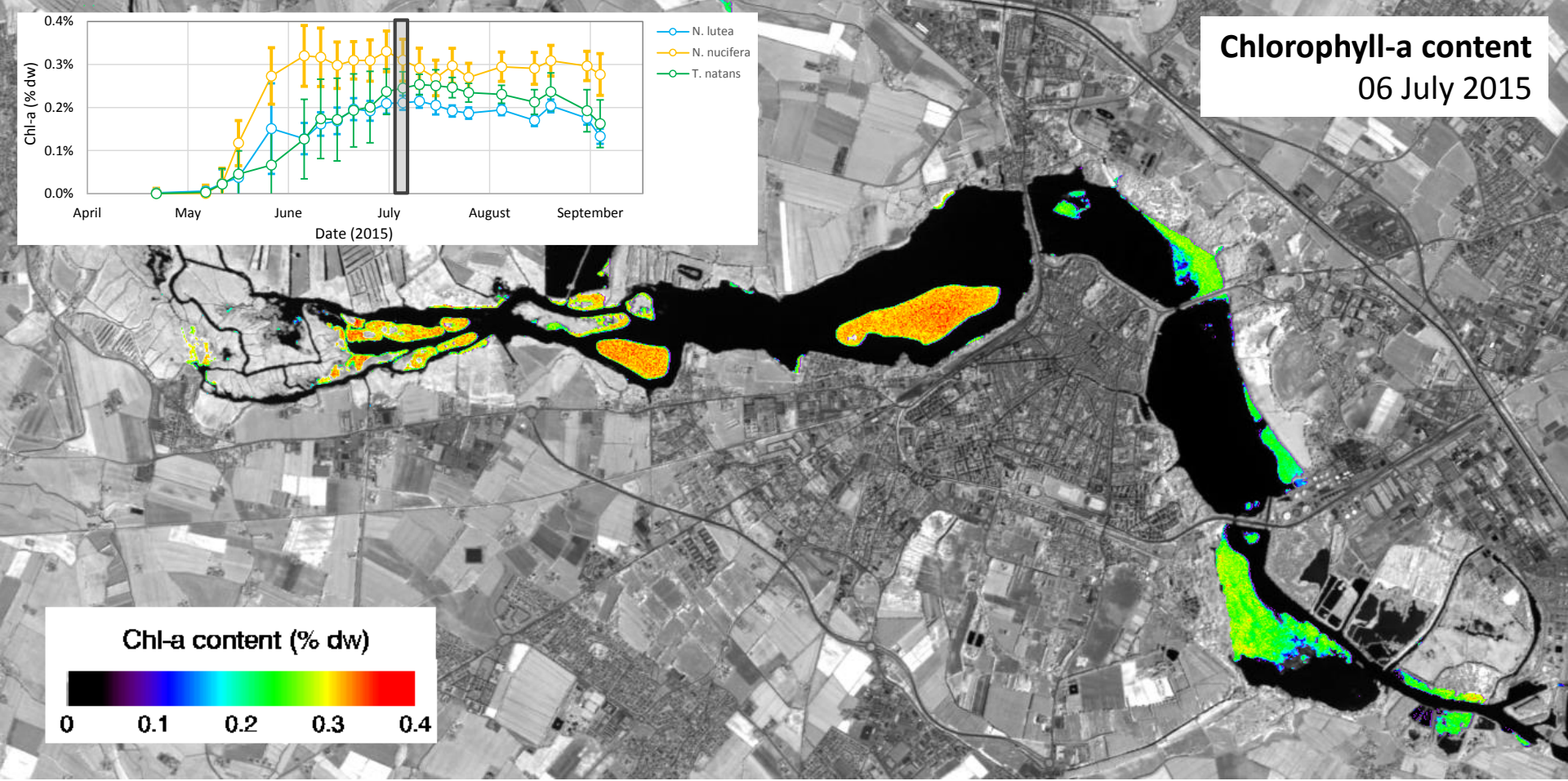
0.4%
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Chl-a (% dw)
April
May
