AN INTEGRATED MODELLING METHODOLOGY TO STUDY THE IMPACTS OF NUTRIENTS ON COASTAL AQUATIC ECOSYSTEMS IN THE CONTEXT OF CLIMATE CHANGE

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Outline

- **Introduction**
  - Climate change in the 21st century
  - Climate change and non-point source pollution (NPS)
- **Methodology & Results**
  - Methodology
    - Case study
    - Climate modelling (CMCC-CM GCM, COSMO-CLM RCM
    - Hydrological modelling (SWAT)
    - Ecosystem modelling (AQUATOX)
  - Results
- **Conclusions**

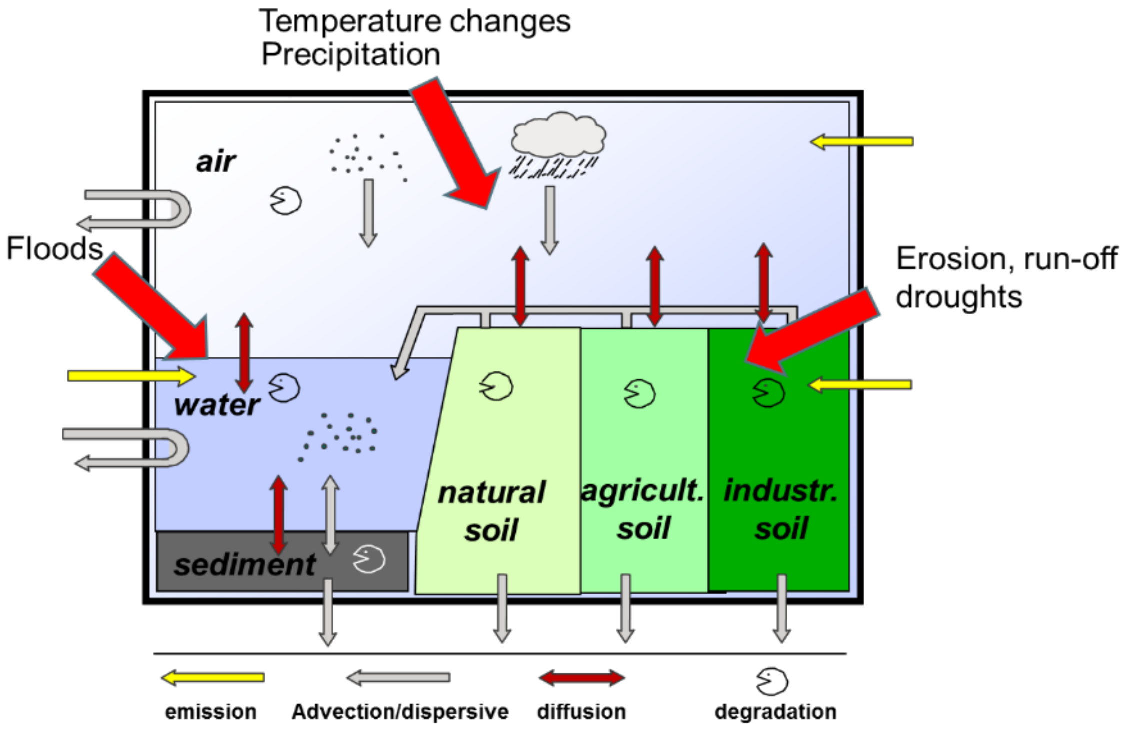
Climate change and non-point source pollution (NPSP)

- Climate change is already affecting **waterbodies** and **aquatic ecosystems** by changing water regimes and quality.
- With point source pollution being drastically reduced, **NPSP** is the **major cause** of most water related issues.
- **Climate change** is likely to affect the **impacts of NPSP** to ecological health of waterbodies by altering:

1. Types and quantities of chemicals released in the environment
2. Transport, accumulation, and fate of chemicals in the environment
3. Sensitivity of organisms to environmental and climate conditions
4. Vulnerability of ecosystems: changes in processes, composition and species interactions

CLIMATE CHANGE AND NUTRIENT POLLUTION

- **Extreme precipitation, storms, and floods:**
  - Increase urban and agricultural runoff into surface waters
- **Extended droughts and dry soil conditions:**
  - Soils more susceptible to erosion
  - Rapid transit of chemicals into groundwaters
- **Changes in structure and functioning of aquatic ecosystems**
  - Shifts in timing and magnitude of phytoplanktonic blooms & consequent effects on higher trophic levels



H.A.M. de Kruijf, 2008

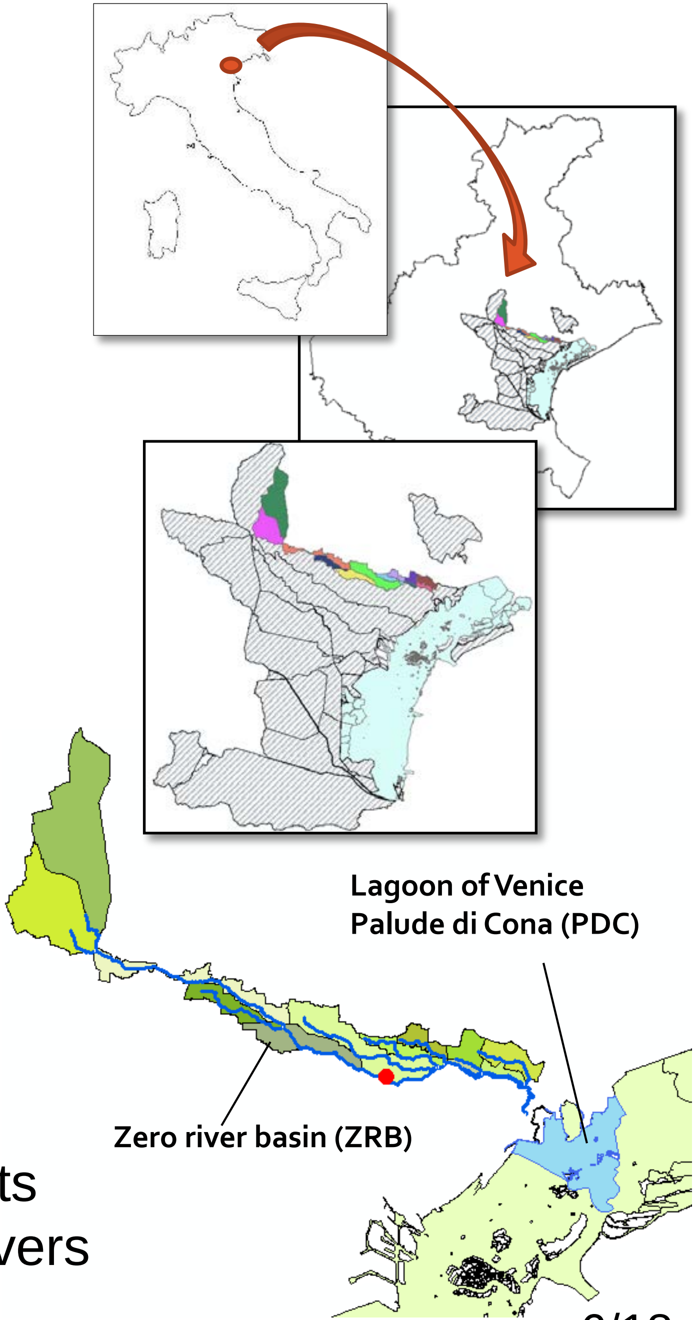
- **Exacerbation of impacts on aquatic ecosystems (e.g. eutrophication)**
  - Reduced water quality (services, aesthetics)
  - Loss of habitat and biodiversity
  - Harmful algal blooms
  - Hypoxic and anoxic events

