Coupling SWAT+ and GOTM-WET to assess Best Management Practices in mitigating Harmful Algal Blooms in a semi-arid coastal lagoon

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WATERITECH

SMART LAGOON

Eutrophication

> Increased Primary Production

> Harmful Algal Blooms (HAB)

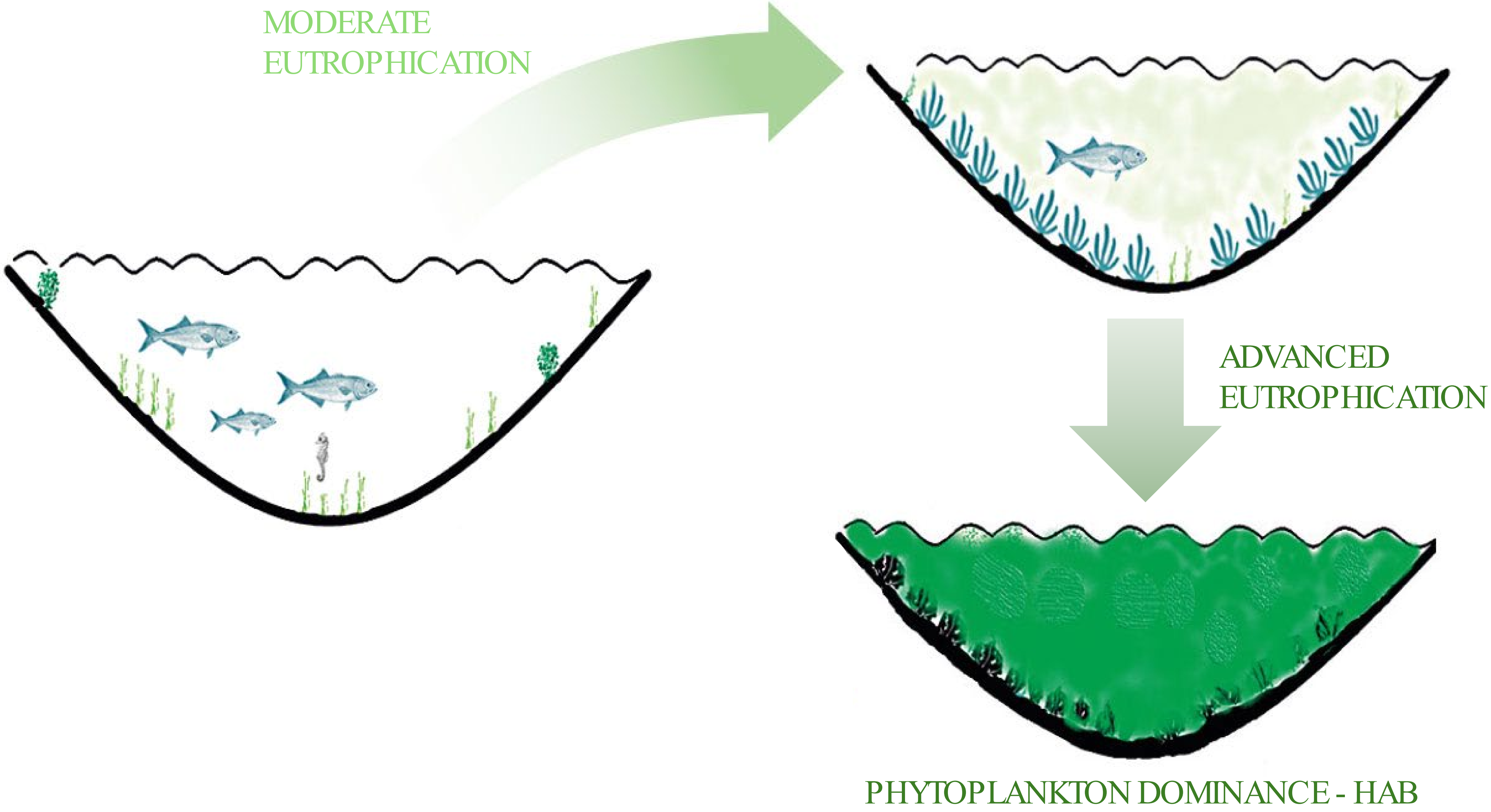
Coastal lagoons:

Highly vulnerable to eutrophication

Shallow = high surface / volume ratio

Sustain high Primary Production

Mainly populated coastal areas



Adapted from McGlathery et al. (2007)

Combined role of

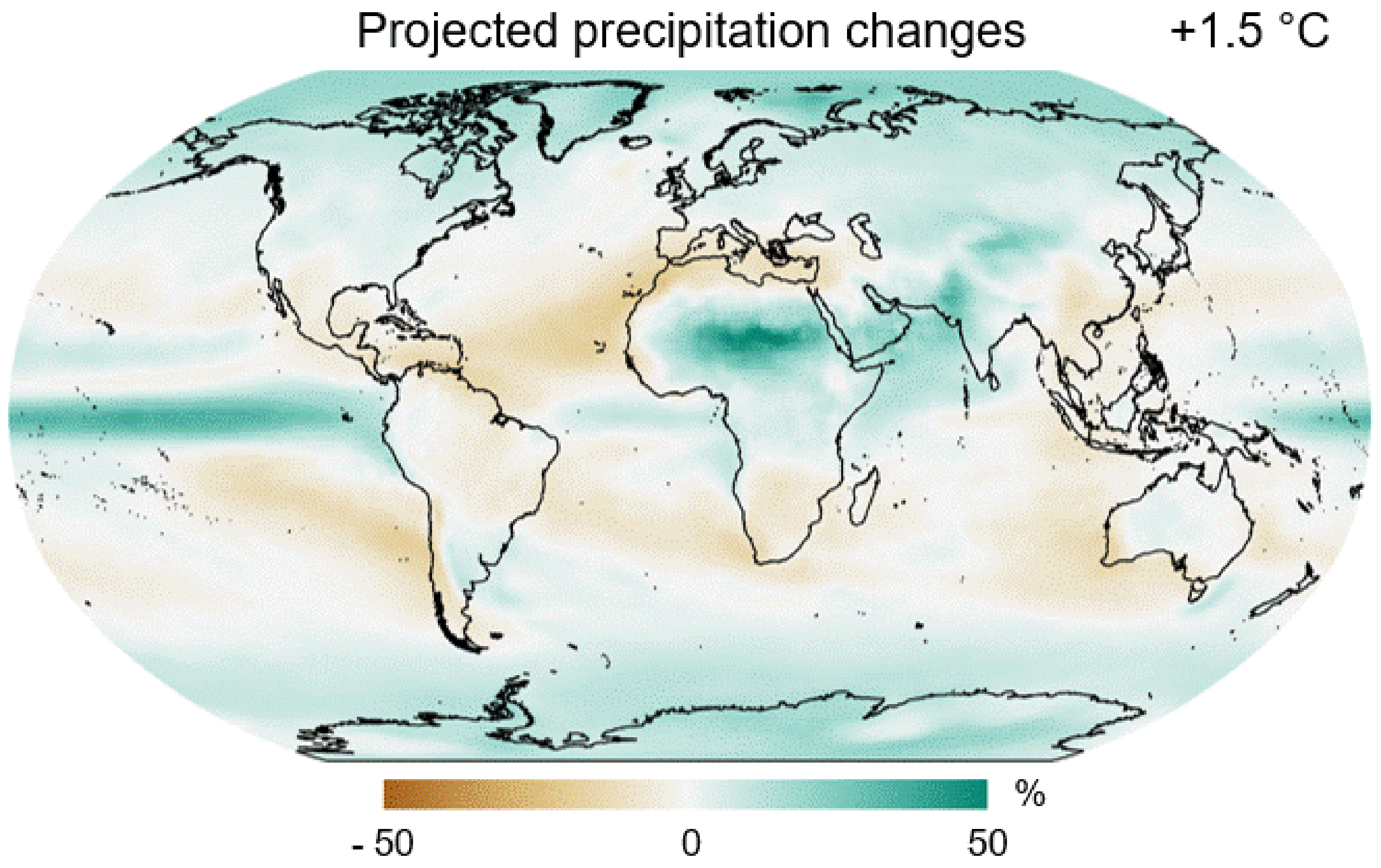
Multiple Stressors of Global Change

- Eutrophication
- Warming
- Altered precipitation
- Extreme events

Semi-Arid regions

Increase peaks of runoff

Higher risk of HAB



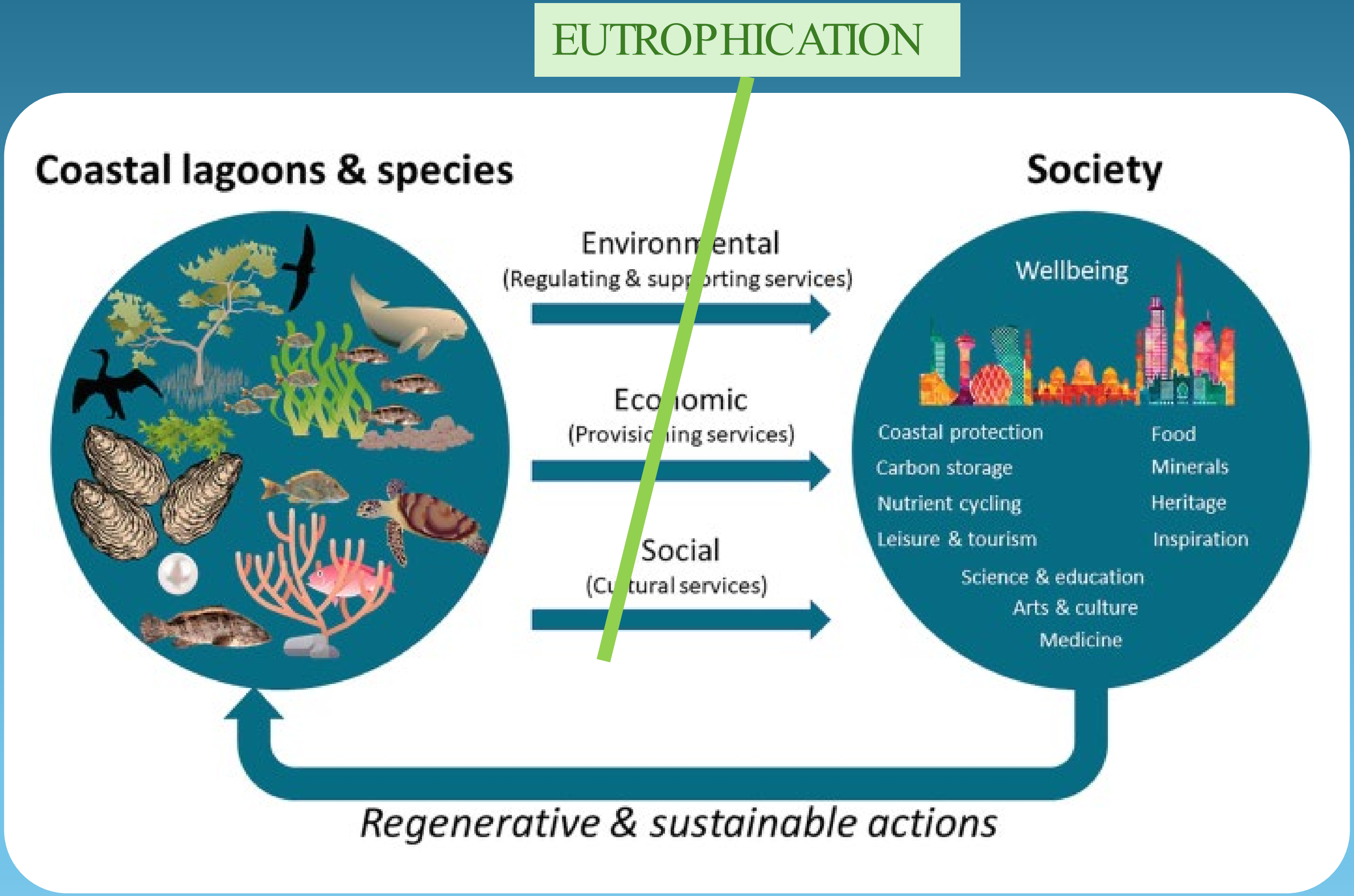
Precipitation changes for different levels of warming from the period 1850-1900.
Source: *Interactive Atlas*, Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) 2021.

IPCC AR6 SPM.5

HABs impacts on:

- Biodiversity
- Ecosystem functions
- Ecosystem Services
- Human wellbeing

Management strategies to restore lagoons + minimize HABs



Mateos – Molina et al. (2023)


Mar Menor - Spain

Mar Menor watershed – Campo de Cartagena

Intensive agricultural production

Highly touristic area

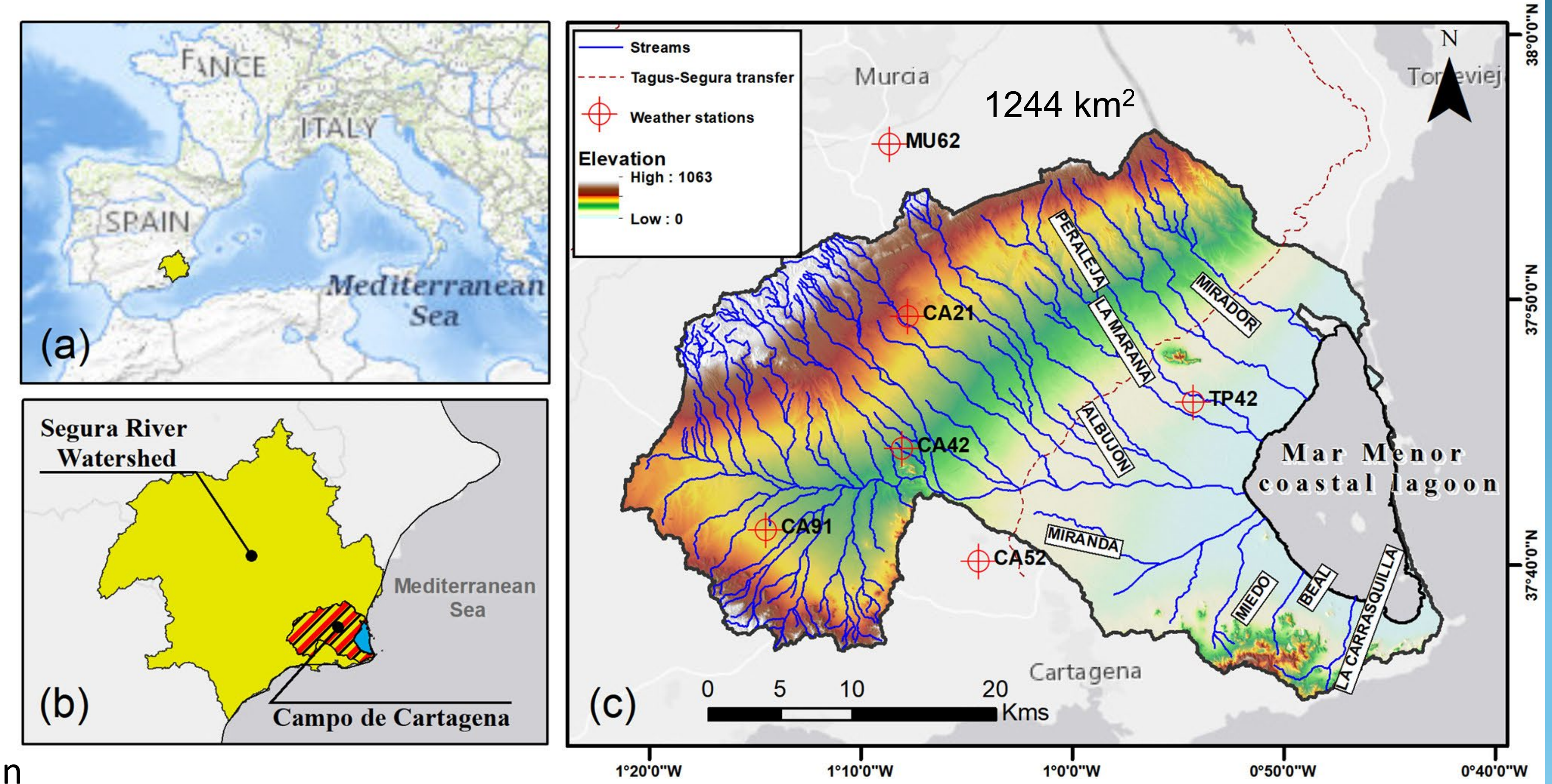
Sustain relevant fisheries

High biodiversity

Arid-Mediterranean climate (300mm/y)

Structural **water deficit** + aggravated by abstraction

Few intense precip. events especially in spring and autumn



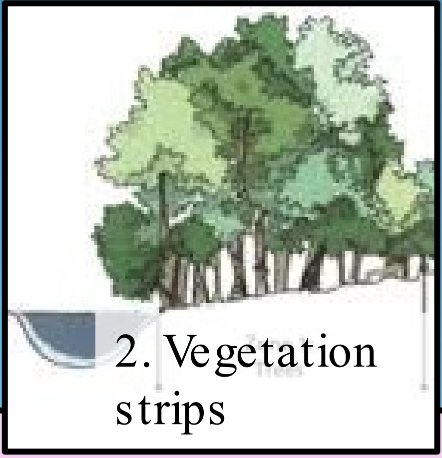
López-Ballesteros et al. (2023)

To evaluate the performance of agricultural best management practices (BMP) in reducing the frequency and intensity of phytoplankton blooms (HAB: chlorophyll a) in a coastal lagoon with intensive agriculture