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July
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September
Date (2015)
N. lutea
N. nucifera
T. natans
Chlorophyll-a content
06 July 2015
Chl-a content (% dw)
0
0.1
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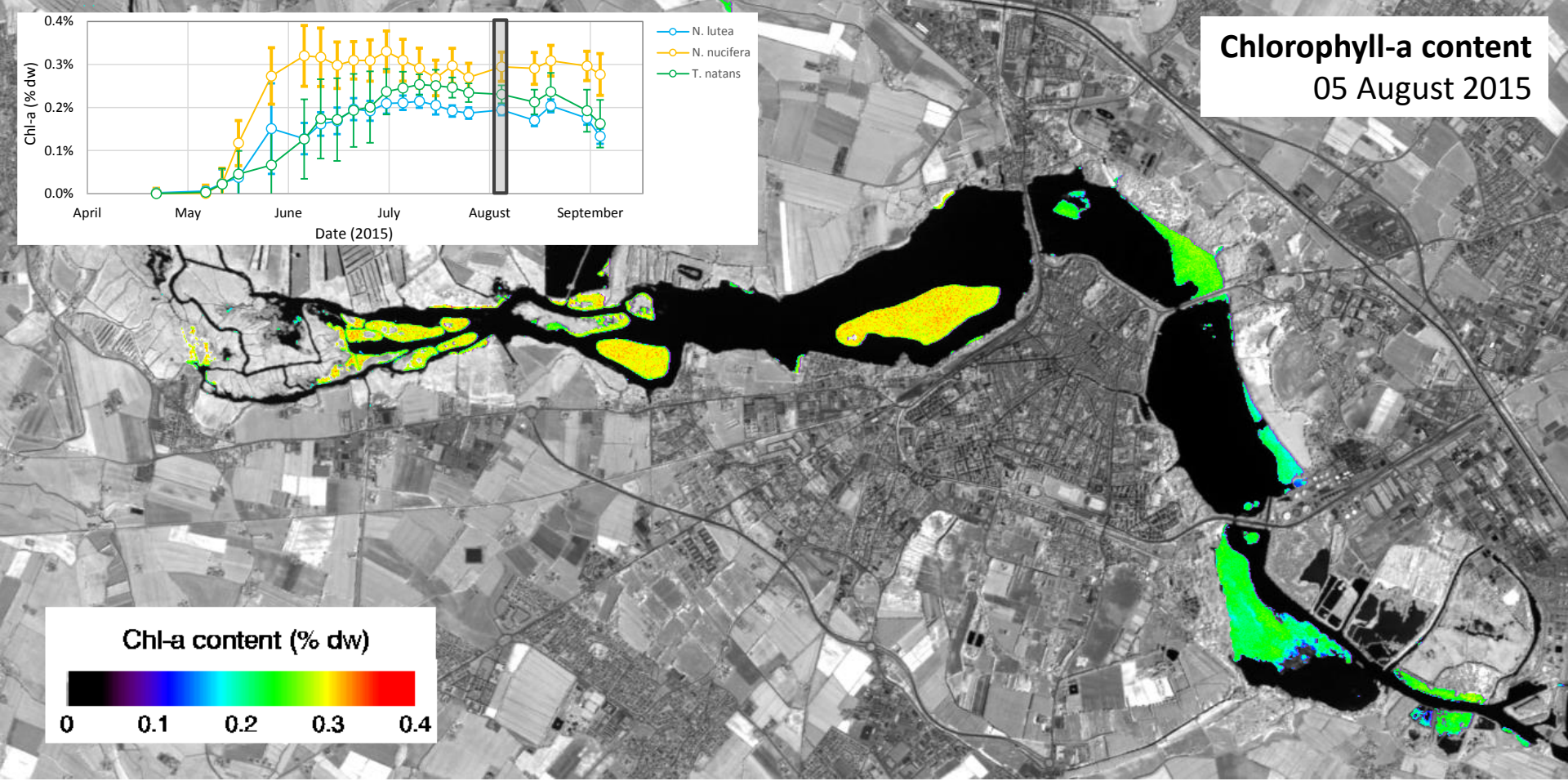
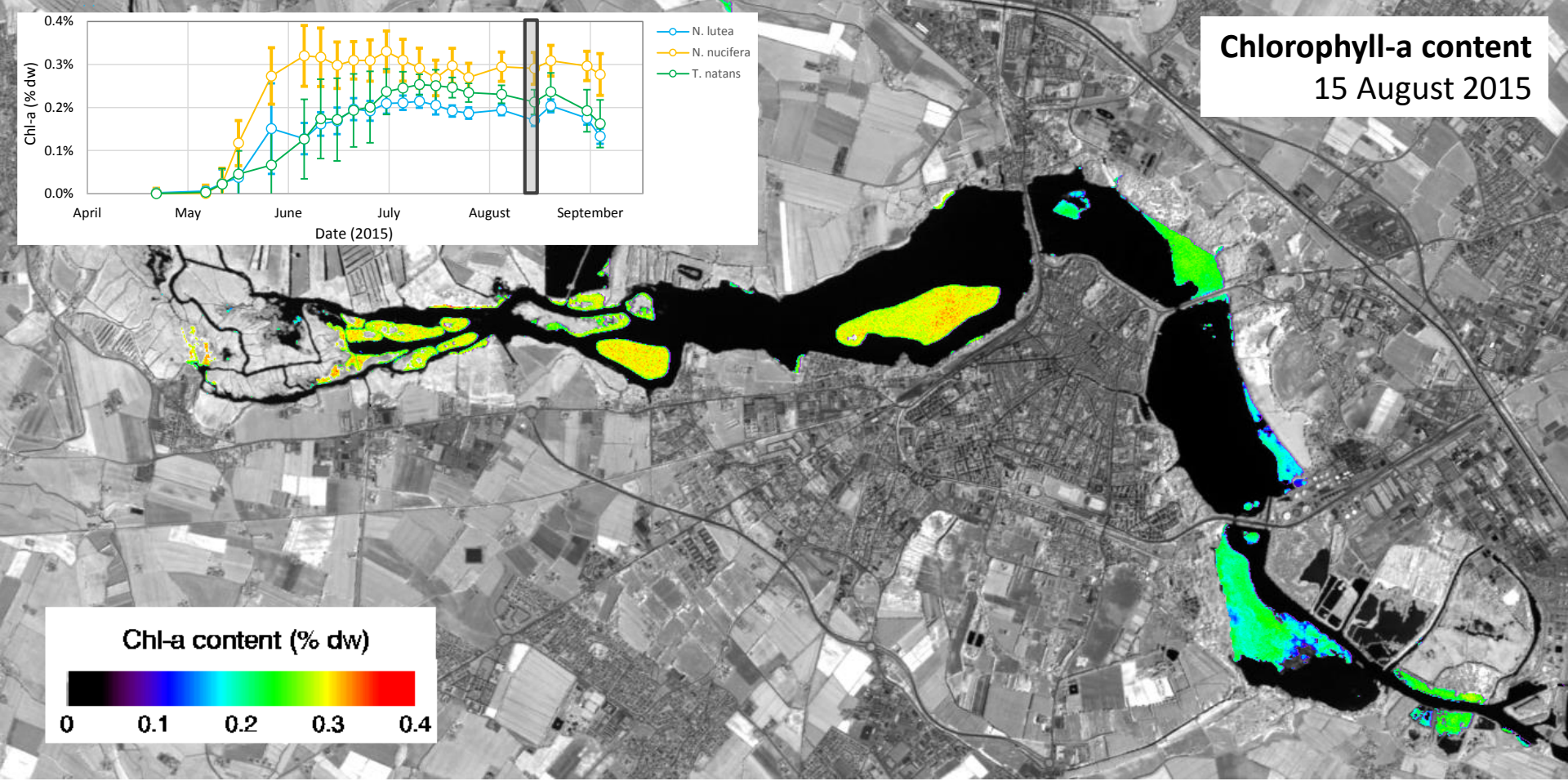
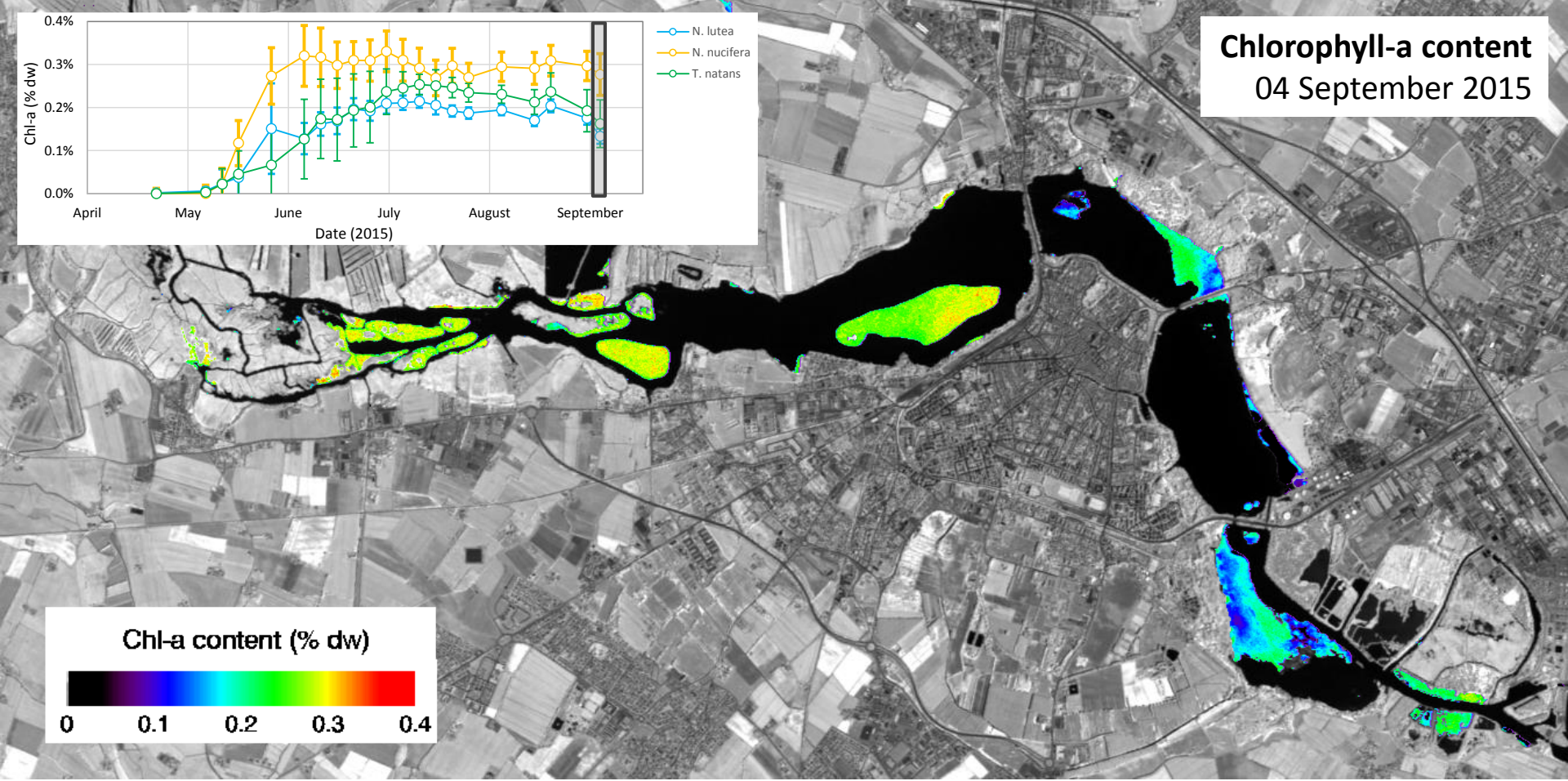