CASE STUDY

Zero River Basin (ZRB)

- Drainage area: 140 km^2
  - Urban areas: 24%
  - Agricultural areas: 69% (corn, soy, wheat)
  - Green & Pasture areas: 7%

- Jointly with Dese river, it delivers the greatest contribution of freshwater and nutrients into the Lagoon of Venice
- Complex hydrological network: *irrigation channels, emergency flow regulation, complex groundwater recharge system*



Palude di Cona (PDC)

- Surface: 2 km^2
  - Shallow waters (mean depth 0.5 m)
  - Main ecological features: salt-marshes & mudflats
  - Influenced by freshwater input of Zero & Dese rivers (average salinity: 23 PSU)

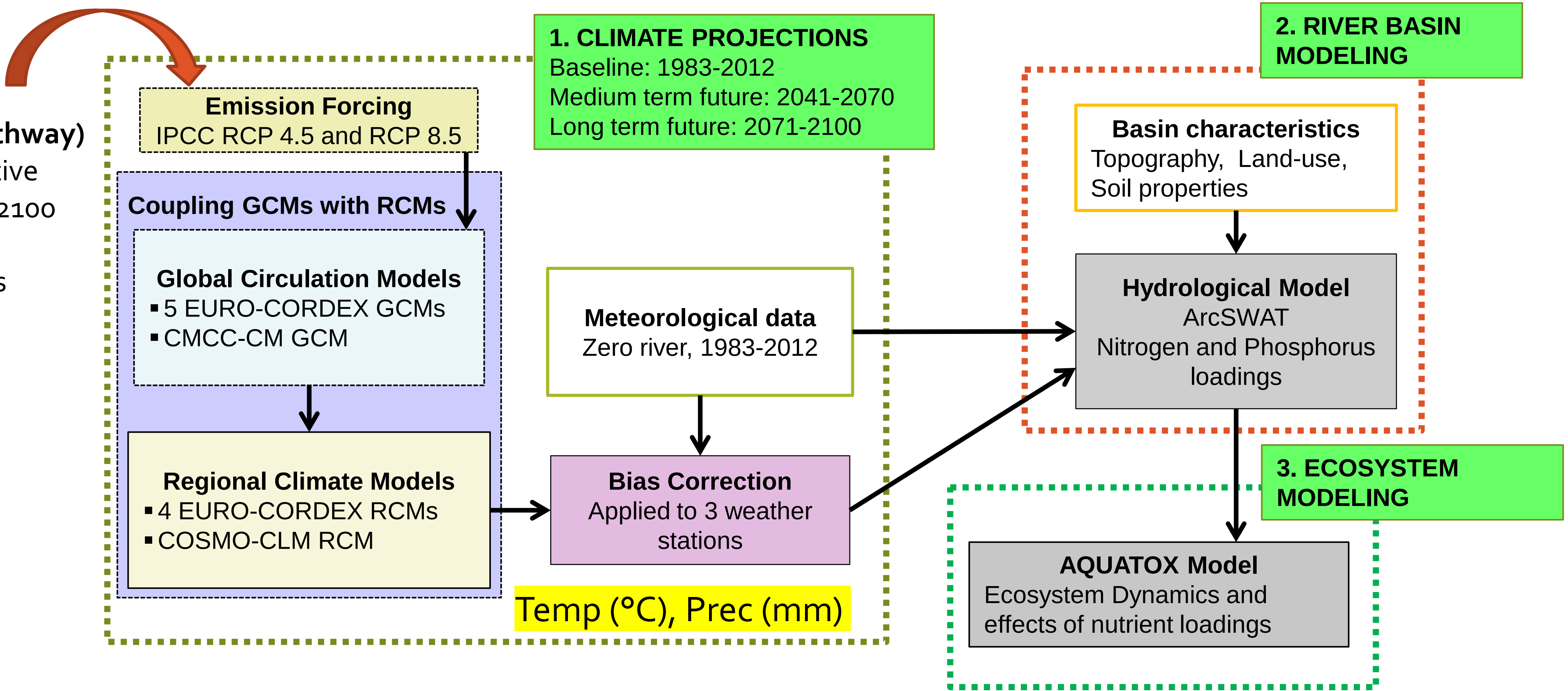
METHODOLOGICAL APPROACH

INTEGRATING CLIMATE-HYDROLOGICAL-ECOTOXICOLOGICAL MODELS

Development & application of an **integrated modeling approach** to study medium to long-term impacts of **climate change** on **nutrient loadings** and the consequent effects on coastal **aquatic ecosystems** over the 21st century.

RCP (Representative Concentration Pathway)
Describe the radiative forcing (W m^{-2}) by 2100

Baseline conditions (1750-1990):
0.5 W m^{-2}



CLIMATE PROJECTIONS

10 GCM/RCM Projections

9 from the EURO-Cordex project

1 from Centro Euro-Mediterraneo Cambiamenti Climatici (CMCC)

2 Representative Concentration Pathways (RCPs): indicate the radiative forcing (W m^{-2}) by 2100:

RCP 4.5 (4.5 W m^{-2} by 2100) → +1.8 °C (1.1 to 2.6 °C)

RCP 8.5 (8.5 W m^{-2} by 2100) → +3.7 °C (2.6 to 4.8 °C)

GCM	RCM	RCPs	Resolution
CMCC-CM	**COSMO-CLM**	**4.5, 8.5**	**8 km**
ICHEC-EC-EARTH	RACMO22E	4.5, 8.5	12.5 km
IPSL-IPSL-CM5A-MR	RCA4	4.5, 8.5	12.5 km
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CNRM-CM5	CCLM4-8-17	4.5, 8.5	12.5 km
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CORDEX SCENARIOS (rows 2–10)