0. Baseline

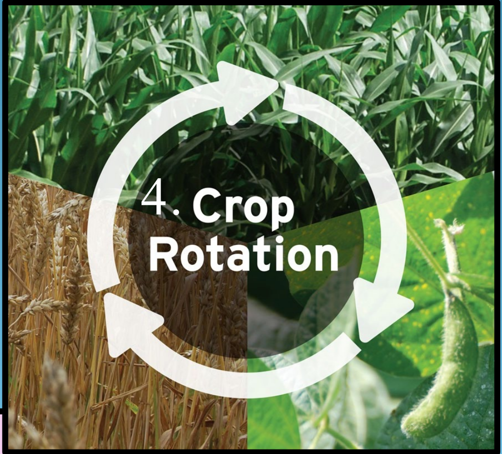
Business as usual

1. Reduced use of fertilizers



2. Vegetation strips

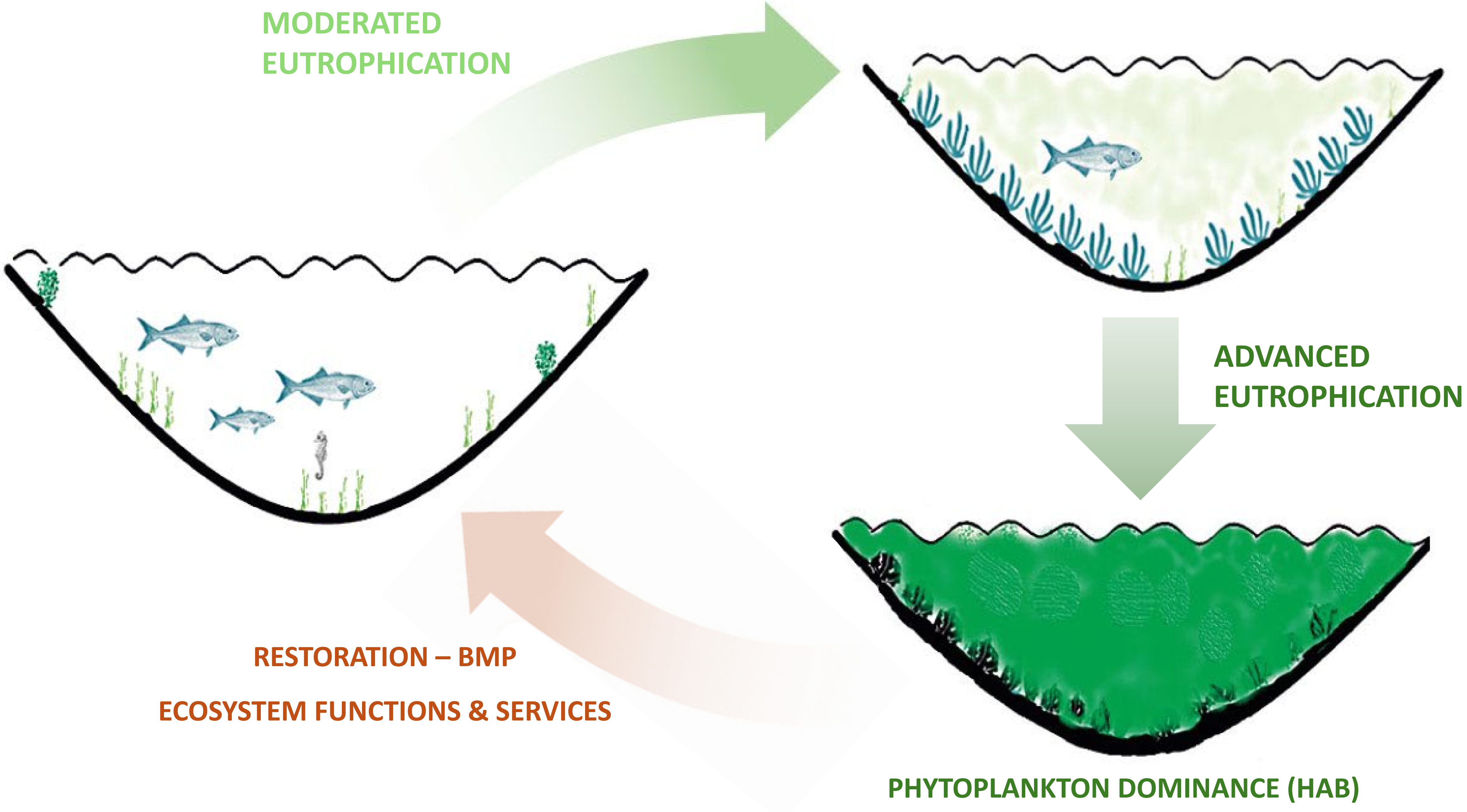
3. Contour farming



4. Crop Rotation

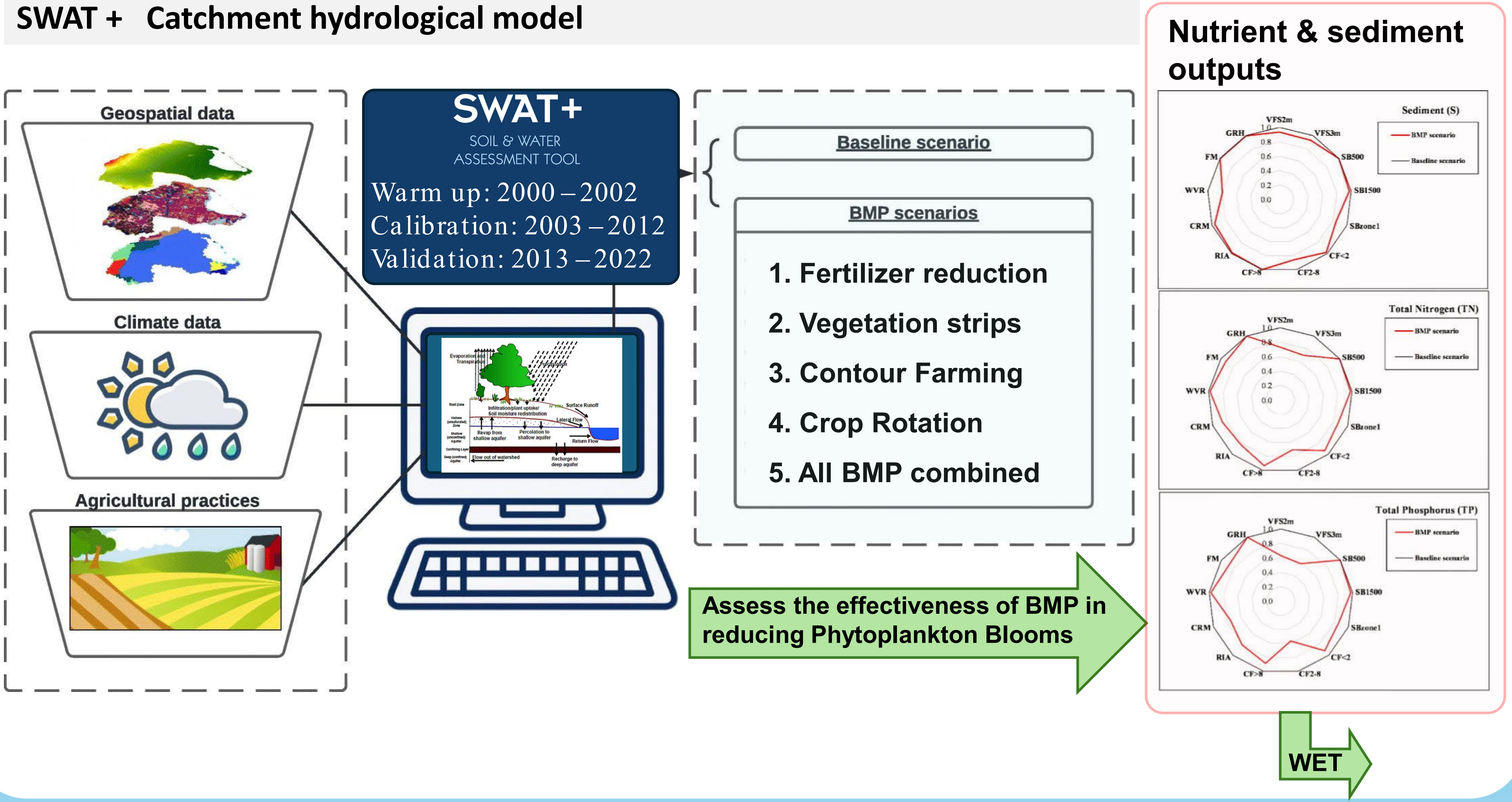
5. All management practices combined

$$\text{Relative effectiveness (\%)} = \frac{Baseline - BMP}{Baseline} \times 100$$



Adapted from McGlathery *et al.* (2007)

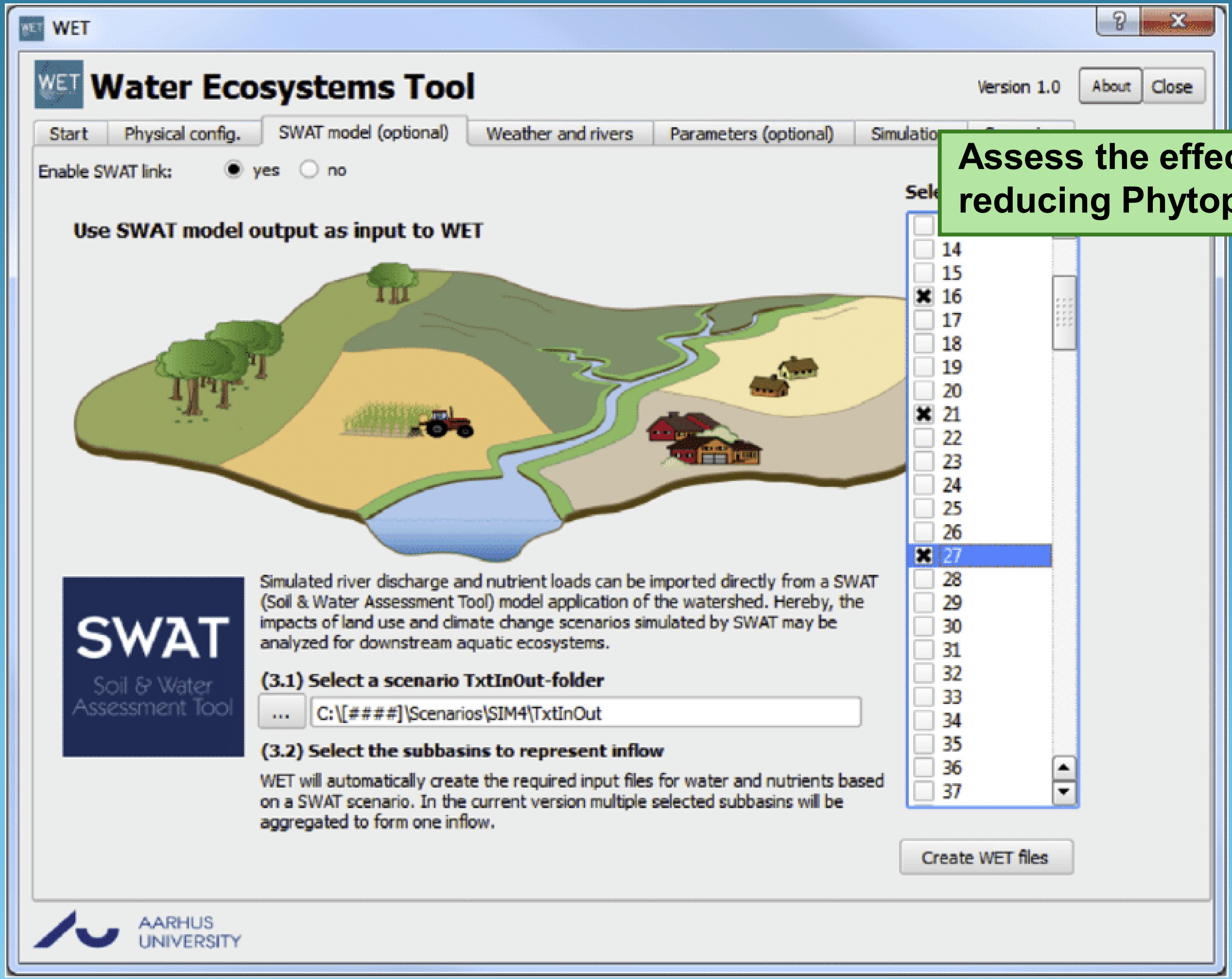
SWAT + Catchment hydrological model



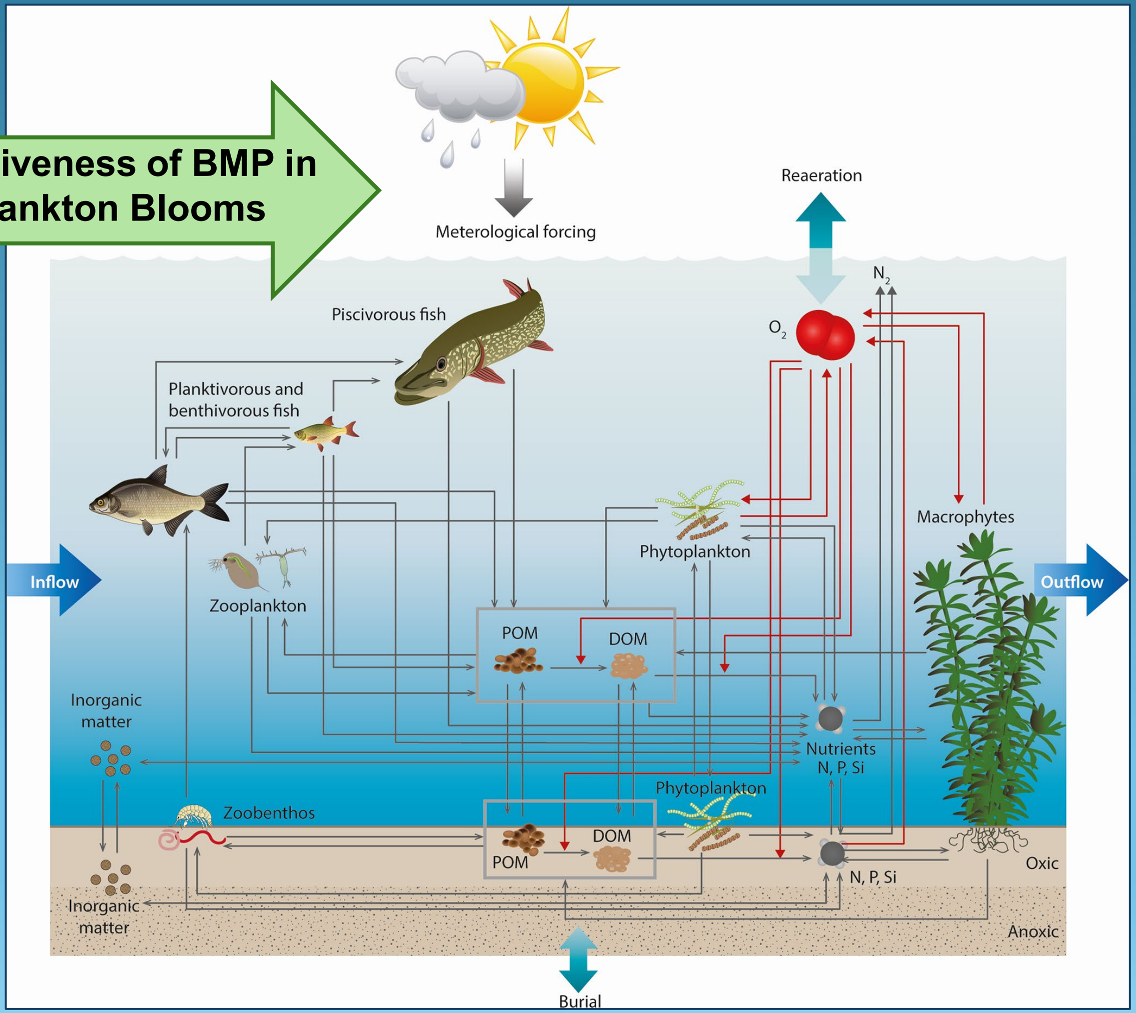
Adapted from López-Ballesteros et al. (2023)

WET: Water Ecosystem Tool (1 D) SWAT+ outputs as WET inputs

Assess the effectiveness of BMP in reducing Phytoplankton Blooms



Nielsen et al. (2017)