Chlorophyll-a content

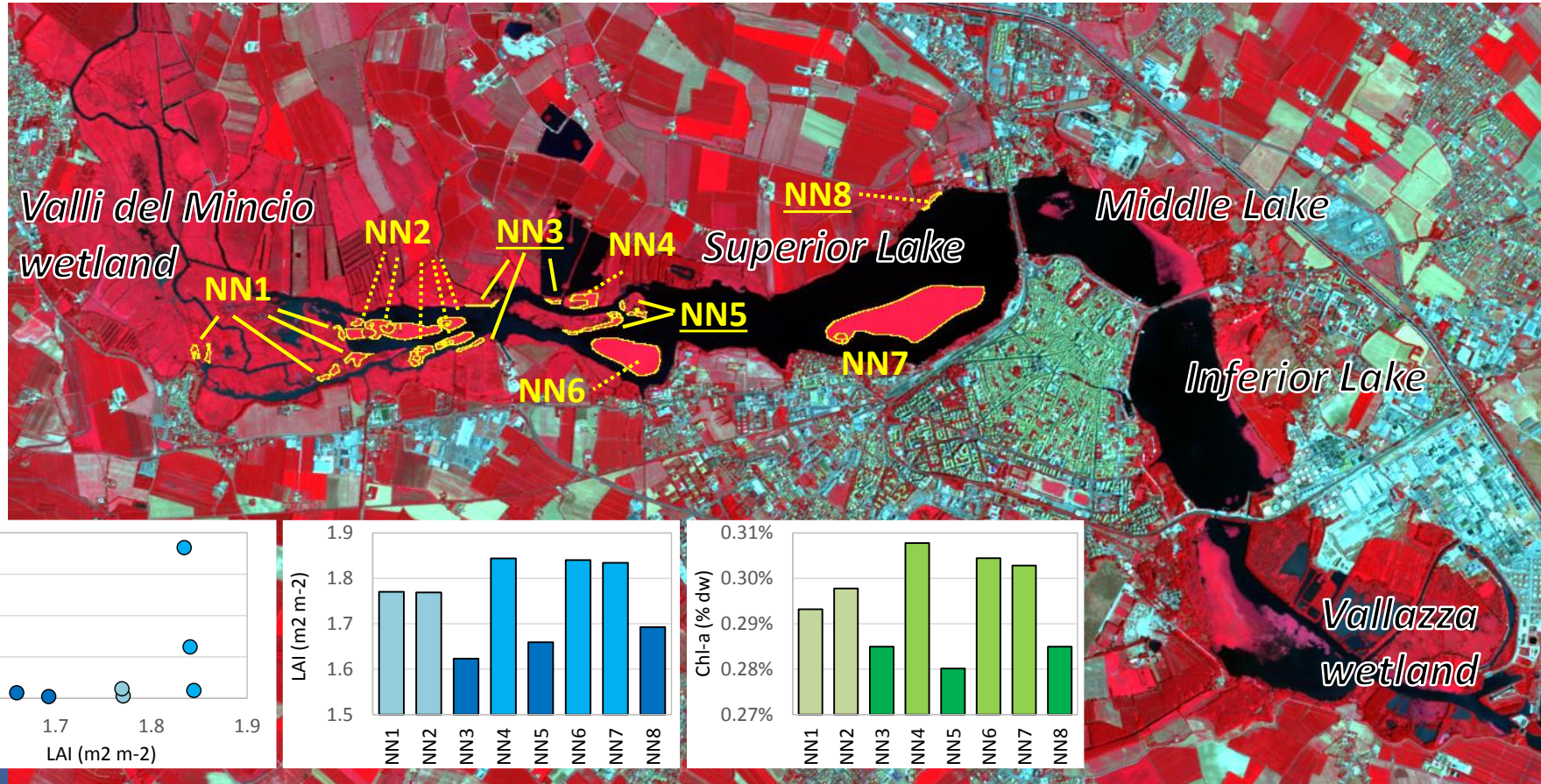
05 August 2015



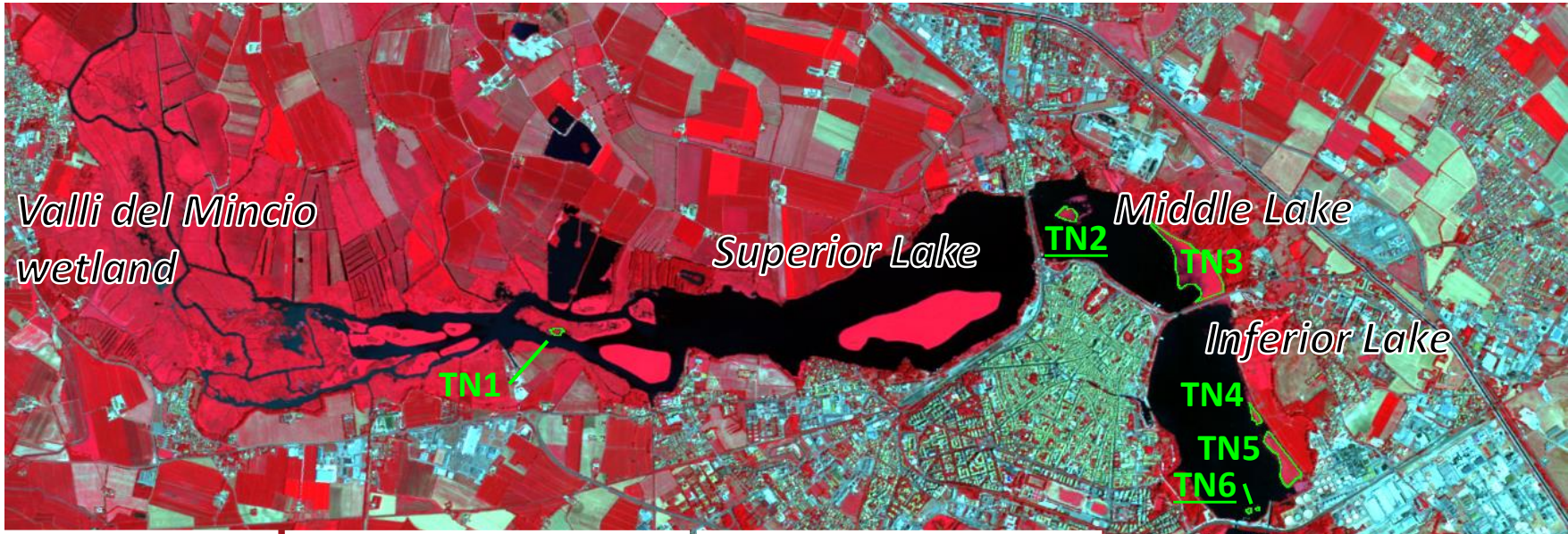
Chlorophyll-a content
15 August 2015

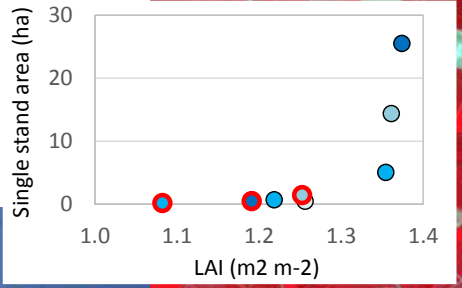

0.4%
0.3%
0.2%
0.1%
0.0%
Chl-a (% dw)
April
May
June
July
August
September
Date (2015)
N. lutea
N. nucifera
T. natans
Chlorophyll-a content
04 September 2015
Chl-a content (% dw)
0
0.1
0.2
0.3
0.4

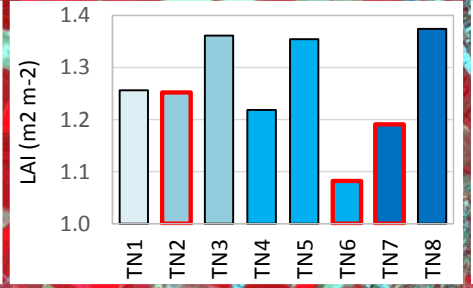
Intra-species variability: *N. nucifera*