Reference Period
1983 - 2012

Medium-term Period
2041 - 2070

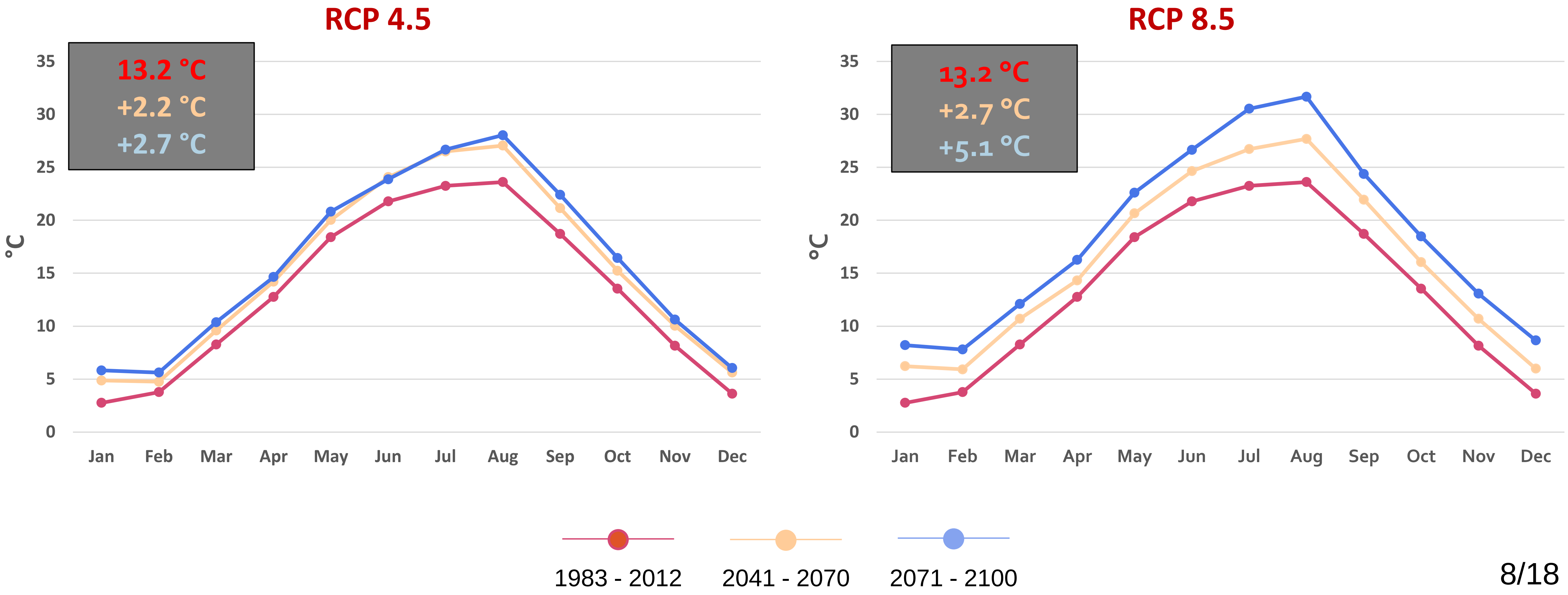
Long-term Period
2071-2100

CLIMATE PROJECTIONS

Projected mean temperature (°C)

30-year monthly mean

CMCC-CM (GCM) / **COSMO-CLM** (RCM)