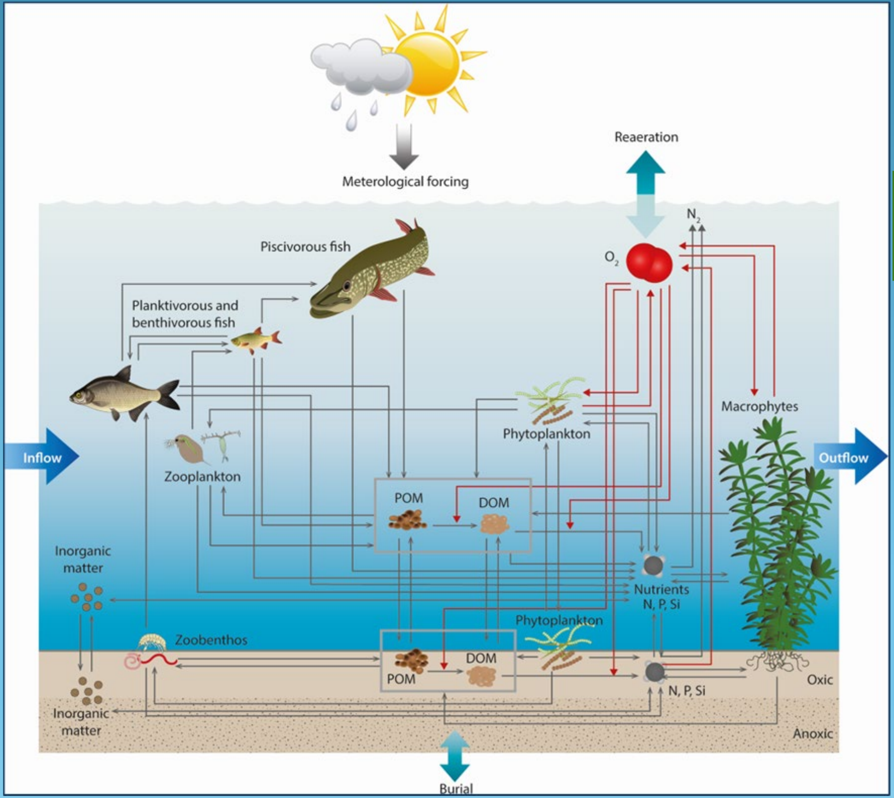


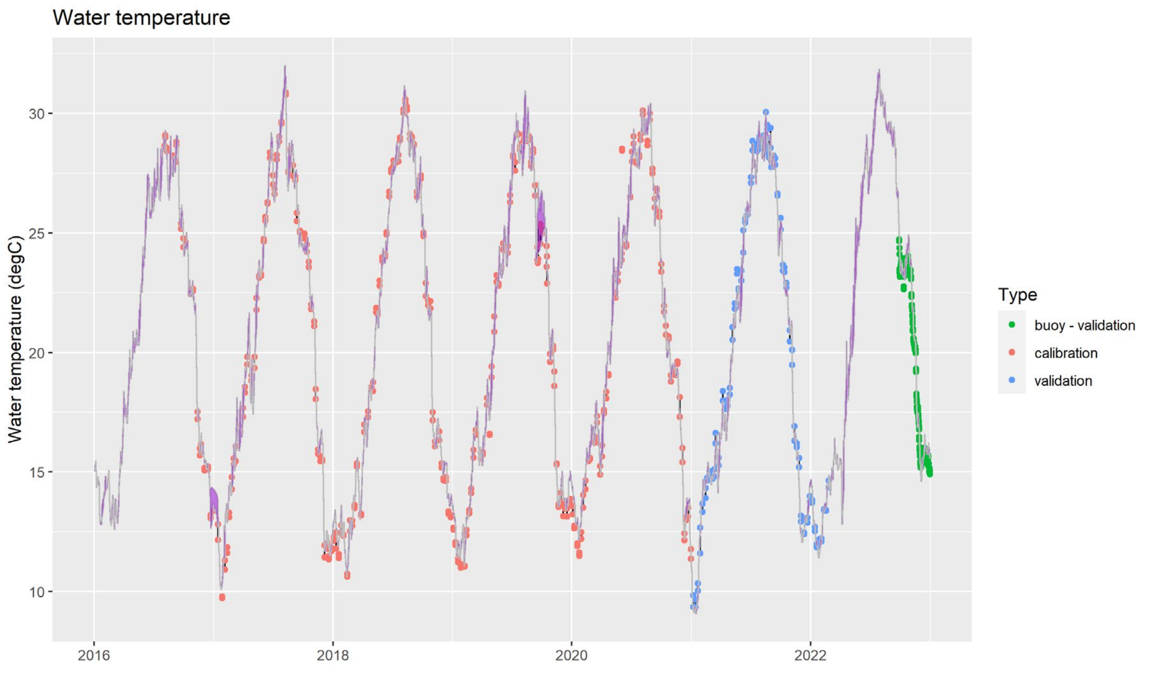
Schnedler-Meyer et al. (2022)

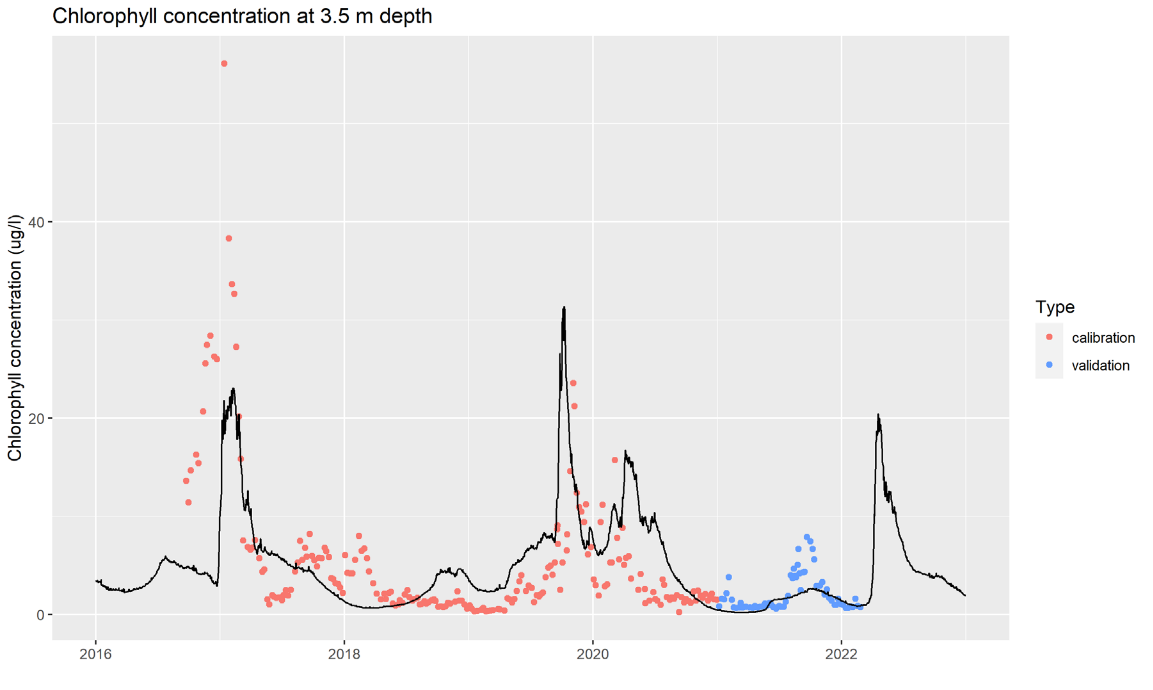
WET: Water Ecosystem Tool

(GOTM-WET 1 D)

Model Calibration + Validation







Period 2016 - 2022

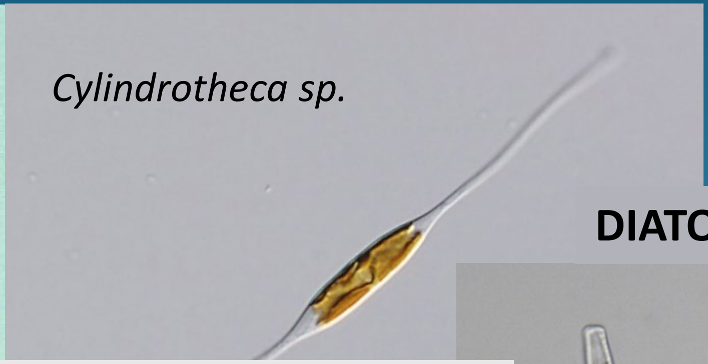
Intense peaks – related
precipitation events that
nutrient runoff