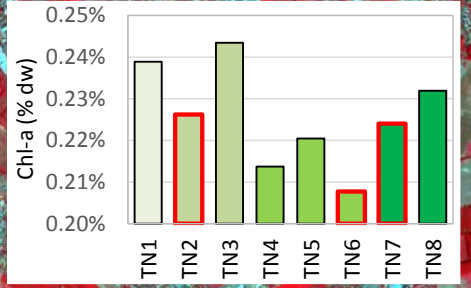


Intra-species variability: *T. natans*





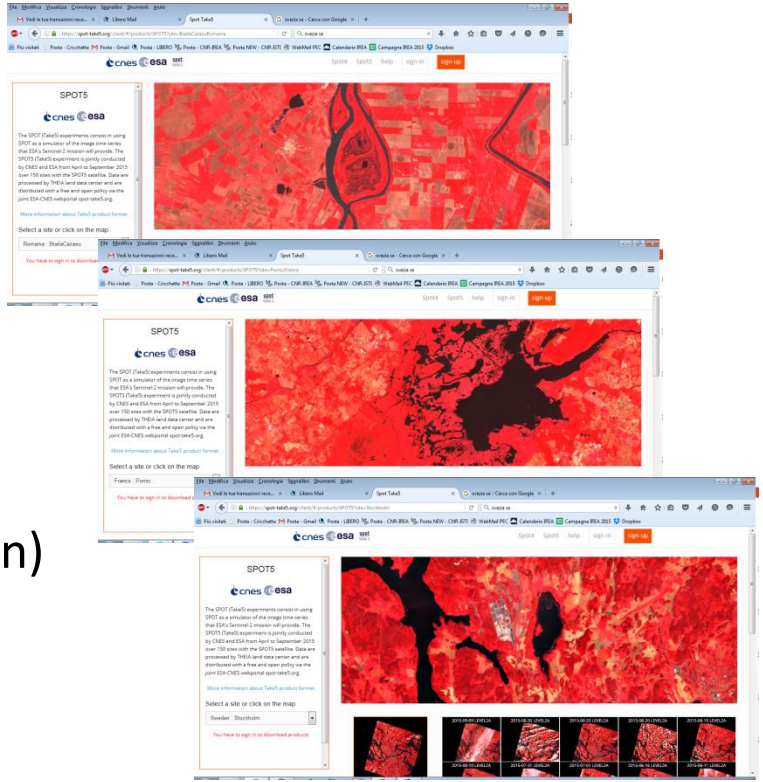




Further developments

- Testing over additional S5T5 sites:
  - Braila islands (RO)
  - Lac du Grand Lieu (FR)
  - Lake Fysigen (SE)

- Sentinel-2 MSI data
  - Integration with S5T5 data (July 2015 on)
  - 2016 (Mantua, Kis-Balaton wetland)



Sentinel-2 MSI capabilities

- Enhanced spectral resolution (Blue bands, RedEdge bands)
  - More reliable sub-type/species distinction?
  - Better estimation of morphological (biomass) and physiological (Chl-a, Cxc) parameters?

Mantua lakes system – Sentinel-2 MSI (13 Aug 2015)

Separability	CD	LM	TN	NL	NN	LH	PA	TV-Lm	TV-Pa	TV-Zm	I-M dist	MSI-OLI diff
C. demersum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**2.00**	**0.00**
L. minor	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	**1.99**	**0.02**
T. natans	0.00	0.02	0.00	0.02	0.00	0.41	0.42	0.08	0.02	0.00	**1.69**	**0.42**
N. lutea	0.00	0.01	0.02	0.00	0.00	0.05	0.00	0.00	0.00	0.00	**1.94**	**0.05**
N. nucifera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**2.00**	**0.00**
L. hexapetala	0.00	0.00	0.41	0.05	0.00	0.00	0.08	0.00	0.01	0.01	**1.69**	**0.41**
P.australis	0.00	0.00	0.42	0.00	0.00	0.08	0.00	0.04	0.26	0.29	**1.64**	**0.42**
TV - L. multiflora	0.00	0.00	0.08	0.00	0.00	0.00	0.04	0.00	0.11	0.16	**1.84**	**0.16**
TV - P. alba	0.00	0.00	0.02	0.00	0.00	0.01	0.26	0.11	0.00	0.43	**1.64**	**0.43**
TV - Z. mais	0.00	0.00	0.00	0.00	0.00	0.01	0.29	0.16	0.43	0.00	**2.00**	**0.43**

Conclusions

- **Spatial and temporal patterns** of macrophyte seasonal dynamics **can be mapped** from dense time series of multispectral data:
  - **High reliability** for canopy density parameters
    - $rRMSE_{fC}$=0.11, $rRMSE_{LAI}$=0.16
  - **Good reliability** for biomass and chlorophyll
    - $rRMSE_{Biom}$=0.41, $rRMSE_{Chl\text{-}a}$=0.54
- **Intra-specific varia**bility for most relevant species **can be disclosed** by exploiting satellite multi-temporal products
  - lentic to lotic conditions gradient for *N. nucifera*
  - open water to coastal stands differences for *T. natans*
- **Enhanced capabilities** will be granted as soon as **Sentinel-2A and B** will be both operational (Blue range bands, RedEdge bands, 5 day revisit)

Thank you for your attention

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