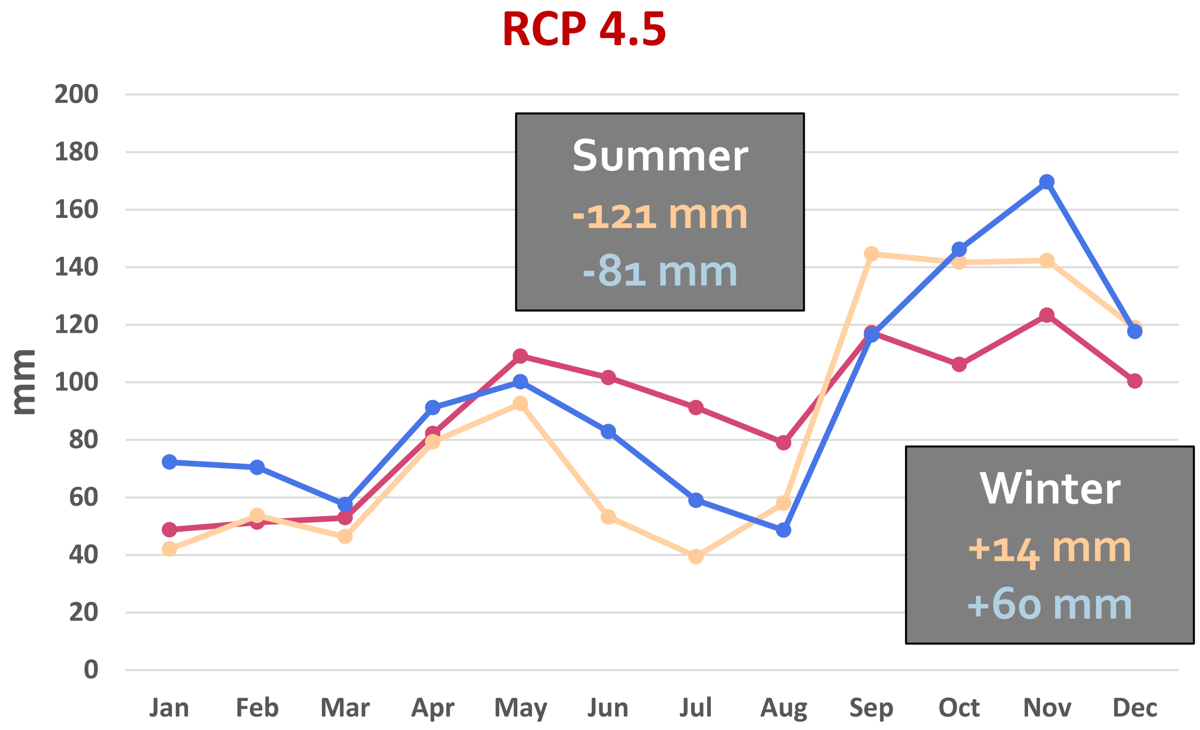


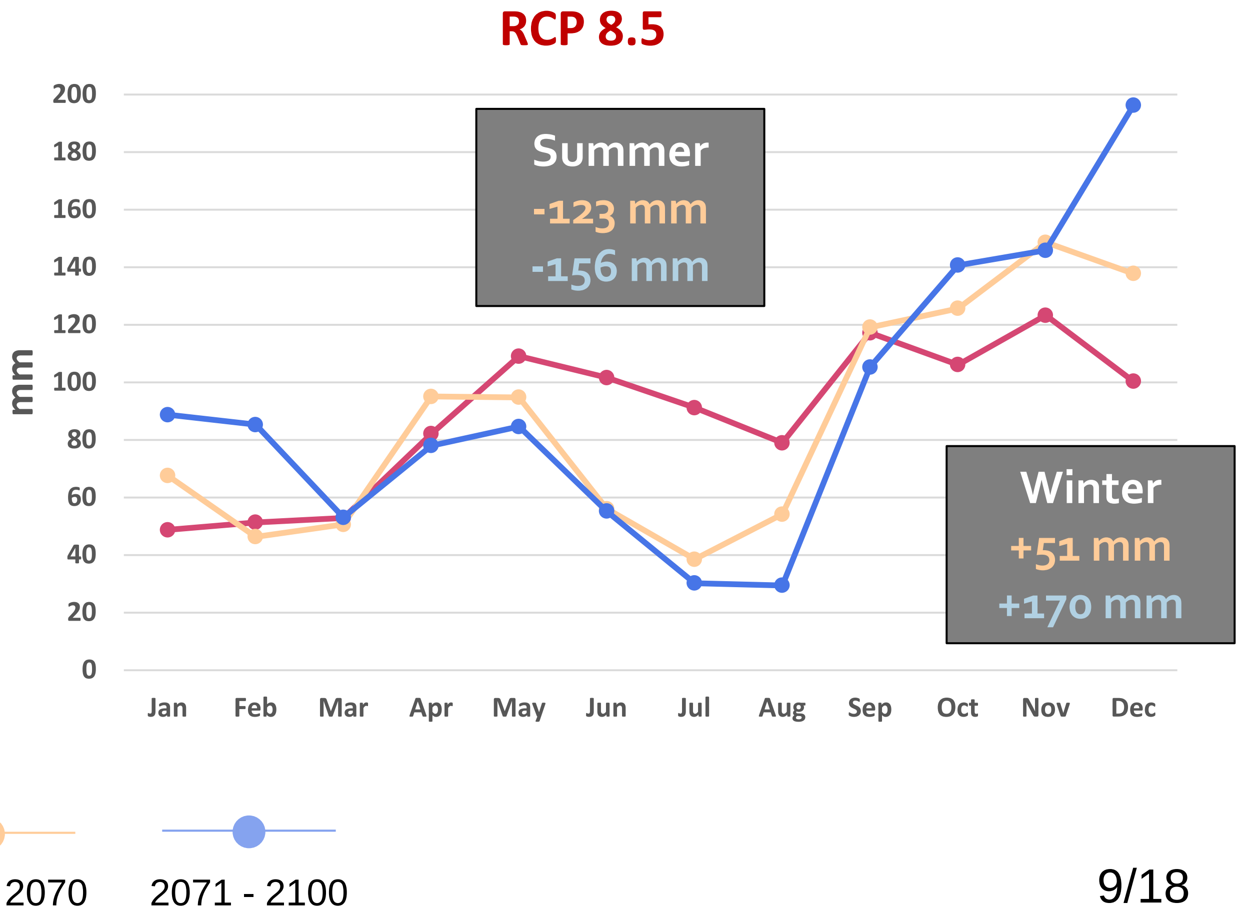
CLIMATE PROJECTIONS

Projected mean precipitation (mm)

30-year monthly mean

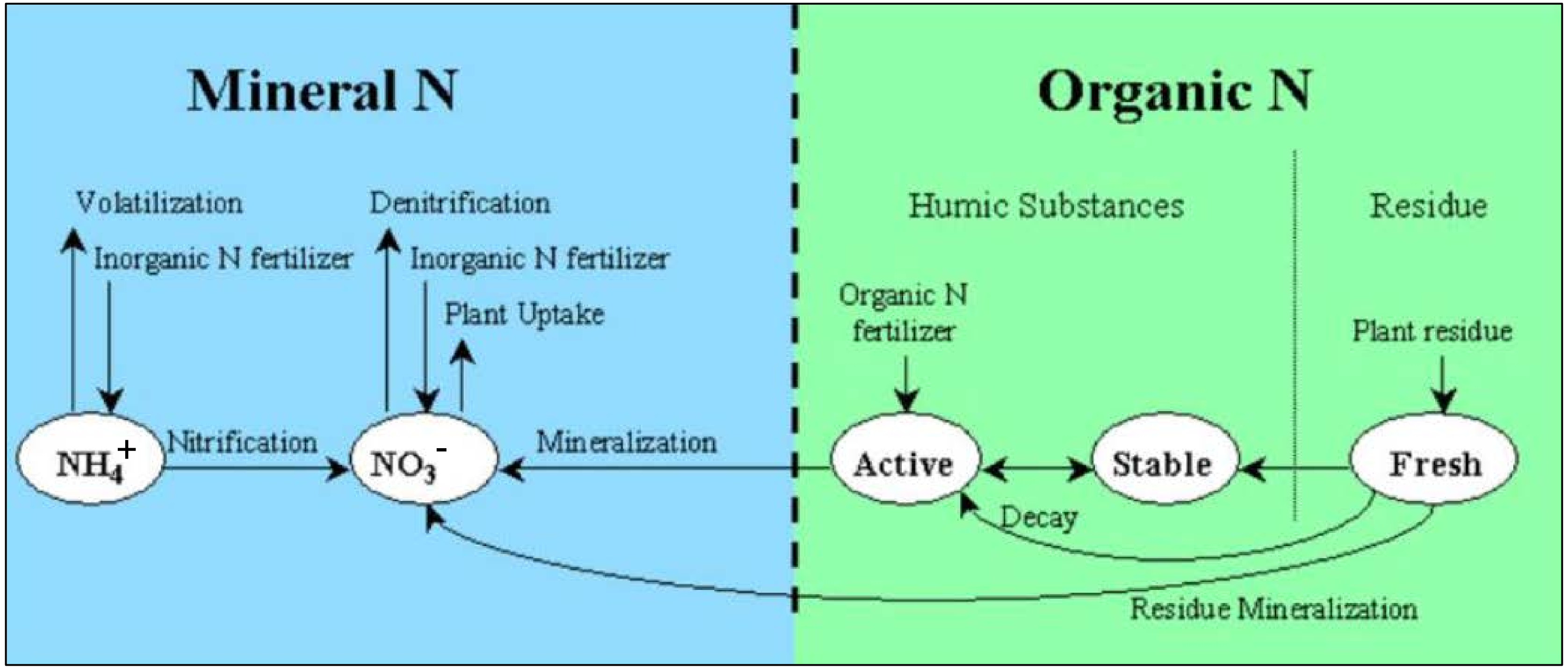
CMCC-CM (GCM) **/ COSMO-CLM** (RCM)





HYDROLOGIC MODELLING: SOIL AND WATER ASSESSMENT TOOL (SWAT)

- Hydrological and water quality model developed for long-term impact assessment studies (climate change, land use change, etc.)
- Model operating at a daily time step concerning water flow, crop growth, sediment and nutrient loadings, etc.
- Physically based: requires specific information about weather, soil properties, topography, vegetation, and land management practices.
- Public domain software – free to use (http://swat.tamu.edu/)



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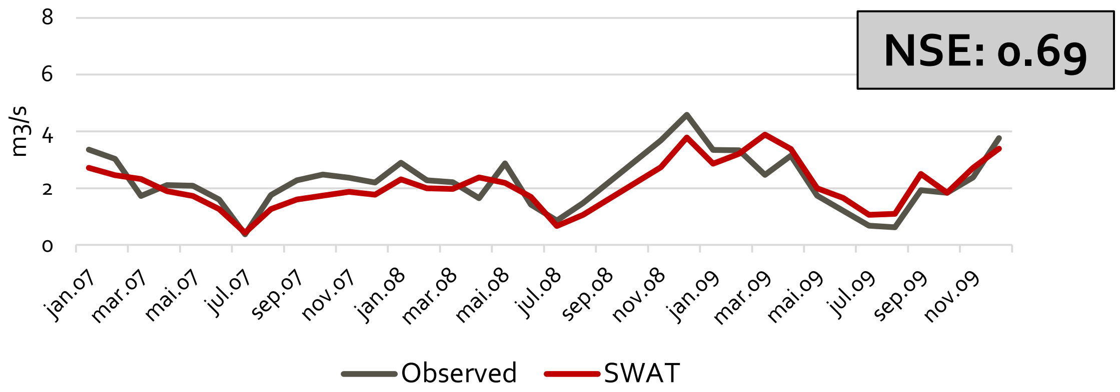