Spring blooms – persiste
Chl a **all-year round**

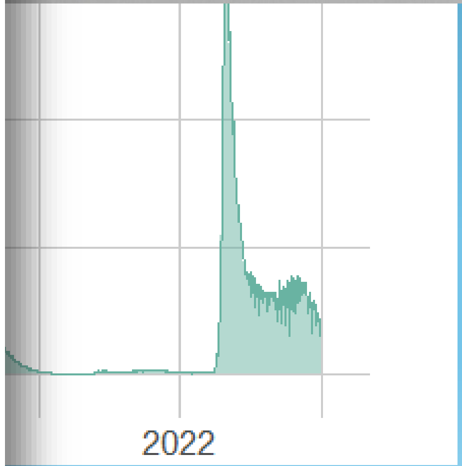
Biggest event for this pe

Chlorophyll a = 34 mg/m

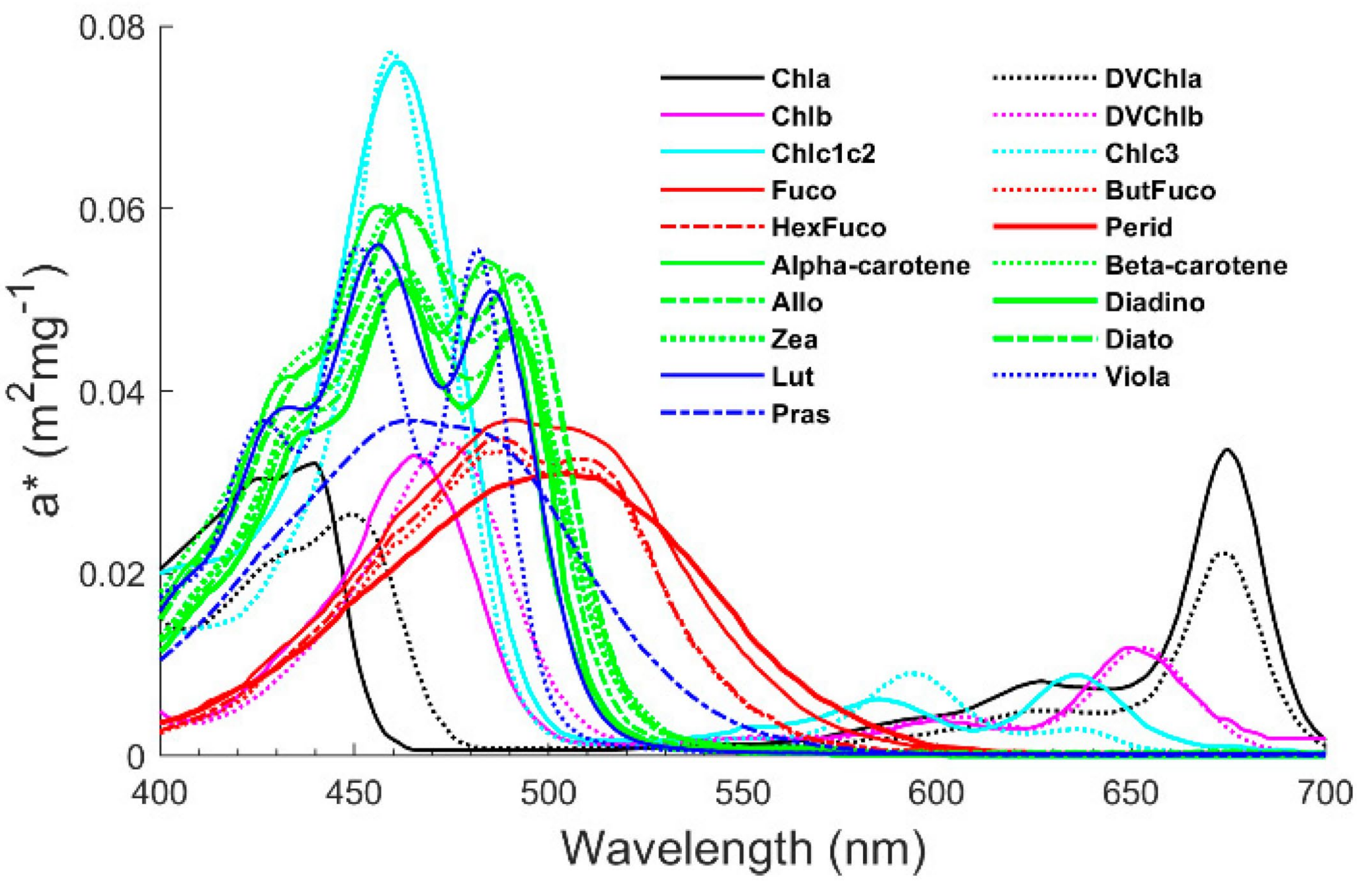
Persistence: April 2019 t



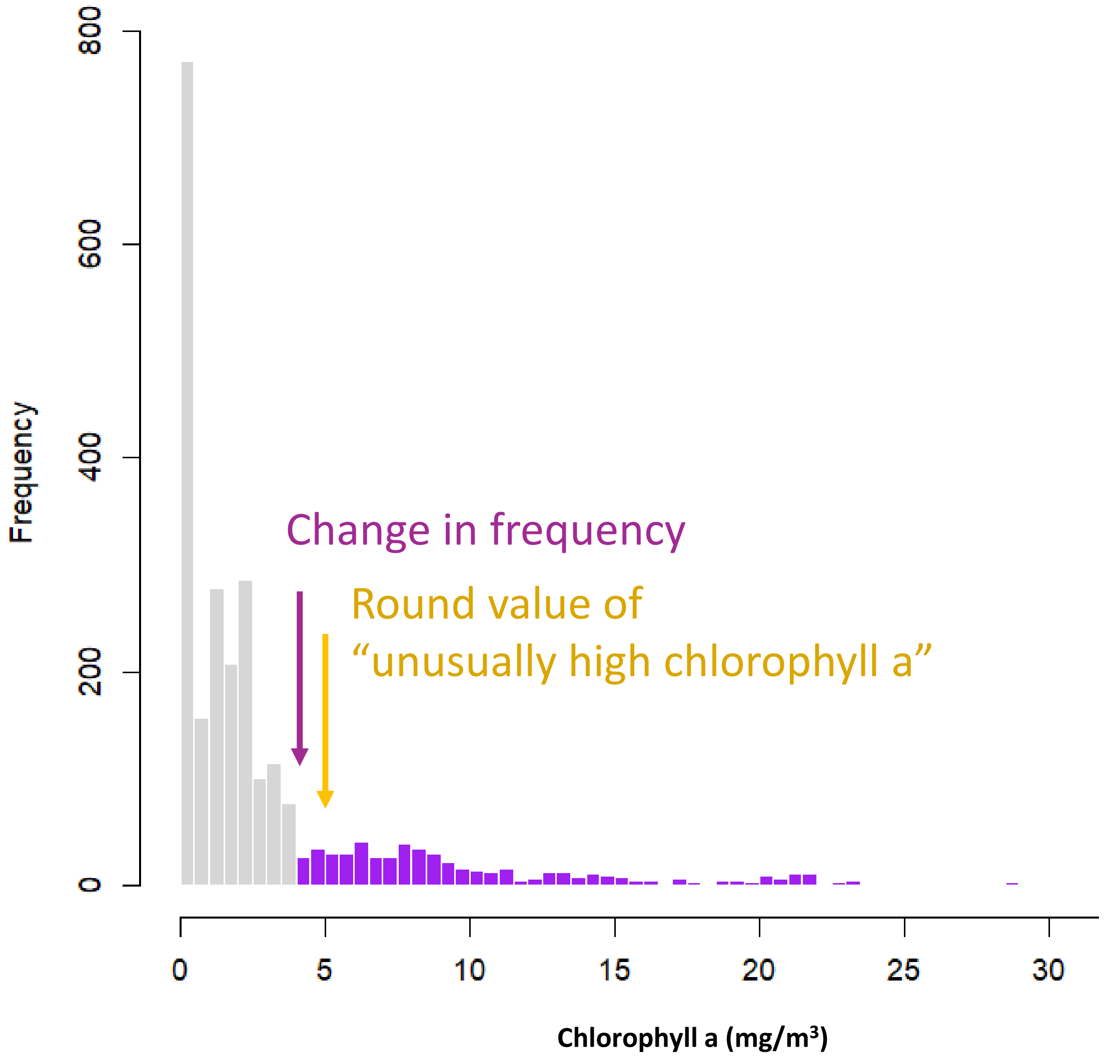
DIATOMS

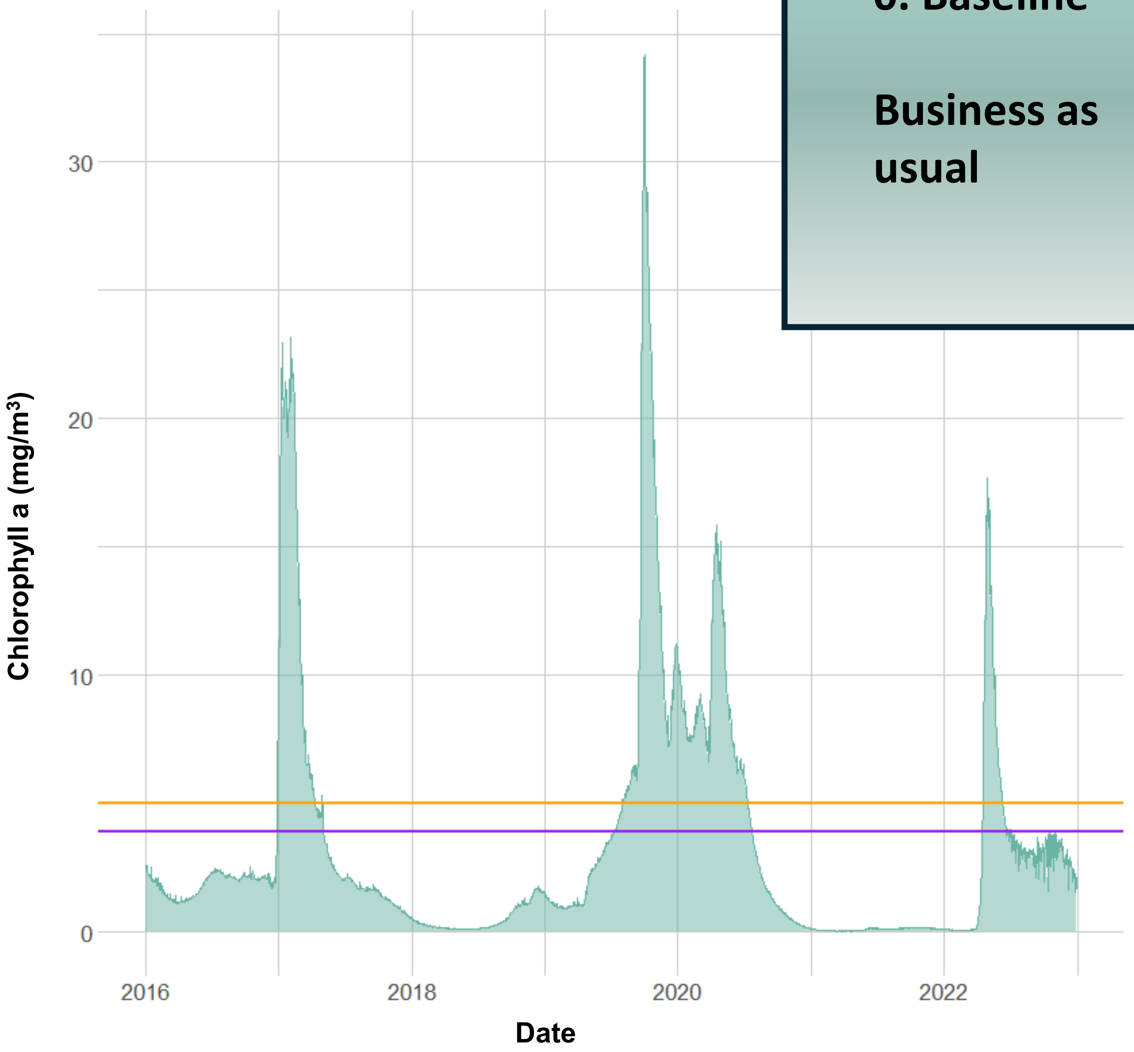


Why Chlorophyll a? -> estimator of biomass for all algal groups



Selection of bloom periods - Baseline

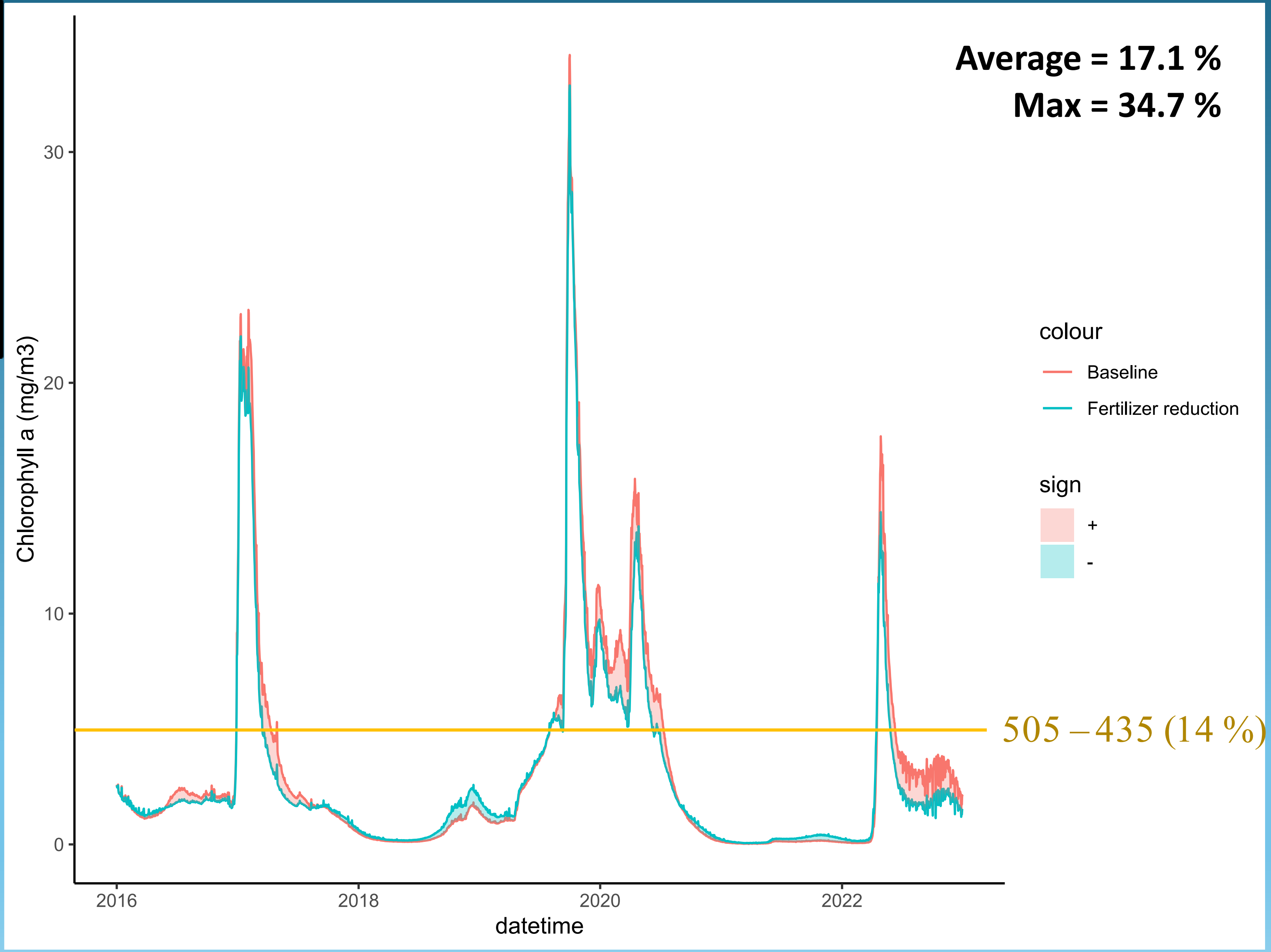




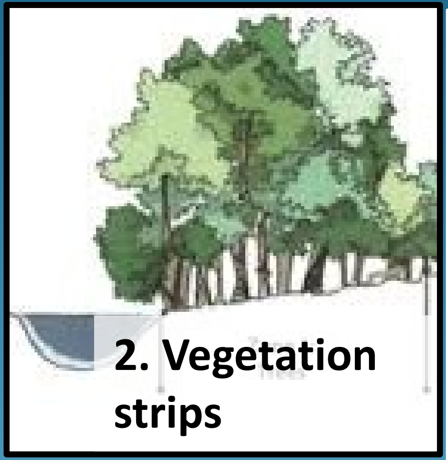
0. Baseline

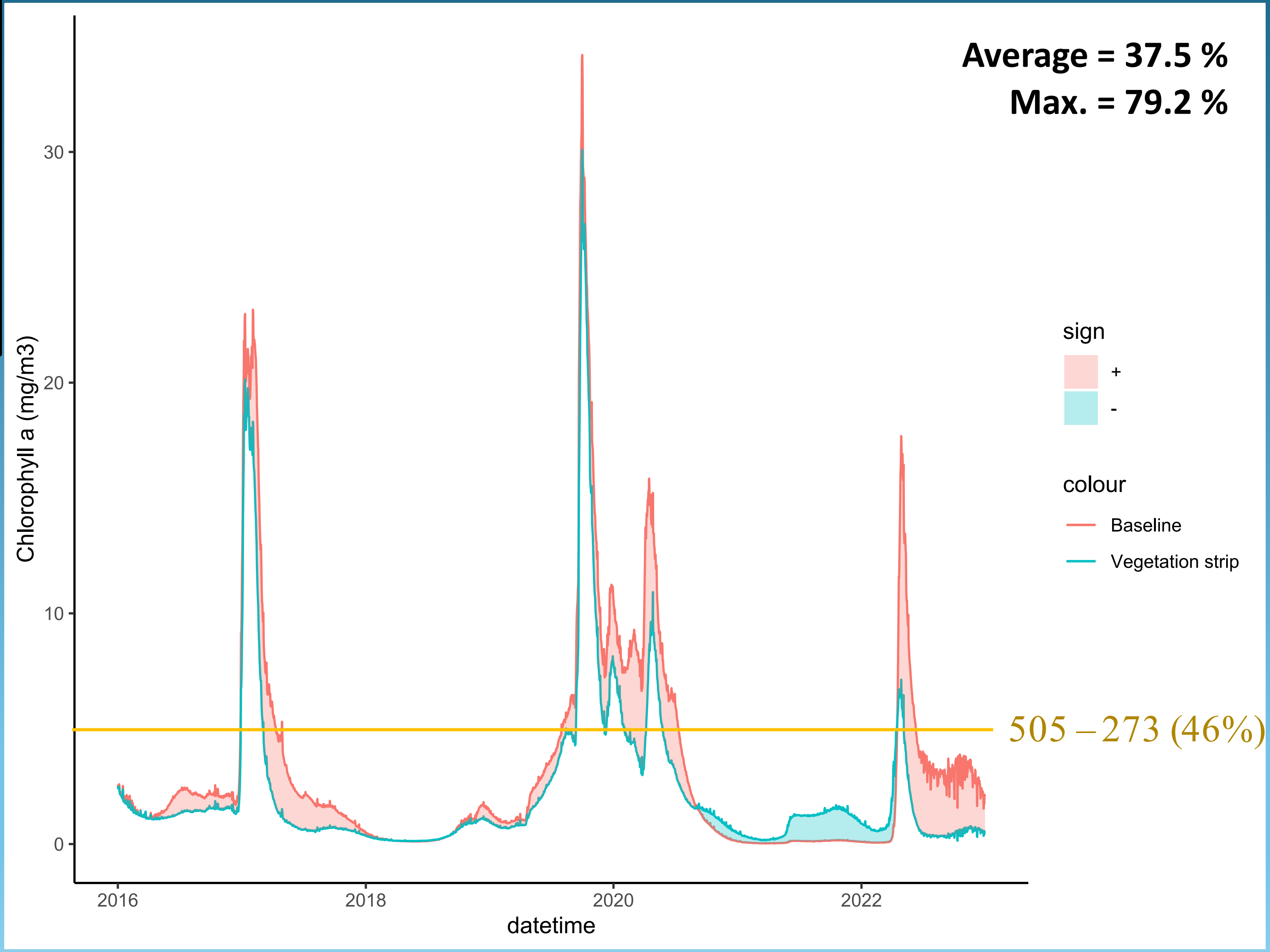
Business as usual

UREA
NEEM COATED
NITROGEN (N) 46%
1. Reduced use of fertilizers
Increase Yield

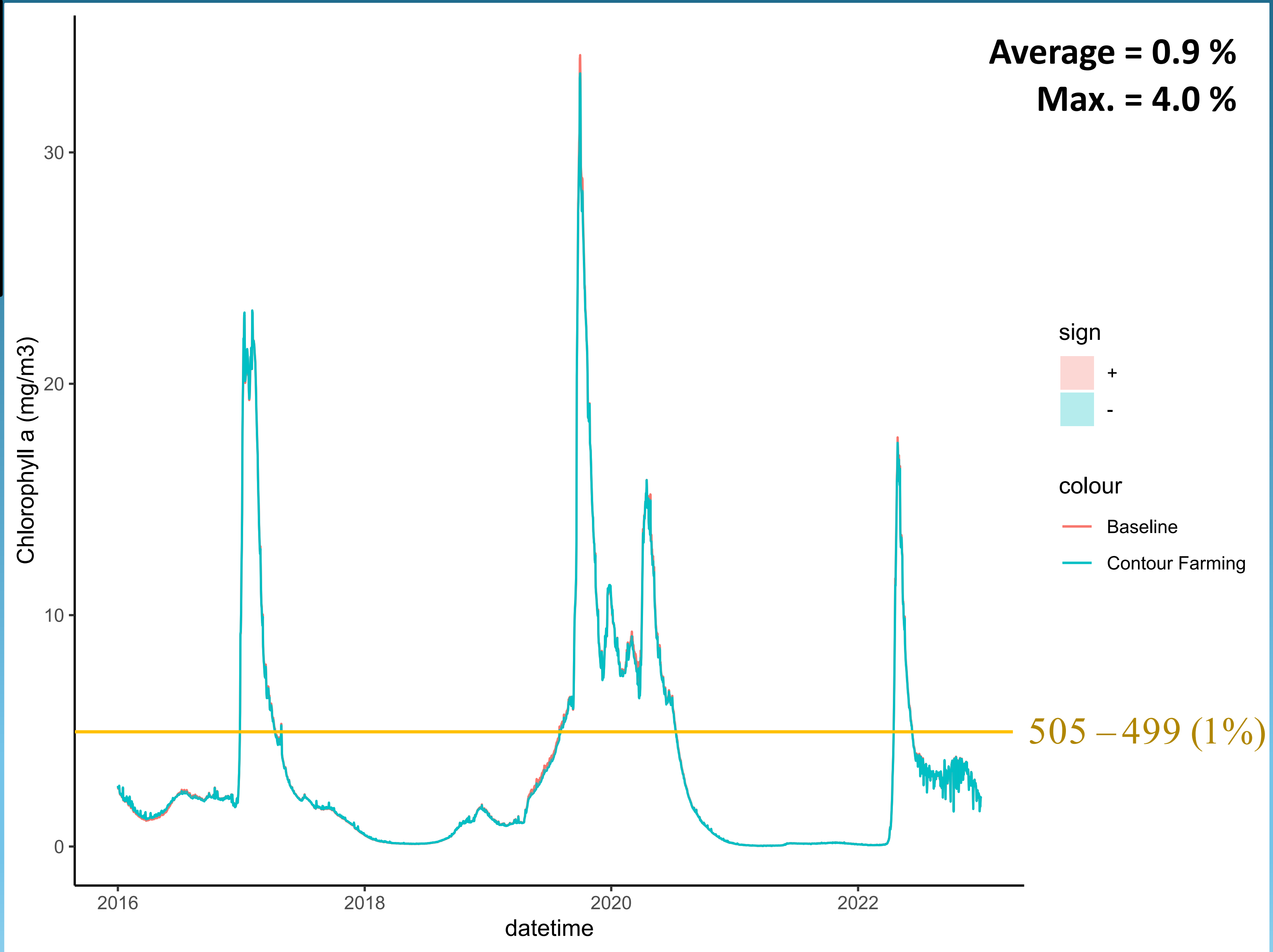


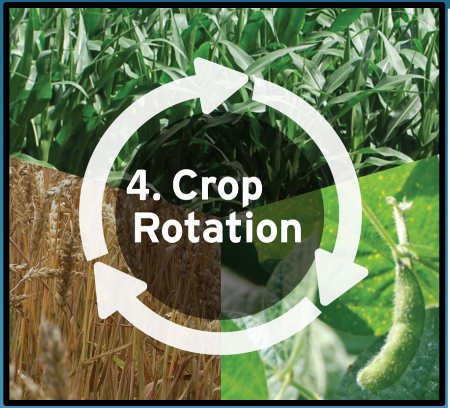
Average = 17.1 %
Max = 34.7 %
Chlorophyll a (mg/m3)
30
20
10
0
2016
2018
2020
2022
datetime
colour
Baseline
Fertilizer reduction
sign
+
-
505 – 435 (14 %)

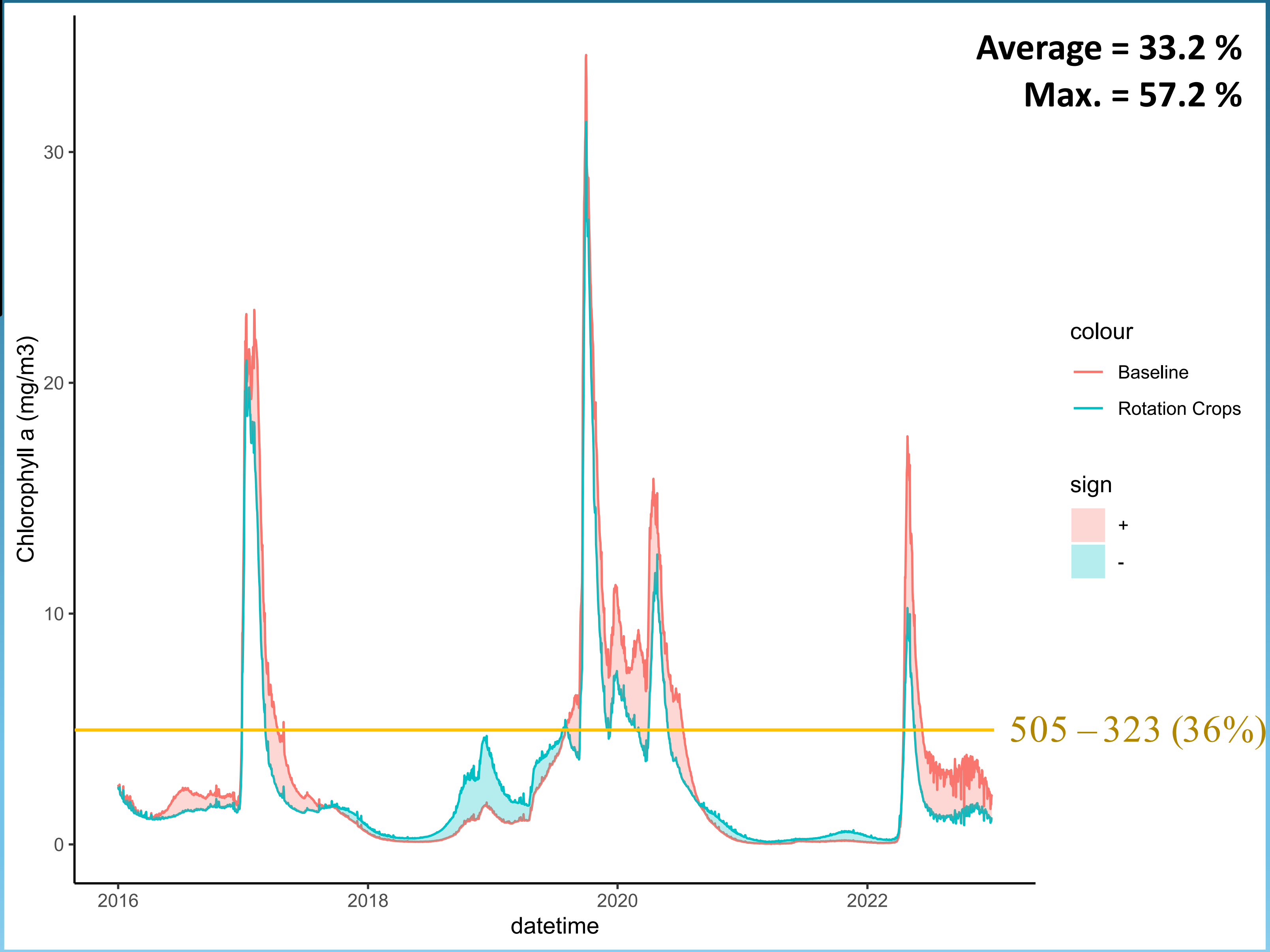

2. Vegetation strips


Average = 37.5 %
Max. = 79.2 %
Chlorophyll a (mg/m3)
0
10
20
30
2016
2018
2020
2022
datetime
505 – 273 (46%)
sign
+
-
colour
Baseline
Vegetation strip

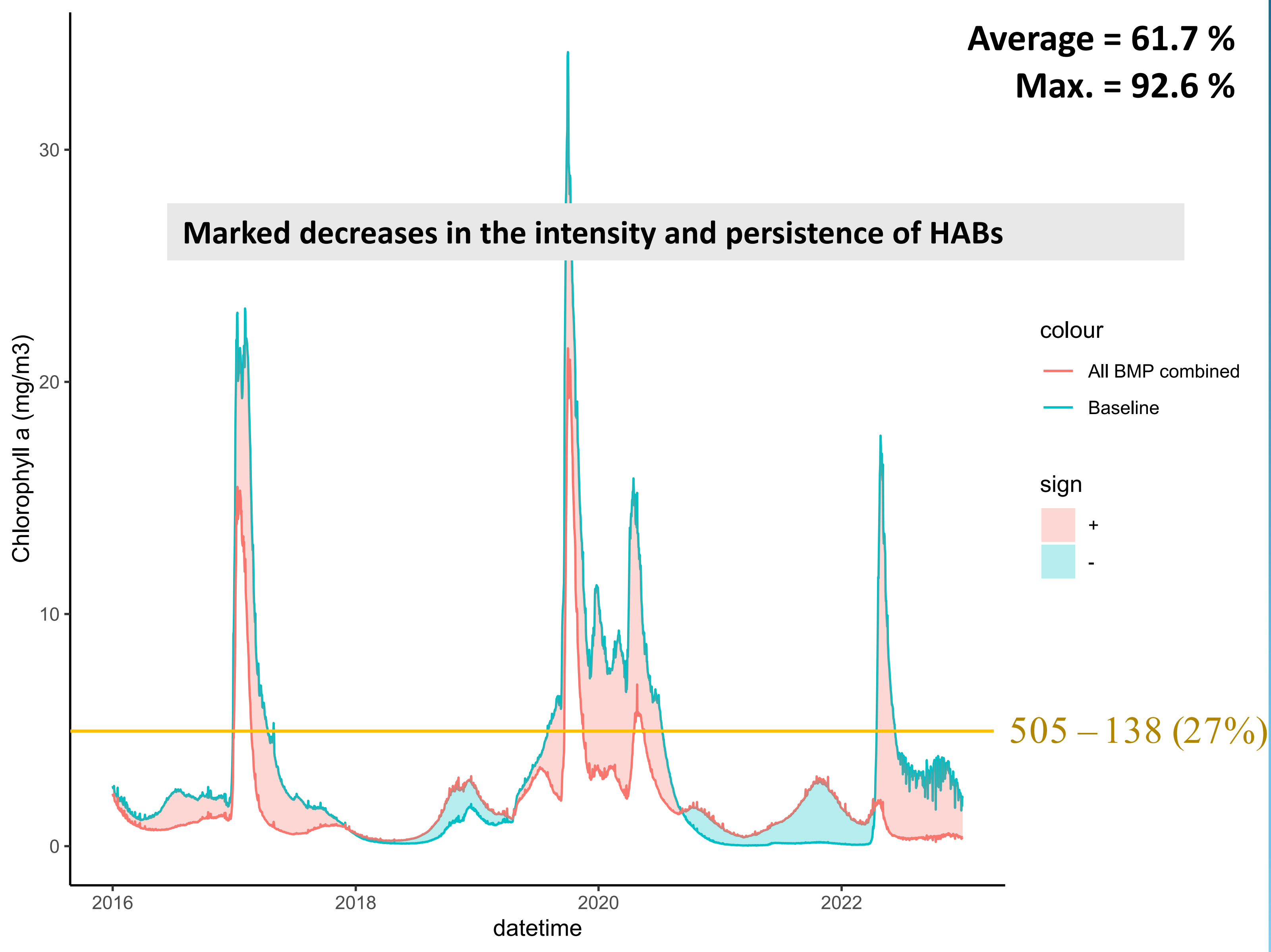

3. Contour
farming


Average = 0.9 %
Max. = 4.0 %
Chlorophyll a (mg/m3)
30
20
10
0
2016
2018
2020
2022
datetime
sign
+
-
colour
Baseline
Contour Farming
505 – 499 (1%)


4. Crop
Rotation

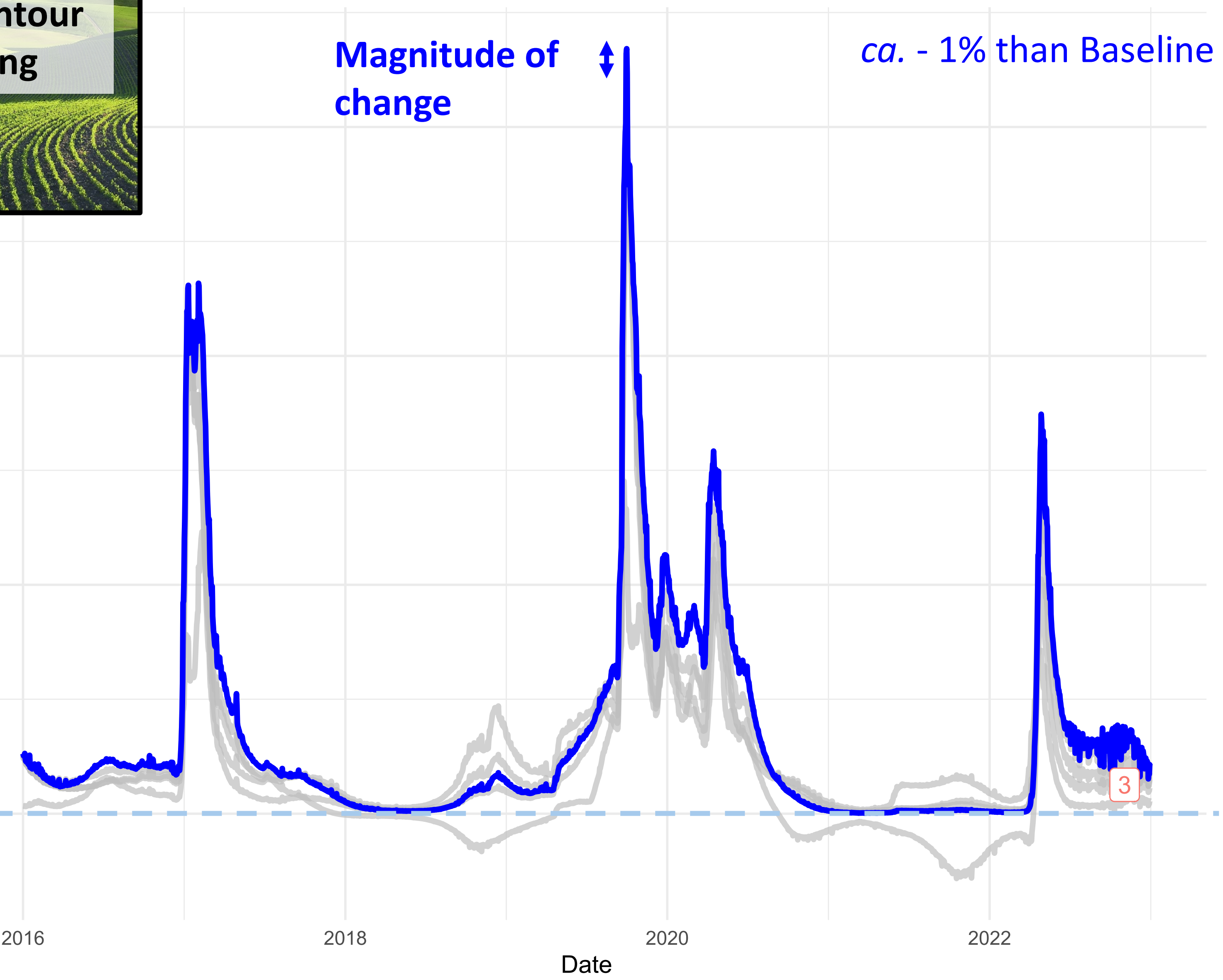

Average = 33.2 %
Max. = 57.2 %
Chlorophyll a (mg/m3)
30
20
10
0
2016
2018
2020
2022
datetime
colour
Baseline
Rotation Crops
sign
+
-
505 – 323 (36%)

5. All BMP combined

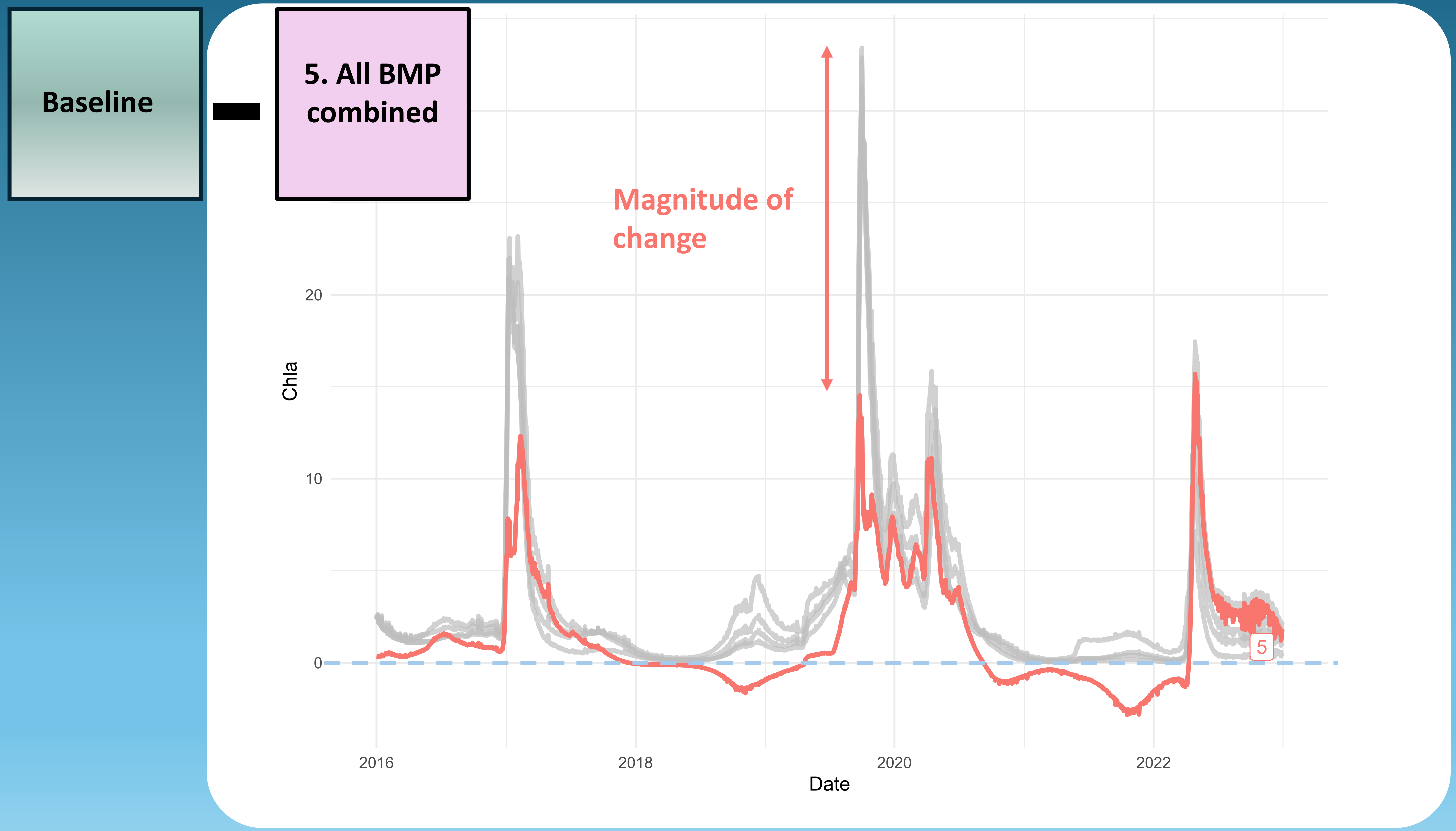


Baseline

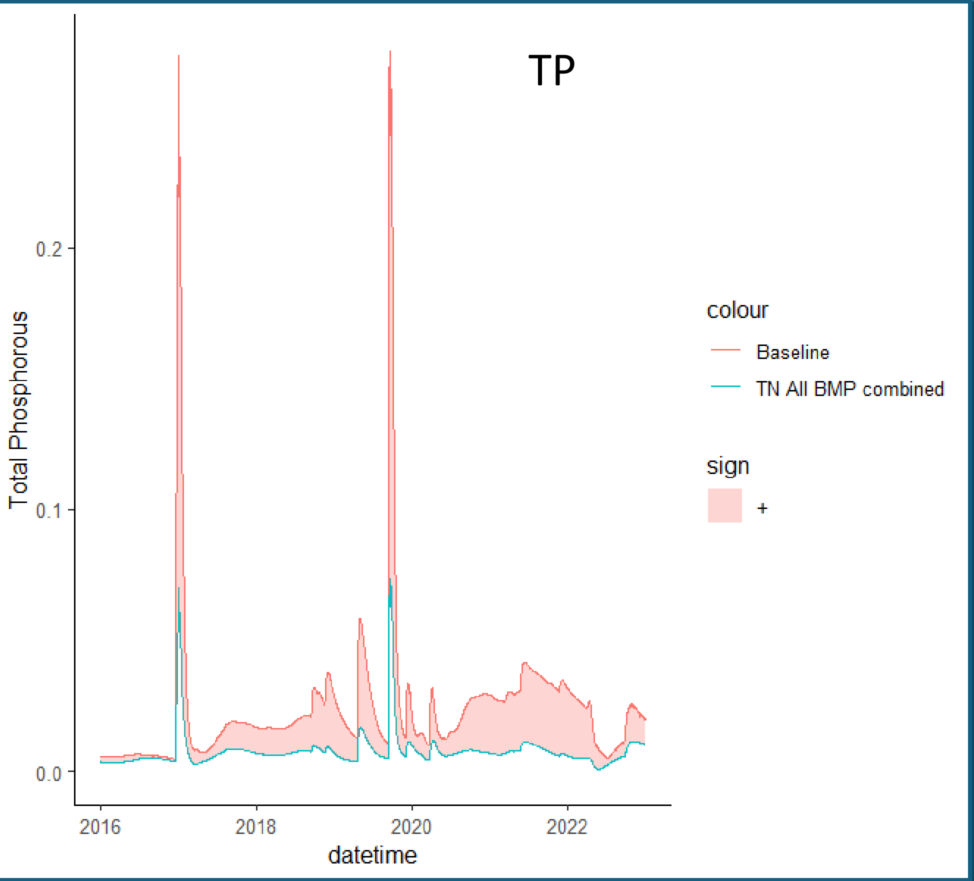
3. Contour farming



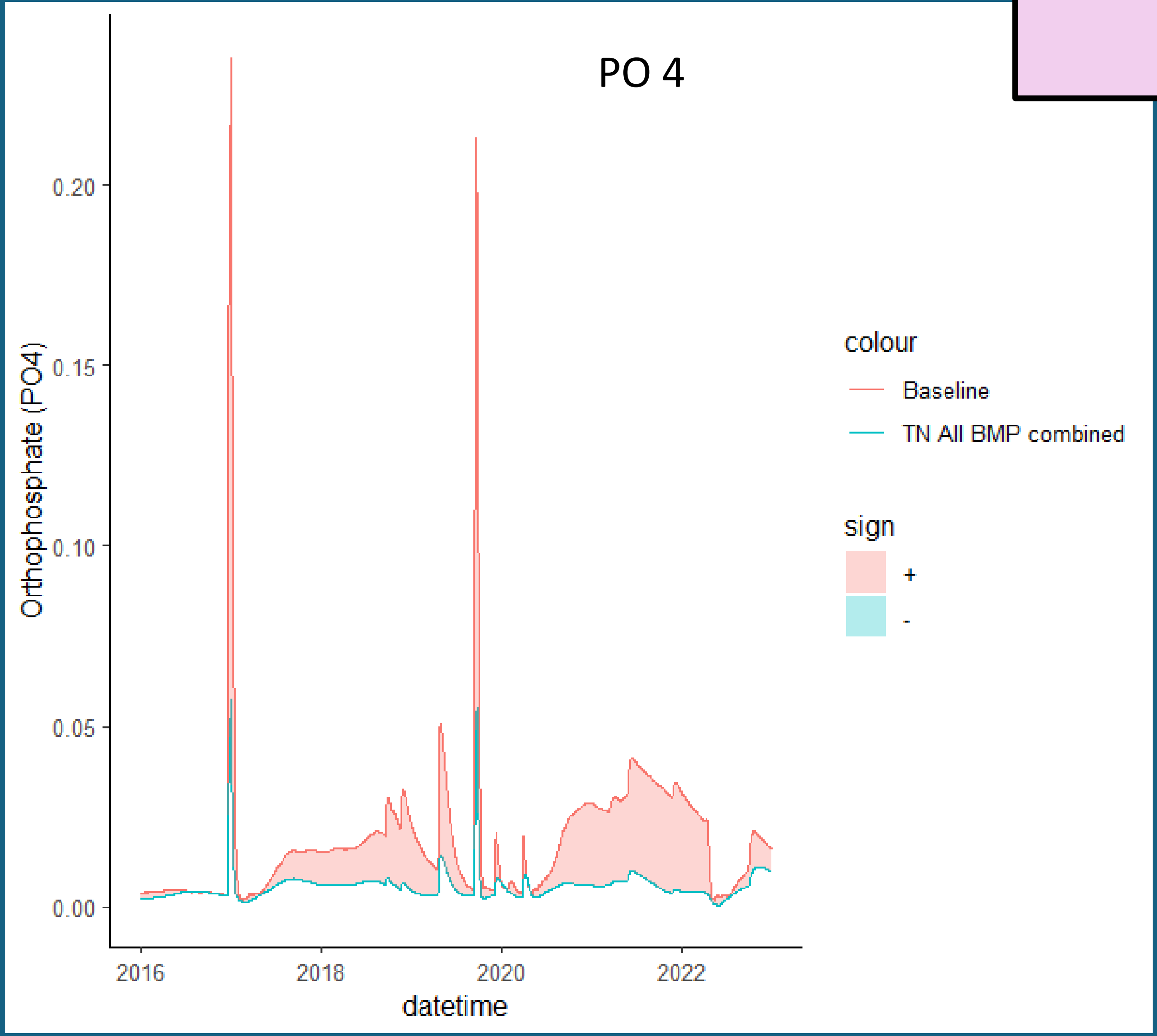
Magnitude of change
ca. - 1% than Baseline
Chla
20
10
0
2016
2018
2020
2022
Date
3