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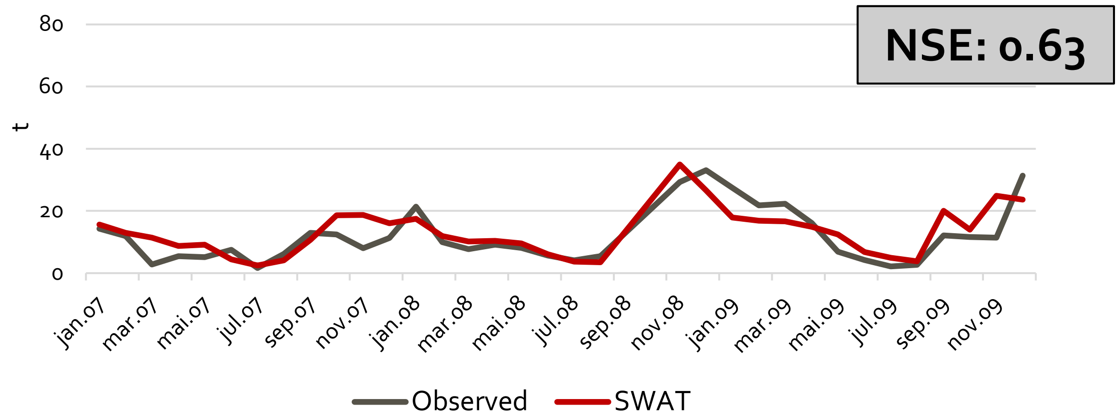

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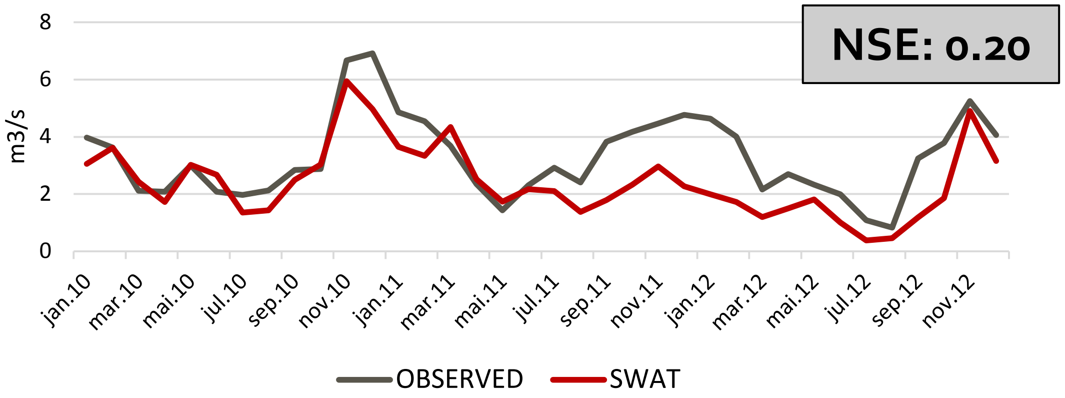

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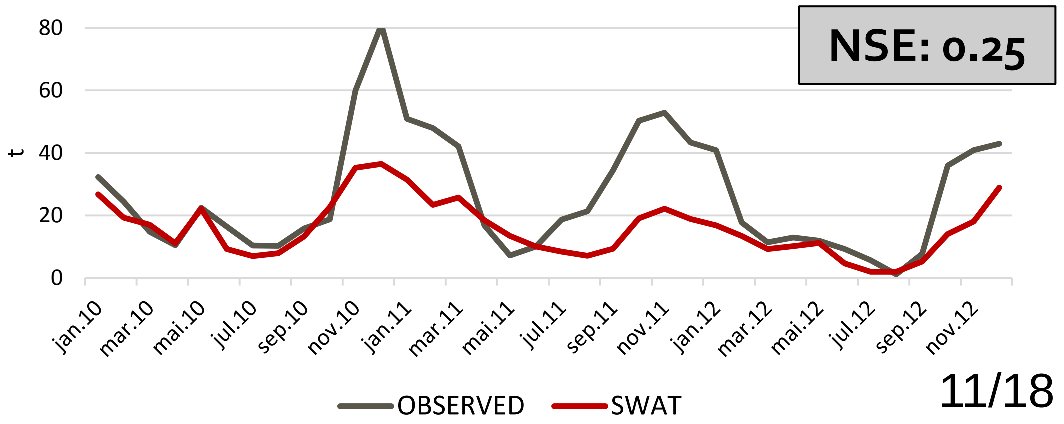


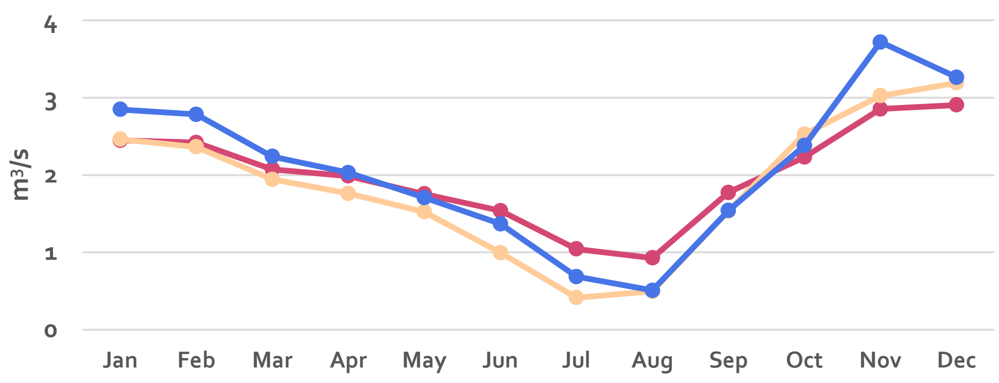
HYDROLOGIC MODELLING: SOIL AND WATER ASSESSMENT TOOL (SWAT)

ZERO RIVER BASIN

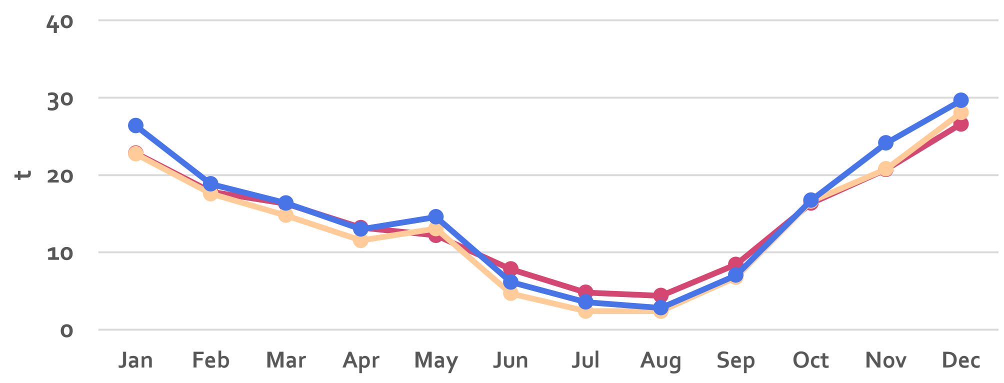
Future projections (30-year monthly mean)

RCP 4.5

Flow rate, Q (m³/s)

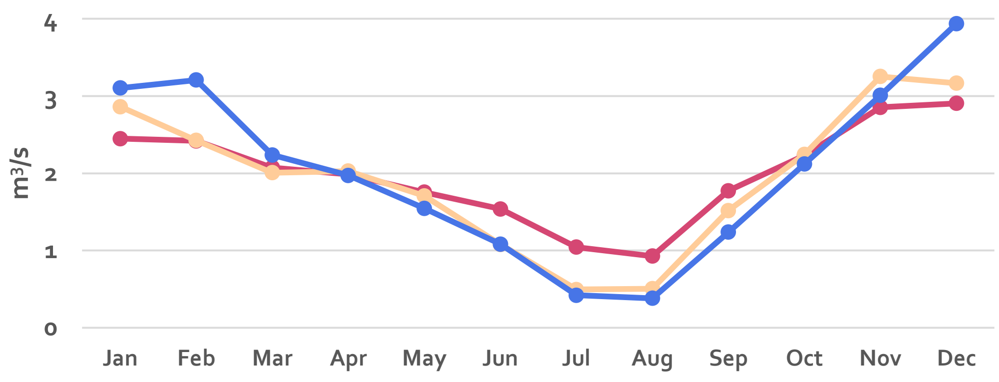


N-NO_3^- loadings (t/mo.)



RCP 8.5

Flow rate, Q (m³/s)



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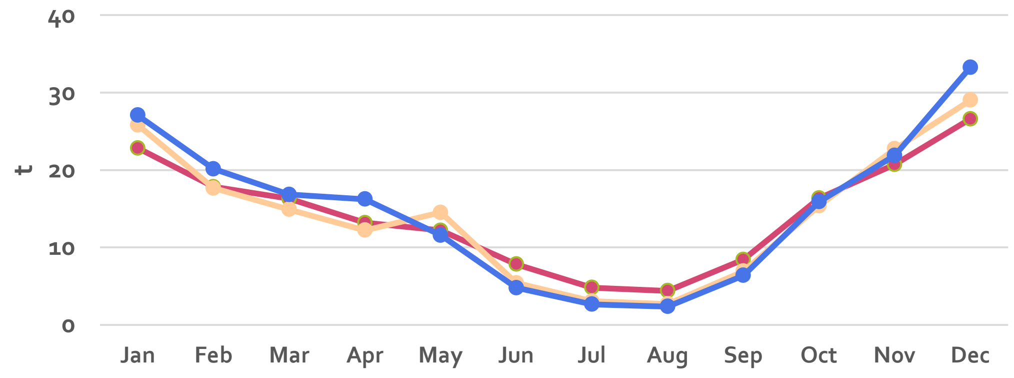


1983 - 2012 | 2041 - 2070 | 2071 - 2100

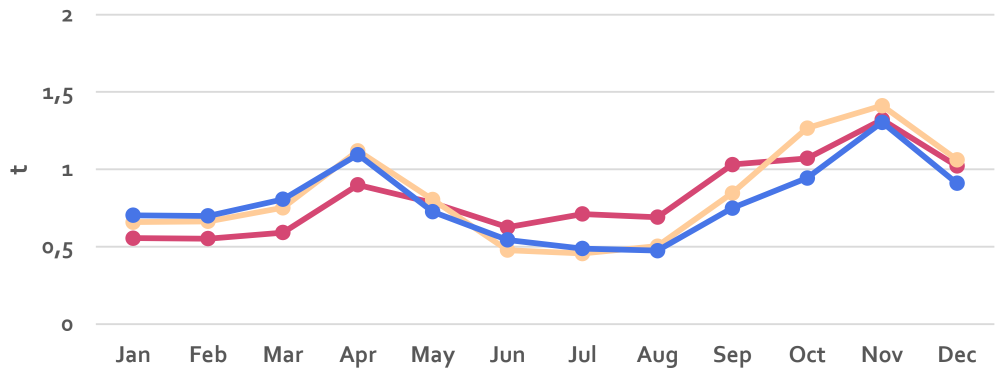
Hydrologic modelling: Soil and Water Assessment Tool (SWAT)

Zero river basin

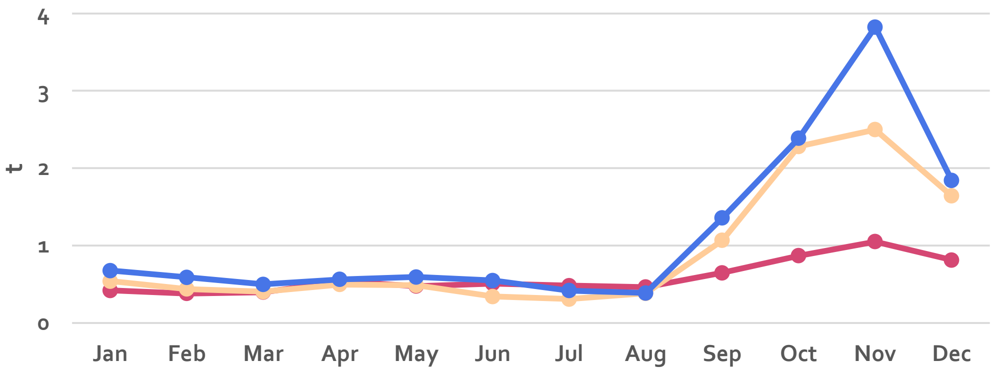
Future projections (30-year monthly mean)

RCP 4.5

N-NH_4^+ loadings (t/mo.)



P-PO_4^{3-} loadings (t/mo.)



RCP 8.5

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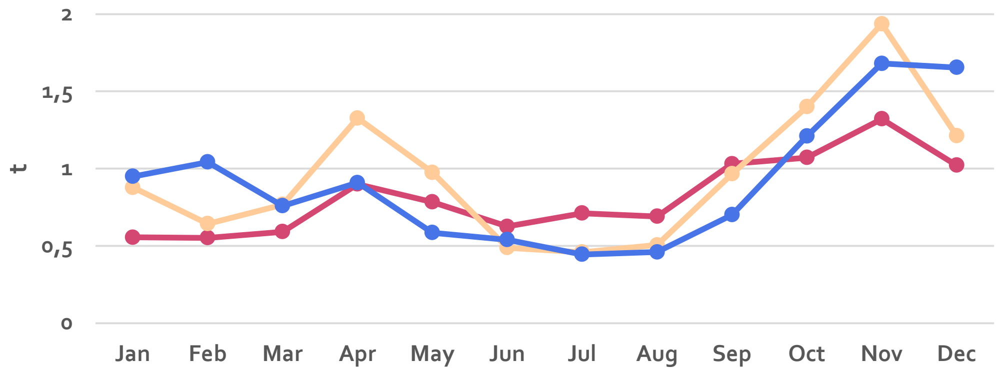