Baseline
5. All BMP combined
Magnitude of change
20
10
0
Chla
5
2016
2018
2020
2022
Date

5. All BMP combined

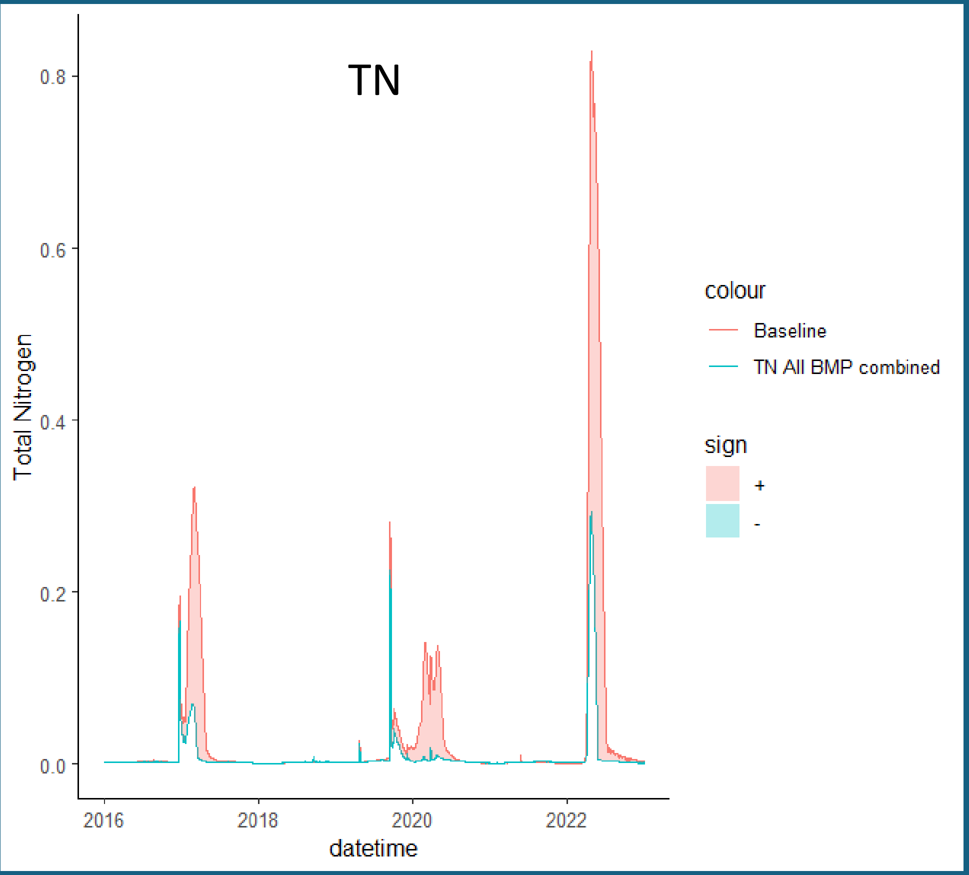


Average TP reduction 60.0 %
Average TP reduction (Chla > 5) 62.9 %

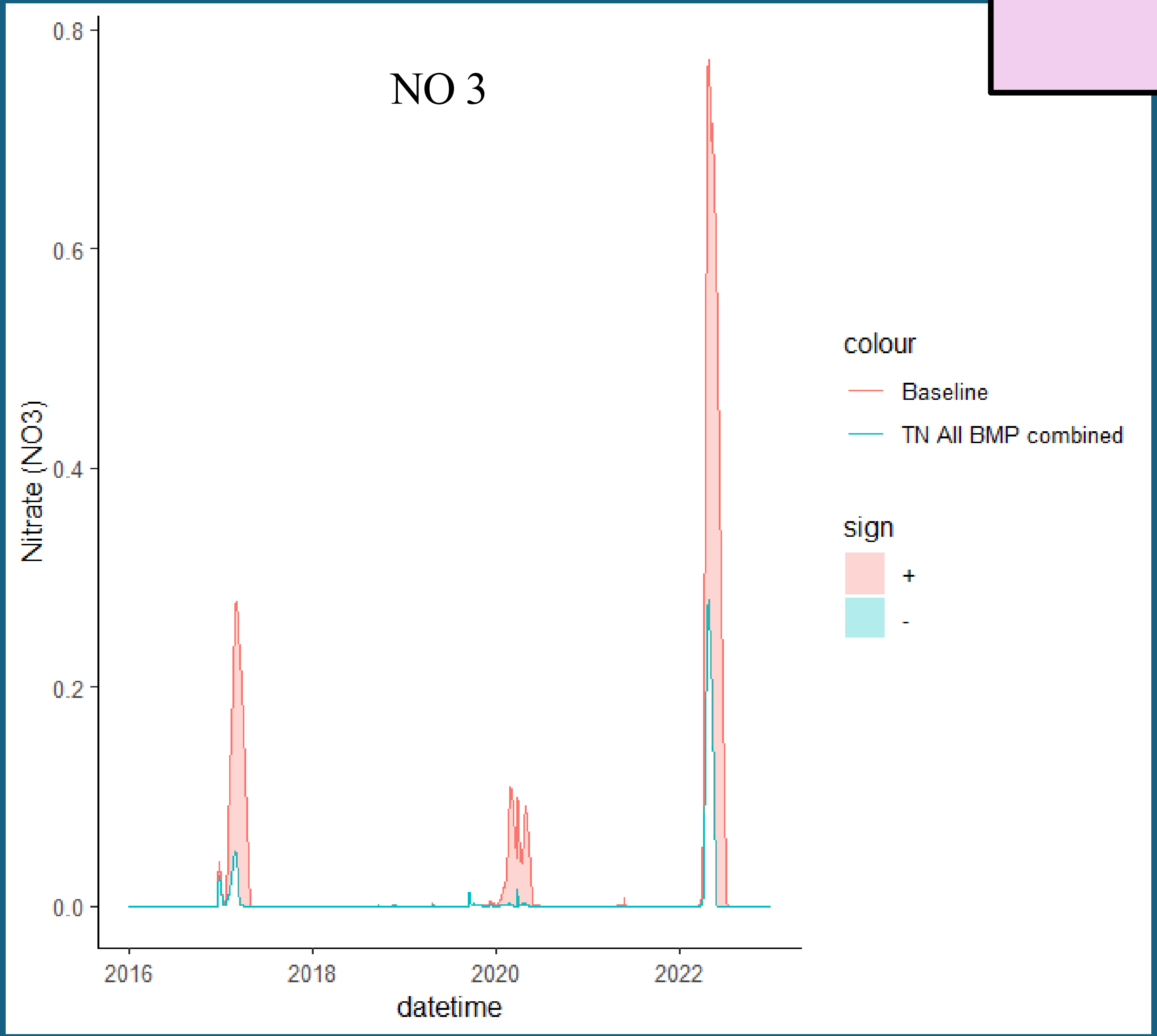


Average PO4 reduction 54.8 %
Average PO4 reduction (Chla > 5) 44.9 %

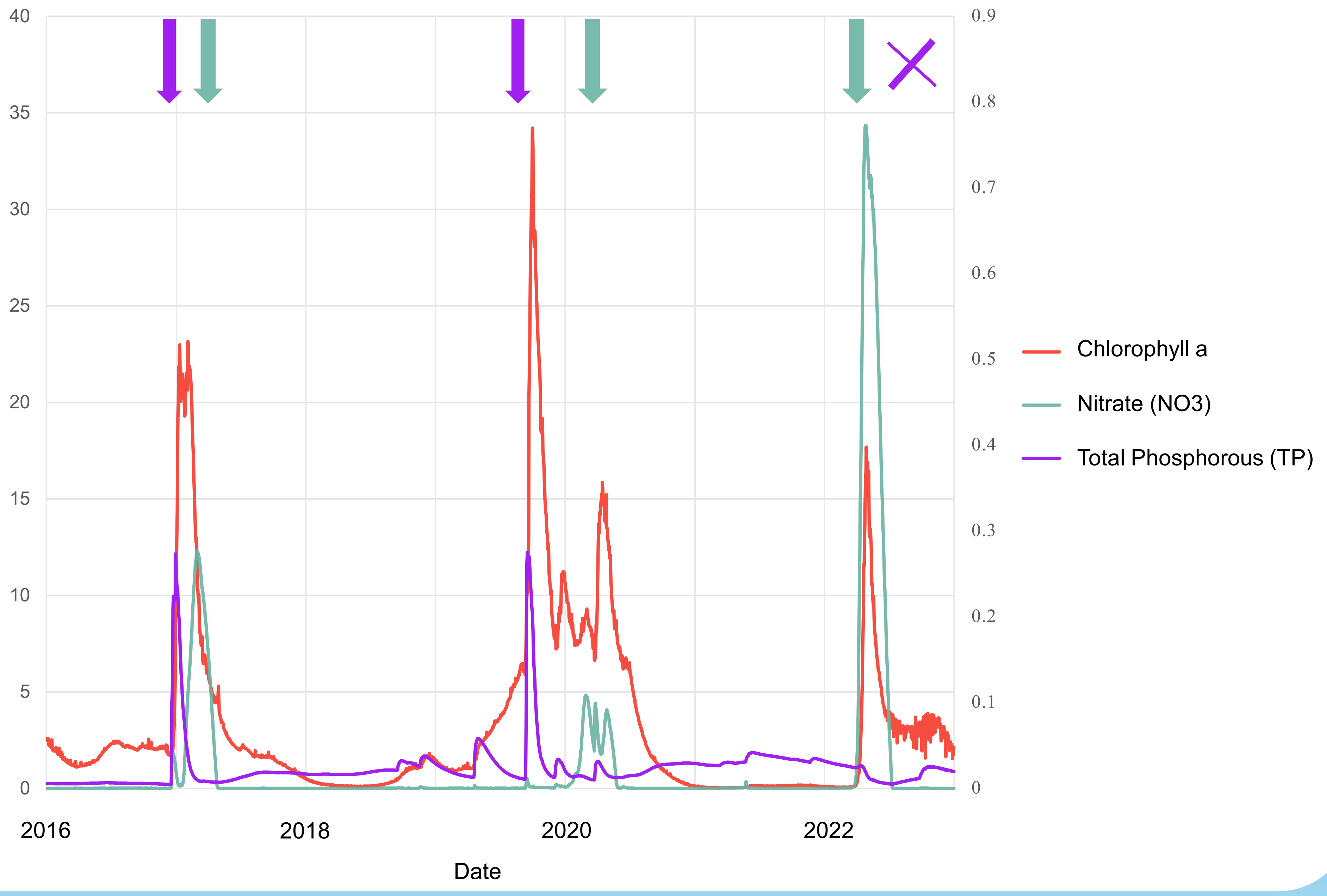
5. All BMP combined



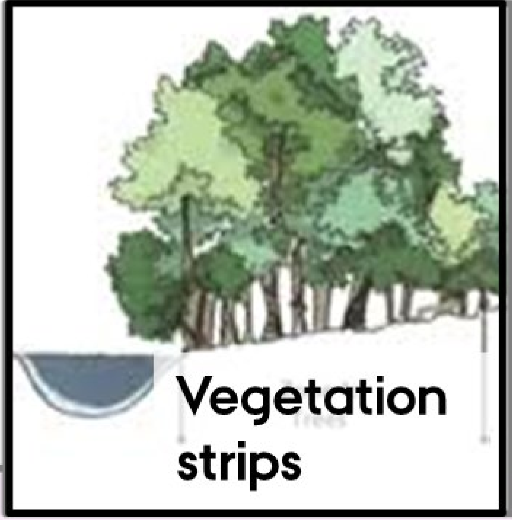
Average TN reduction 16.7 %
Average TN reduction (Chla > 5) 69.8 %

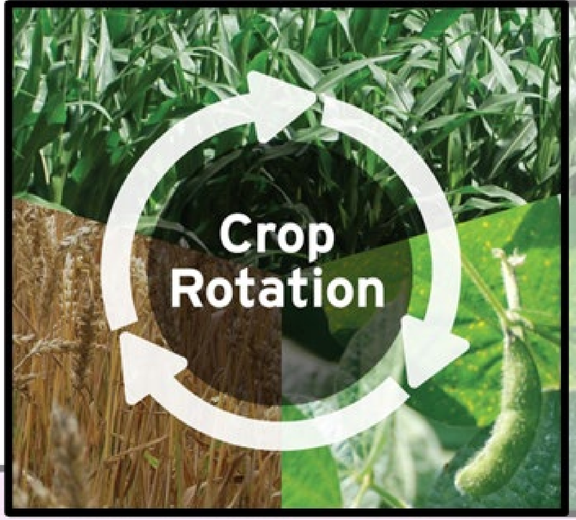


Average NO3 reduction 7.8 %
Average NO3 reduction (Chla > 5) 64.8 %



40
35
30
25
20
15
10
5
0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2016
2018
2020
2022
Date
Chlorophyll a
Nitrate (NO3)
Total Phosphorous (TP)





Agricultural BMP can help offset the effects of eutrophication on HAB in Mar Menor

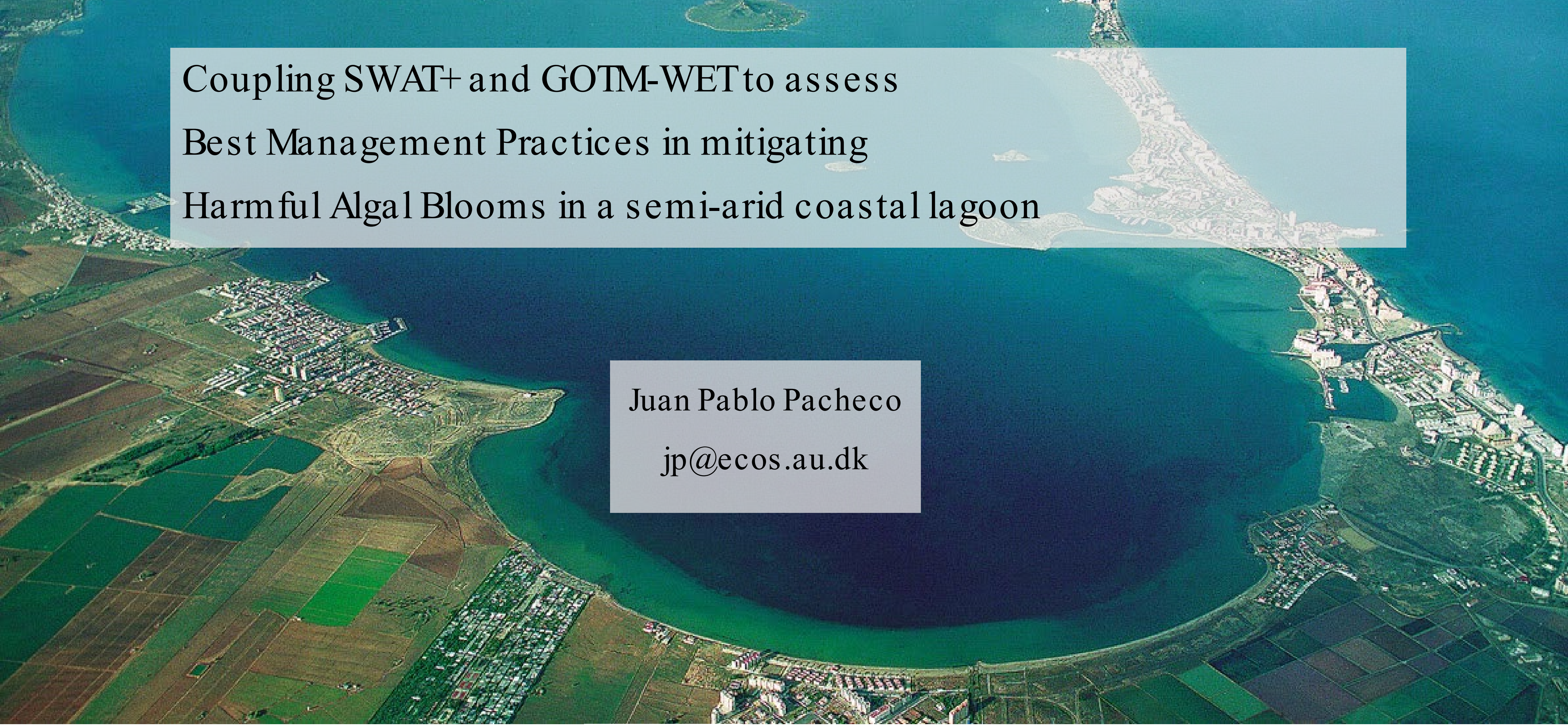
Most effective BMP: **Vegetation strips** and **Crop rotation**

Less effective BMP : Contour farming

Coupled **SWAT+ & GOTM-WET** modelling -> assess **most effective BMP** strategies in controlling HABs