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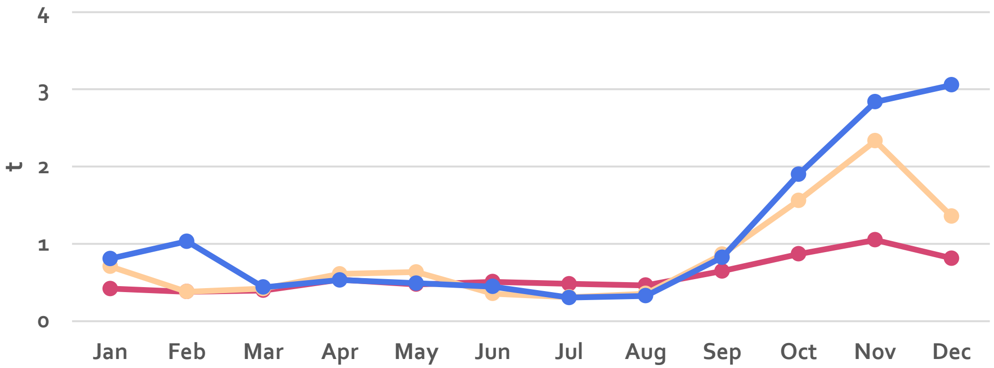
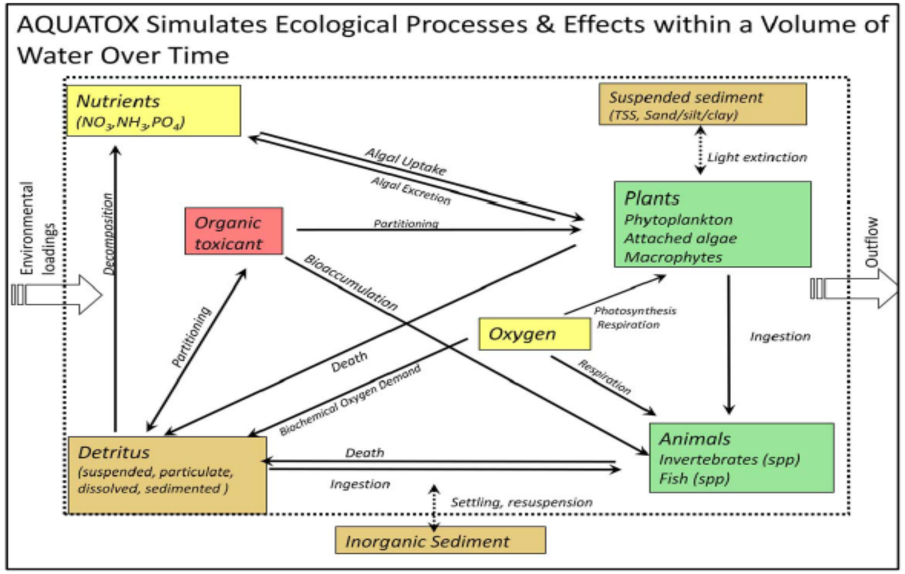
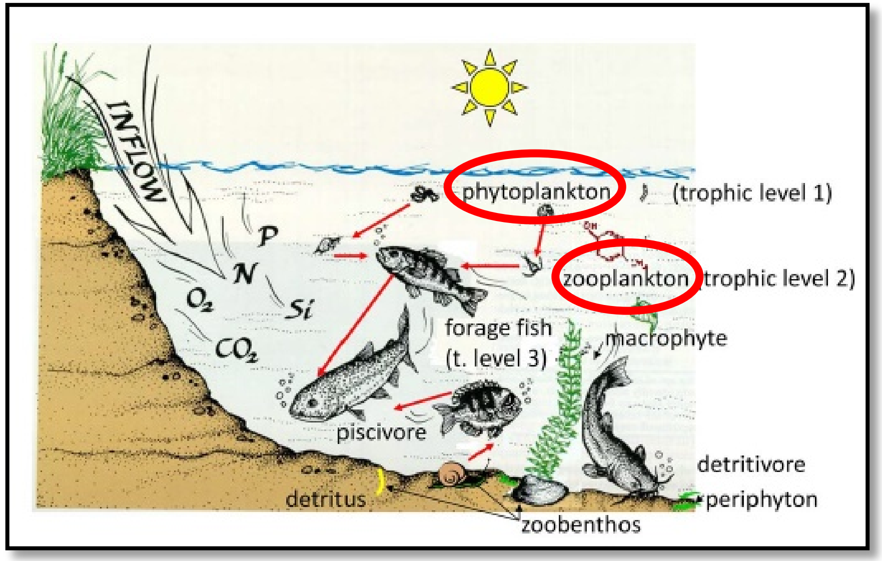


1983 - 2012 | 2041 - 2070 | 2071 - 2100

ECO-TOXICOLOGICAL MODELLING: AQUATOX

- Simulation model for aquatic ecosystems
- Continuous model operating at a daily time step
- Predicts the fate of nutrients and organic chemicals, and their effect on the ecosystems.
- Simulates the transfer of biomass, energy and chemicals from one compartment of the ecosystem to another
- Simulates algae/plants (phytoplankton, periphyton, macrophytes) & animals (zooplankton, benthos, fish)
- Potential to establish causal links between chemical water quality and biological response:
  - o **Temperature effects**
  - o **Effects of nutriens on eutrophication**
  - o Fate & bioaccumulation of organics
  - o Food web & ecotoxicological effects