Take it with **caution**: preliminary results on restricted dataset + relate to lake process

Support decision-makers in developing agricultural strategies to mitigate eutrophication + restoration strategies according to key ES



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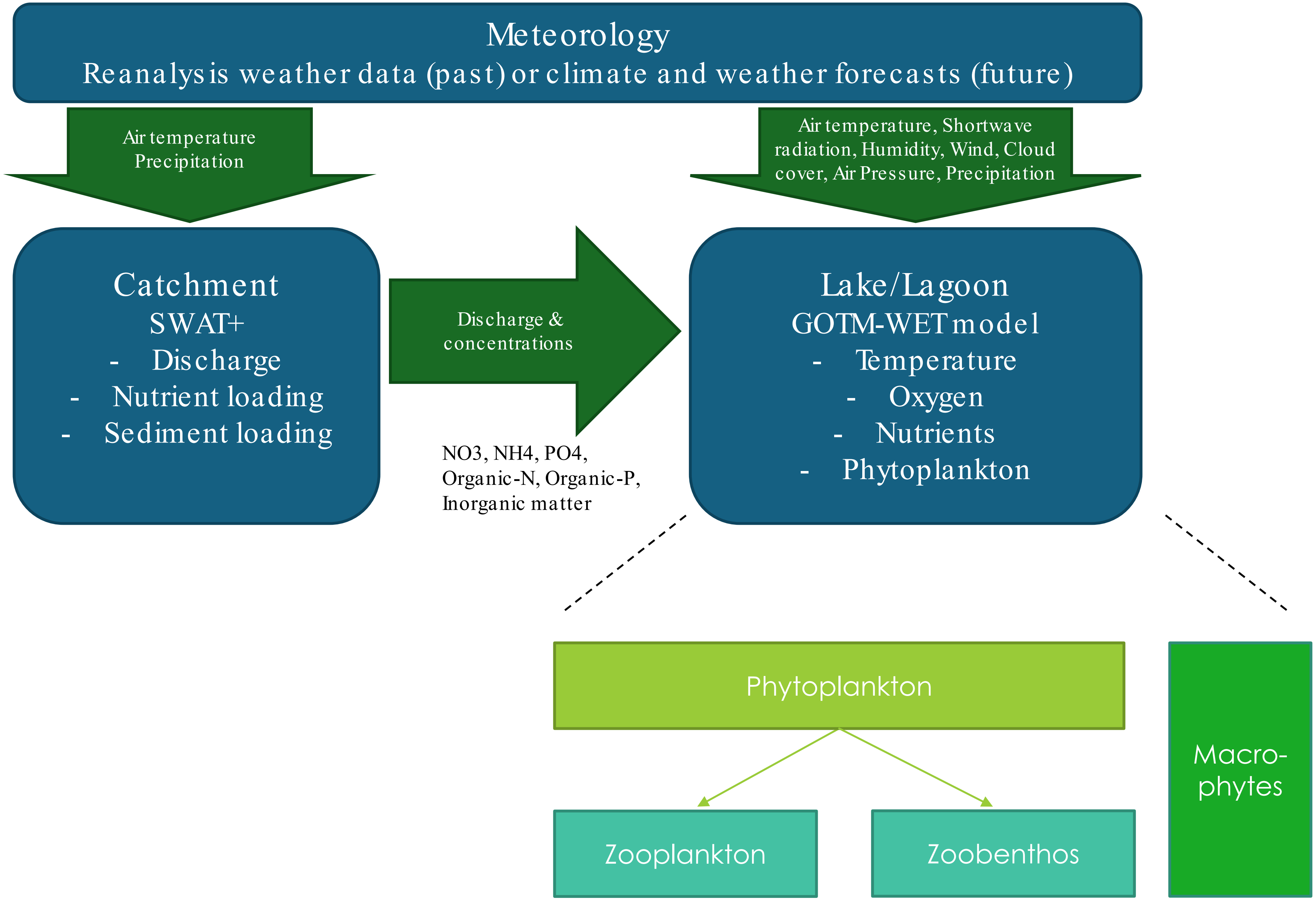
WATERITECH

SMART LAGOON


Meteorology
Reanalysis weather data (past) or climate and weather forecasts (future)
Air temperature
Precipitation
Air temperature, Shortwave radiation, Humidity, Wind, Cloud cover, Air Pressure, Precipitation
Catchment
SWAT+
- Discharge
- Nutrient loading
- Sediment loading
Discharge & concentrations
NO3, NH4, PO4, Organic-N, Organic-P, Inorganic matter
Lake/Lagoon
GOTM-WET model
- Temperature
- Oxygen
- Nutrients
- Phytoplankton
Phytoplankton
Zooplankton
Zoobenthos
Macro-phytes

Software

SMART LAGOON

- QGIS 3.34
- QSWAT+ 2.4.0
- SWAT+ Editor 2.3.3
- SWAT+ rev60.5.7
- SWATplus-CUP 2022 v3.0

Adrián López-Ballesteros
Universidad Católica San Antonio de Murcia (UCAM)

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101017861.

Model INPUTS

SMART LAGOON

Data	Description	Source
DEM	25 m x 25 m resolution map	Spanish National Geographic Institute (IGN)
Land use map	Vector database	MAPA DE CULTIVOS Y APROVECHAMIENTOS DE ESPAÑA 2000-2009
Soil map	250 m x 250 m resolution map	Digital Soil Open Land Map (DSOLMap)
Climate data (2000-2022)	Daily meteorological stations called CA21, CA42, CA52, CA91, MU31, MU62, TP42.	Murcian Institute of Agrarian and Food Research and Development (IMIDA)

Utilizar DSOLMAP de MapSWAT (ya que si hay huecos da fallo las HRUs)

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Model SETUP

SMART LAGOON

STEP 1: Delineate Watershed

- **Thresholds:** 2 km^2 (channel) / 6 km^2 (stream)
- **Sub-basins: 144**
- **Channels: 340**
- **Landscape Units: 396**
- **Reservoirs (Lakes): 1**
- **Area:** 122,791.34 ha
- **Elevation:** 0 – 1063 m.a.s.l. (150 m.a.s.l.)

STEP 2: Create HRUs

- **Slope bands:** [0, 2, 8, 9999]
- **HRUs:** 13889 (No filter)
- **Filter by area:** <100ha (1km^2)
- **HRUs: 750**
- **Burn ramblas.shp**

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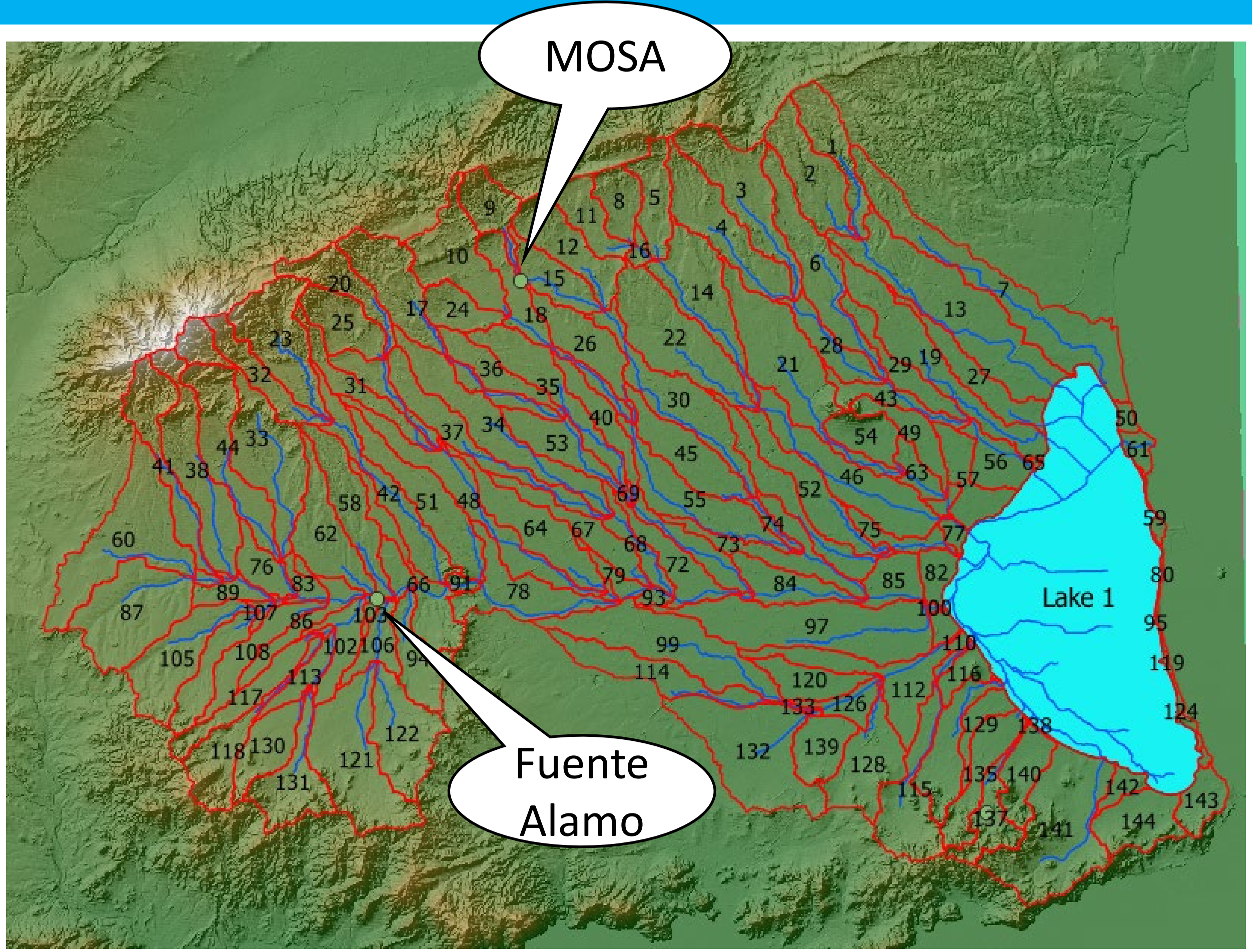
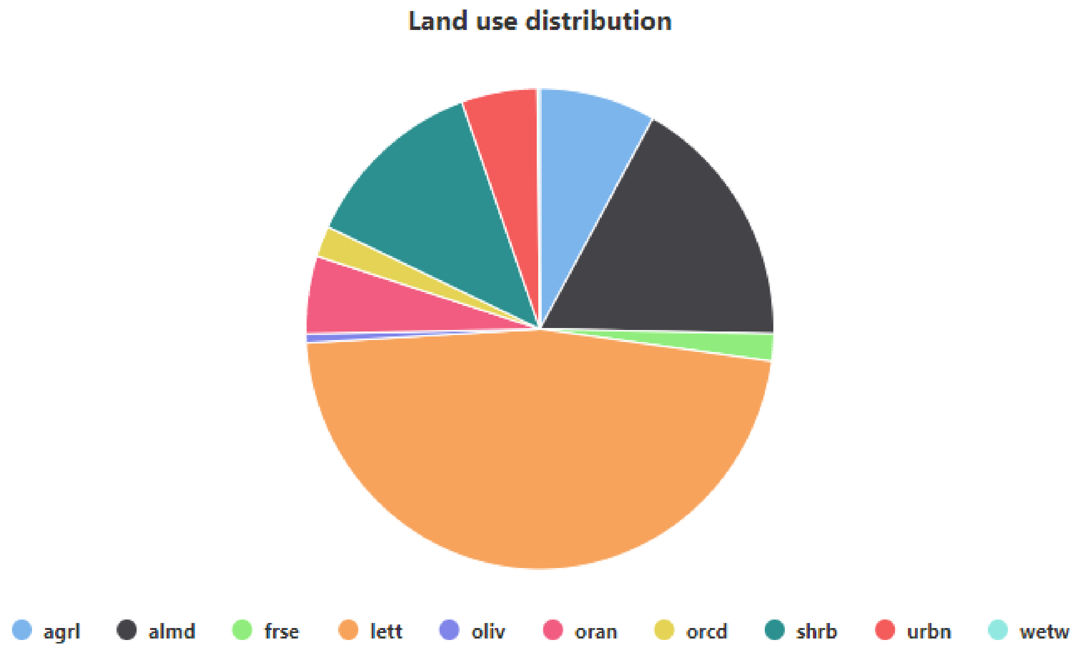
Model SETUP





<u>Agricultural land:</u> 80%

- **<u>Irrigated</u>: 52 %**
- **<u>Rainfed</u>: 28 %**

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Model SETUP

SMART LAGOON

STEP 3: Edits Inputs and Run SWAT

- **ETP: Penman-Monteith**

- **Simulation period**: 2000 – 2022*
  - **Warm up:** 2000 – 2002* (3 years)
  - **Calibration:** 2003 – 2012* (10 years)
  - **Validation:** 2013 – 2022* (10 years)

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Model SETUP

SMART LAGOON

STEP 3: Edits Inputs and Run SWAT

- **Agricultural practices:** ***(López-Ballesteros et al., 2023)***

Year	Date		Operation	Application Rate	Crop
	Month	Day			
1	January	1	Planting begin		Broccoli
1	January	1	Irrigation	**~45 mm/month**	Broccoli
1	January	1	Fertilization[1]	245 KgN/ha/year 100 KgP/ha/year	Broccoli
1	April	30	Harvest and kill		Broccoli
1	May	1	Planting begin		Cantaloupe
1	May	1	Irrigation	**~48 mm/month**	Cantaloupe
1	May	1	Fertilization[1]	225 KgN/ha/year 105 KgP/ha/year	Cantaloupe
1	August	31	Harvest and kill		Cantaloupe
1	September	1	Planting begin		Lettuce
1	September	1	Irrigation	**~31 mm/month**	Lettuce
1	September	1	Fertilization[1]	100 KgN/ha/year 58 KgP/ha/year	Lettuce
1	December	31	Harvest and kill		Lettuce

[1] Total amount applied throughout the crop schedule.

El riego ha sido obtenido de la UDA 58 - Regadíos redotados del TTS de la ZRT Campo de Cartagena. – *Agua del trasvase.*

PLAN HIDROLÓGICO DE LA DEMARCACIÓN DEL SEGURA 2015/21. ANEJO 3 USOS Y DEMANDAS.

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Model SETUP

SMART LAGOON

STEP 3: Edits Inputs and Run SWAT

- **Applied Nitrogen (solo inorgánico)**

Mas usado en la fertirrigación,
ya que es mas soluble.

Name

Nitrogen

Description (optional)

Value	Description	SWAT+ Variable	Default	Recommended Range
1	Fraction of fertilizer that is mineral N (NO3+NH3)	min_n	0	0 - 1
0	Fraction of fertilizer that is mineral P	min_p	0	0 - 1
0	Fraction of fertilizer that is org N	org_n	0	0 - 1
0	Fraction of fertilizer that is org P	org_p	0	0 - 1
0	Fraction of mineral N content of fertilizer that is NH3	nh3_n	0	0 - 1

Operations/Chemical Applications / Edit

Name

fertigate

Description (optional)

Dataset Value	Your Value		Description	SWAT+ Variable
liquid	liquid		Chemical form	chem_form
spray	spray		Application type	app_typ
0.9	1		Application efficiency	app_eff
0.5	0,5		Foliar efficiency	foliar_eff
0	0	mm	Injection depth	inject_dp
1	1		Surface fraction amount in upper 10mm	surf_frac
0.2	0,2		Drift potential	drift_pot
1	1		Aerial uniformity	aerial_unif

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Model SETUP

SMART LAGOON

STEP 3: Edits Inputs and Run SWAT

- **Applied Phosphorus (solo inorgánico)**

Fertilizer / Edit

Name

Phosphorus

Description (optional)

Value	Description	SWAT+ Variable	Default
0	Fraction of fertilizer that is mineral N (NO3+NH3)	min_n	0
0,45	Fraction of fertilizer that is mineral P	min_p	0
0	Fraction of fertilizer that is org N	org_n	0
0	Fraction of fertilizer that is org P	org_p	0
0	Fraction of mineral N content of fertilizer that is NH3	nh3_n	0

BROCULI

Absorción de nutrientes en el ciclo de cultivo para una producción de 20 t/ha

Intervalo	Distribución de nutrientes a lo largo del ciclo de cultivo en kg/ha.				
ddt	N	P2O5	K2O	Ca	Mg
0-15	5	5	10		
15-30	15	10	20		
30-45	30	15	40		
45-60	50	20	65	10	4
60-75	75	30	85	10	6
75-90	70	20	80	15	5
TOTAL	**245**	**100**	**300**	**35**	**15**

The conversion between phosphorus (P) and **phosphorus pentoxide (P2O5)** is done by multiplying the P2O5 content by a conversion factor, which is approximately 0.44.

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Model CALIBRATION

SMART LAGOON

- **Automatic Multivariable Calibration:**

SWATplus-CUP 2022 v3.0

- **Multi-Objective function:**
  R2; NSE; PBIAS; KGE
- **Time step:**
  Monthly
- **Application scale:**
  Watershed

- **Actual Evapotranspiration (ET)**
- **Soil Water Content (SW)**

Smsurf
+
Smroot

GLEAM v3.7b: A global dataset spanning the 20-year period from **2003 to 2022**. The dataset is based on **satellite data**.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017861.

Model CALIBRATION

SMART LAGOON

- **Sensitivity Analysis:** 14 SWAT+ parameters → 2 parameters mas sensibles Pvalues < 0.1

Parameter Name	t-Stat	P-Value
v__perco.hru	2.782750244	0.006639937
r__BD().sol	2.593827189	0.011175427
r__cn3_swf.hru	1.462426584	0.147312029
v__deep_seep.aqu	-1.388500432	0.168612723
r__AWC().sol	1.295879900	0.198524721
v__sp_yld.aqu	1.098786985	0.274963572
r__K().sol	-0.709893804	0.479712985
v__epco.hru	-0.666696515	0.506771689
r__cn2.hru	-0.515783042	0.607344991
v__esco.hru	0.479174213	0.633045188
v__REVAP_CO.aqu	-0.387572165	0.699301491
v__flo_min.aqu	-0.182419735	0.855687710
v__revap_min.aqu	0.133094365	0.894433341
v__alpha.aqu	0.082609967	0.934355905

v__perco.hru

r__BD().sol

\+

r__cn2.hru

v__esco.hru

v__epco.hru

r__AWC().sol

(López-Ballesteros et al., 2023)

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Model CALIBRATION

SMART LAGOON

- **Calibrated VALUES:**

r__cn2.hru	0.063125 -> 6.31%
v__esco.hru	0.474
v__epco.hru	0.254
r__AWC().sol	0.132500 -> 13.25%
r__BD().sol	0.0672 -> 6.72%
v__perco.hru	0.963

v__lat_ttime.hyd **2** -> From subdaily tests in SWAT2012.
v__rchrg_dp.aqu **0.4** -> From Jiménez-Martínez et al. (2011).
V__sw_init.hyd **0.5** -> Manual calibration to increase initial SW.
Usle P = 1 -> Up-down-slope
Urban runoff -> USGS_reg (Aumenta los nutrientes de las áreas urbanas)

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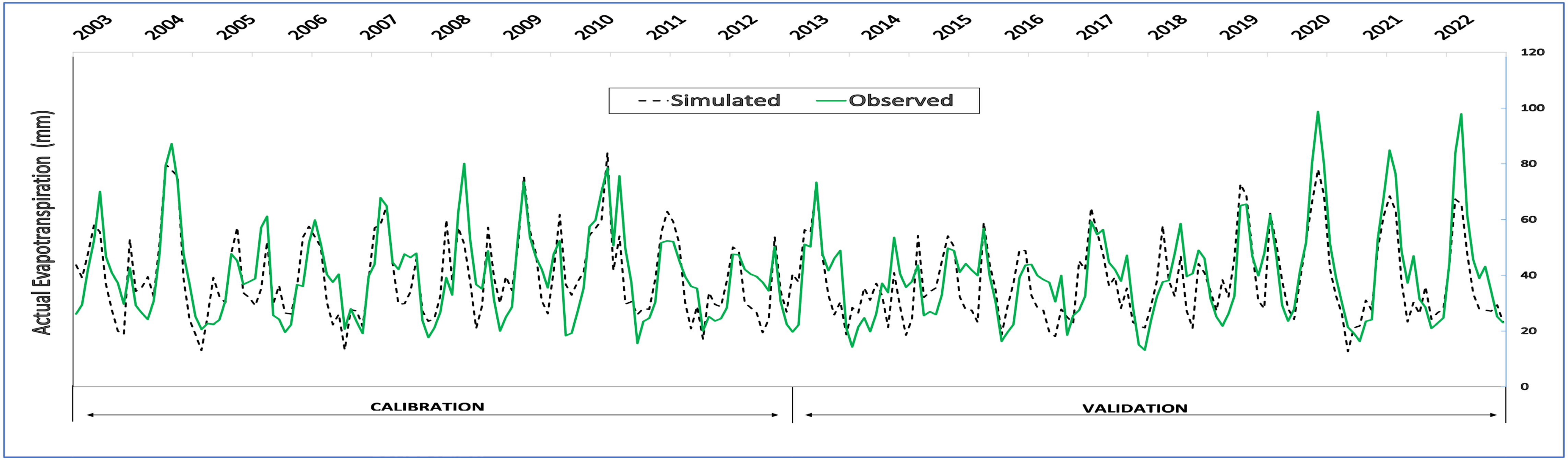
Model RESULTS

- **Actual Evapotranspiration:**



Monthly AET GLEAM 3.7b (2003 – 2022):

Calibration [2003-2012] (R^2 = 0.62, PBIAS = 1.86 %, NS = 0.59 and KGE = 0.77)

Validation [2013-2022] (R^2 = 0.63, PBIAS = 5.89 %, NS = 0.61 and KGE = 0.73)

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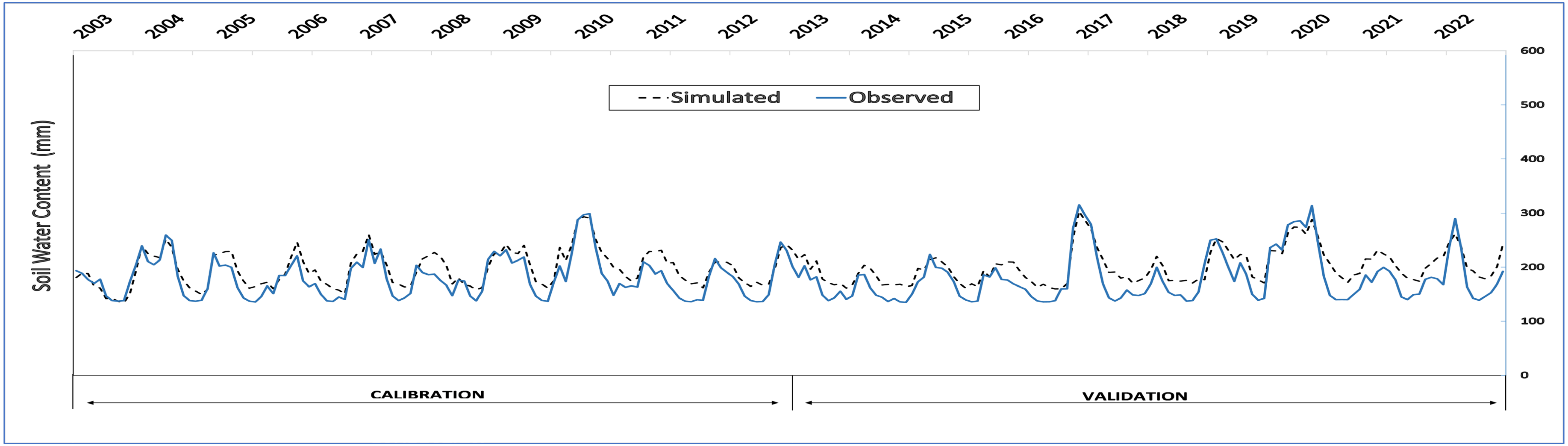
Model RESULTS

SMART LAGOON

- **Soil Water Content:**



Monthly SW GLEAM 3.7b (2003 – 2022):

Calibration [2003-2012] (R^2 = 0.81, PBIAS = -0.11%, NS = 0.81 and KGE = 0.85)

Validation [2013-2022] (R^2 = 0.87, PBIAS = -2.99%, NS = 0.81 and KGE = 0.72)

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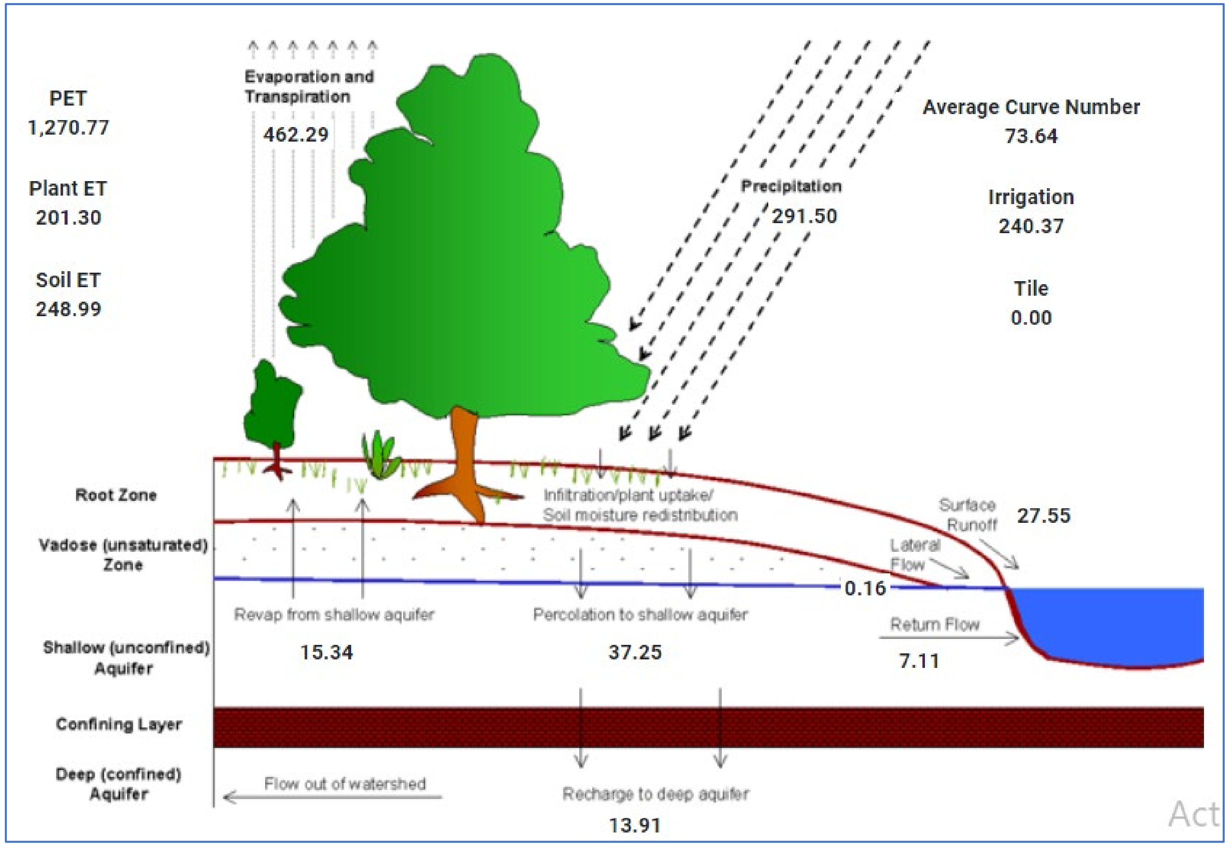
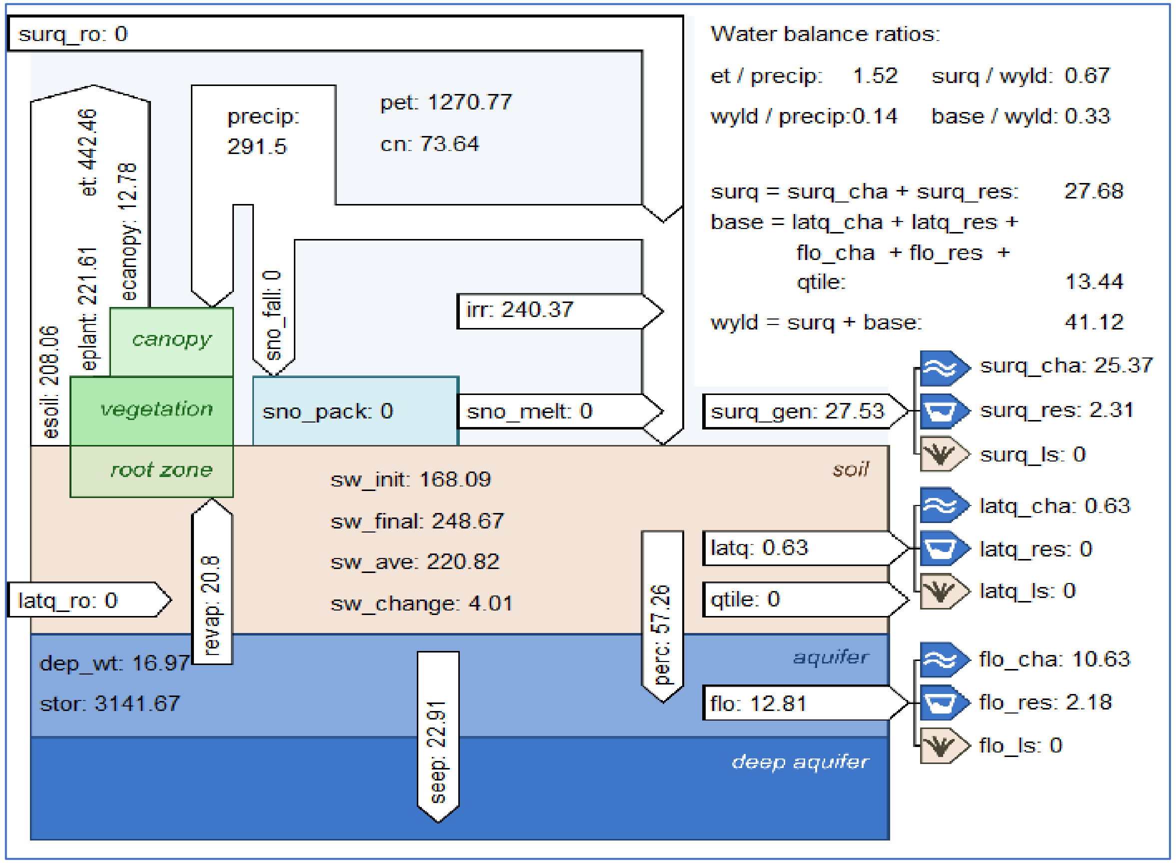
Model RESULTS

- **Water balance:**





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Model RESULTS

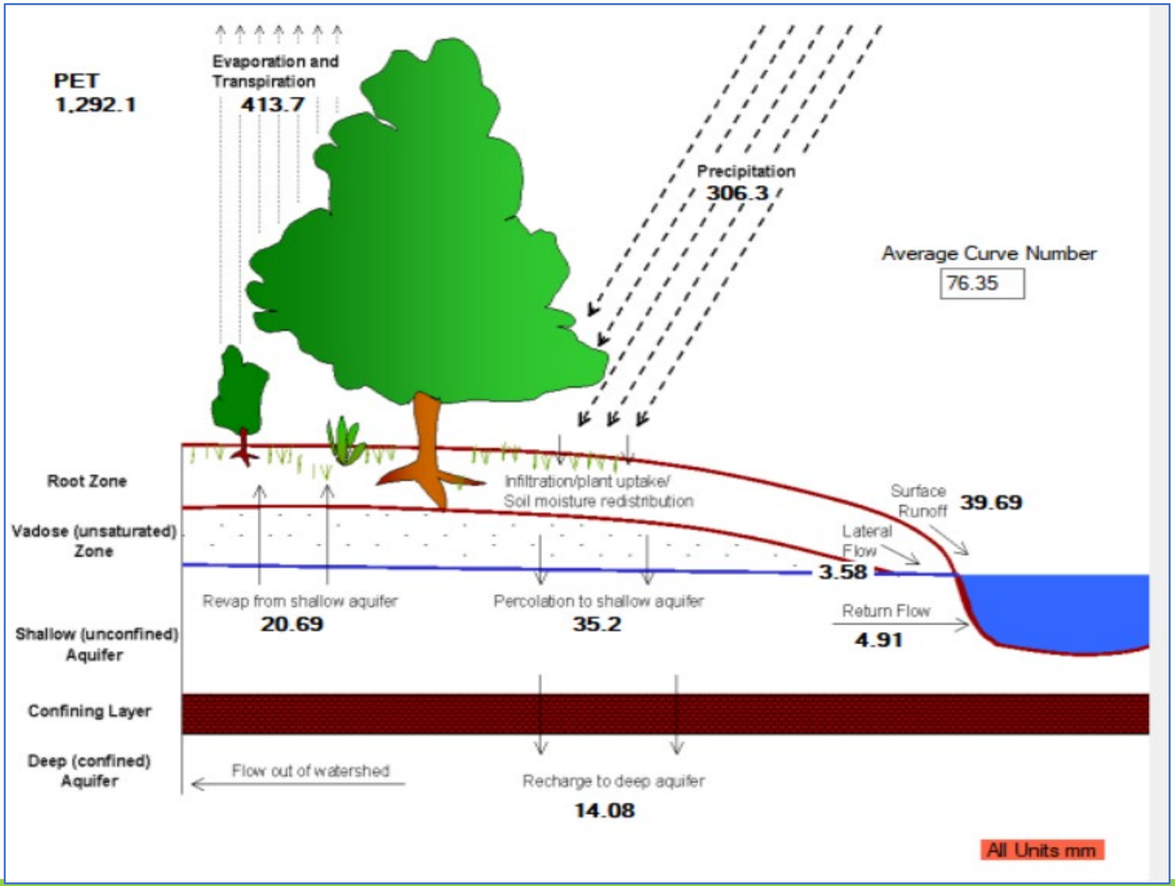
- **SWAT+** (2003 – 2022*)

El balance de agua puede ser justificado con las otras publicaciones, es muy parecido.

(López-Ballesteros et al., 2023)

(Senent-Aparicio et al., 2021)

- **SWAT2012** (2003 – 2022*)



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Contour farming: increase soil infiltration capacity, intercept surface runoff and reduce sediment and nutrient losses.

simulated by activating the contouring option in the scheduled management operations tool (.ops) for the non-woody agricultural land uses in SWAT

Vegetation filter strips (buffer): Dense vegetation is installed along the perimeter of the field to intercept and filter surface runoff. Sediment and nutrient loads are trapped in the strip vegetation.

Fertilizer reduction: Maximum doses of fertilizer were established in the context of agricultural land use, based on the guidelines provided by a regional regulation known as the Code of Good Agricultural Practices of Murcia [2], which entails a reduction of about 15%–25% of the maximum amount of elemental nitrogen applied to each crop per year

High sediment and nutrient yields without retention

Non-pointed pollutants by agriculture is the main source of nutrients

Increased turbidity (phytoplankton blooms) +

High discharge -> concentrated nutrients runoff + decreased salinity -> Phytoplankton blooms

Testing BMP allows to predict effect of practices on ecosystems, e.g. for management or restoration strategies

Agricultural BMPs are the most cost-effective strategies in reducing nutrient inputs compared to other as structural (e.g. dam removal)

Extra: Campo de Cartagena was a very active mining region for hundreds of years, although the area is currently abandoned