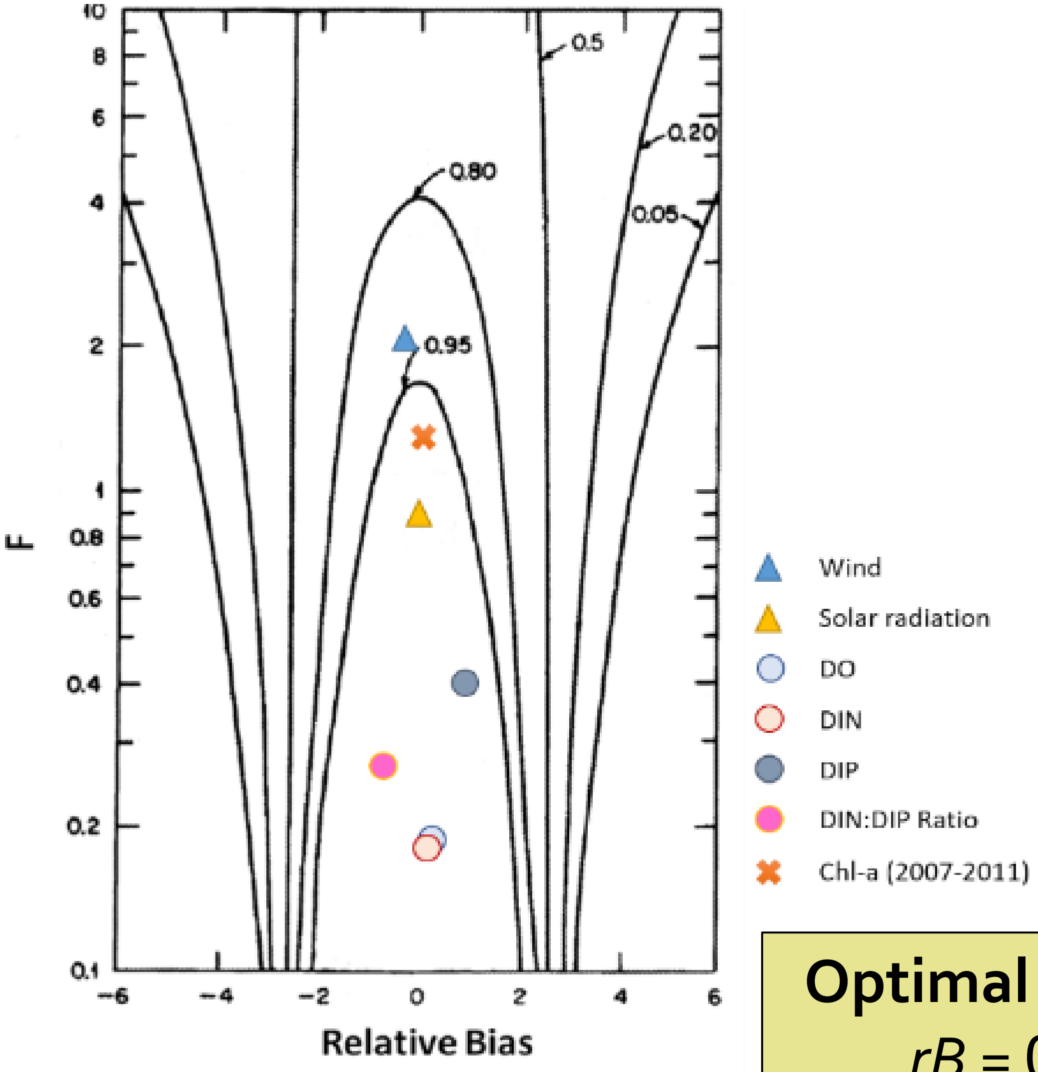




ECO-TOXICOLOGICAL MODELLING: AQUATOX

PALUDE DI CONA

Model performance



Relative bias: $$rB = \frac{\left(\overline{Mod} - \overline{Obs}\right)}{S_{obs}}$$

F-test: $$F = \frac{S_{Mod}^2}{S_{Obs}^2}$$

$\overline{Mod}$: mean modeled values

$\overline{Obs}$: mean observed values

S_{Obs} : variance observed values

S_{Mod} : variance modeled values

Optimal condition:
$rB = 0,\ F = 1$

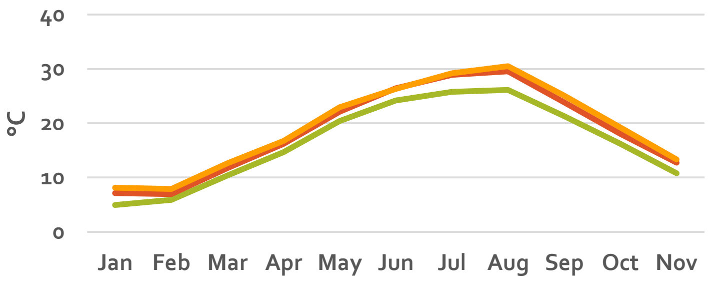
Eco-Toxicological modelling: AQUATOX

Palude di Cona

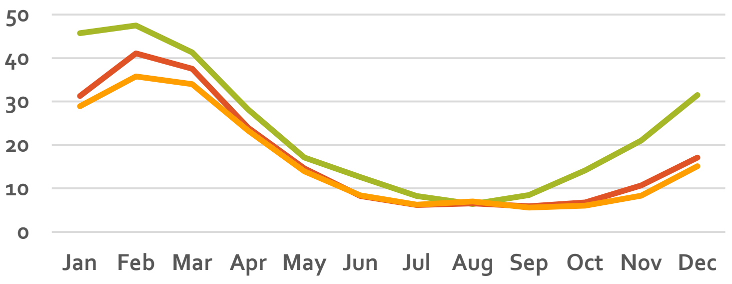
30-year monthly mean

RCP 4.5

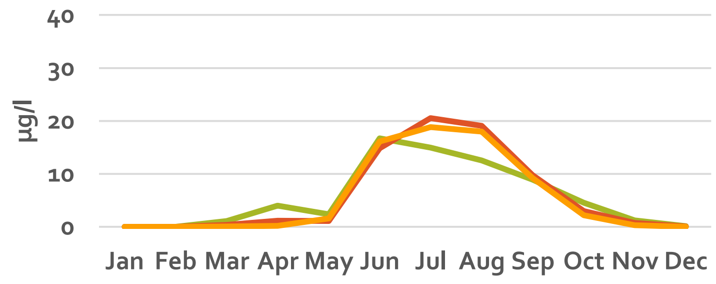
Temperature (°C)



DIN:DIP Ratio



Chl-a (µg/l)



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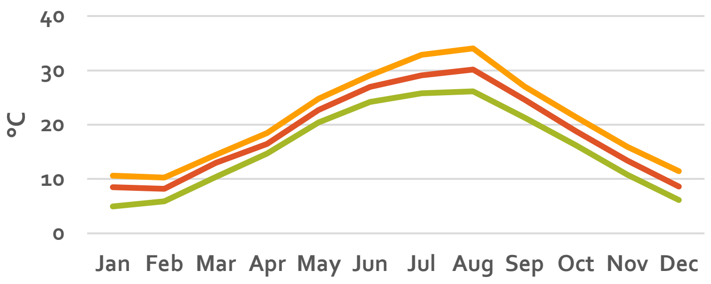

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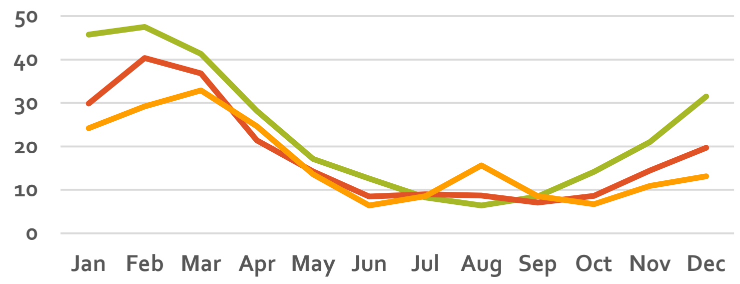

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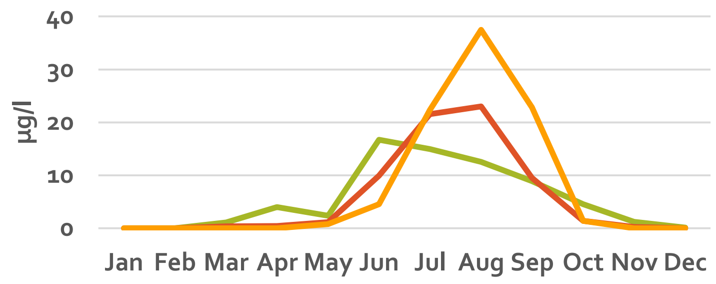
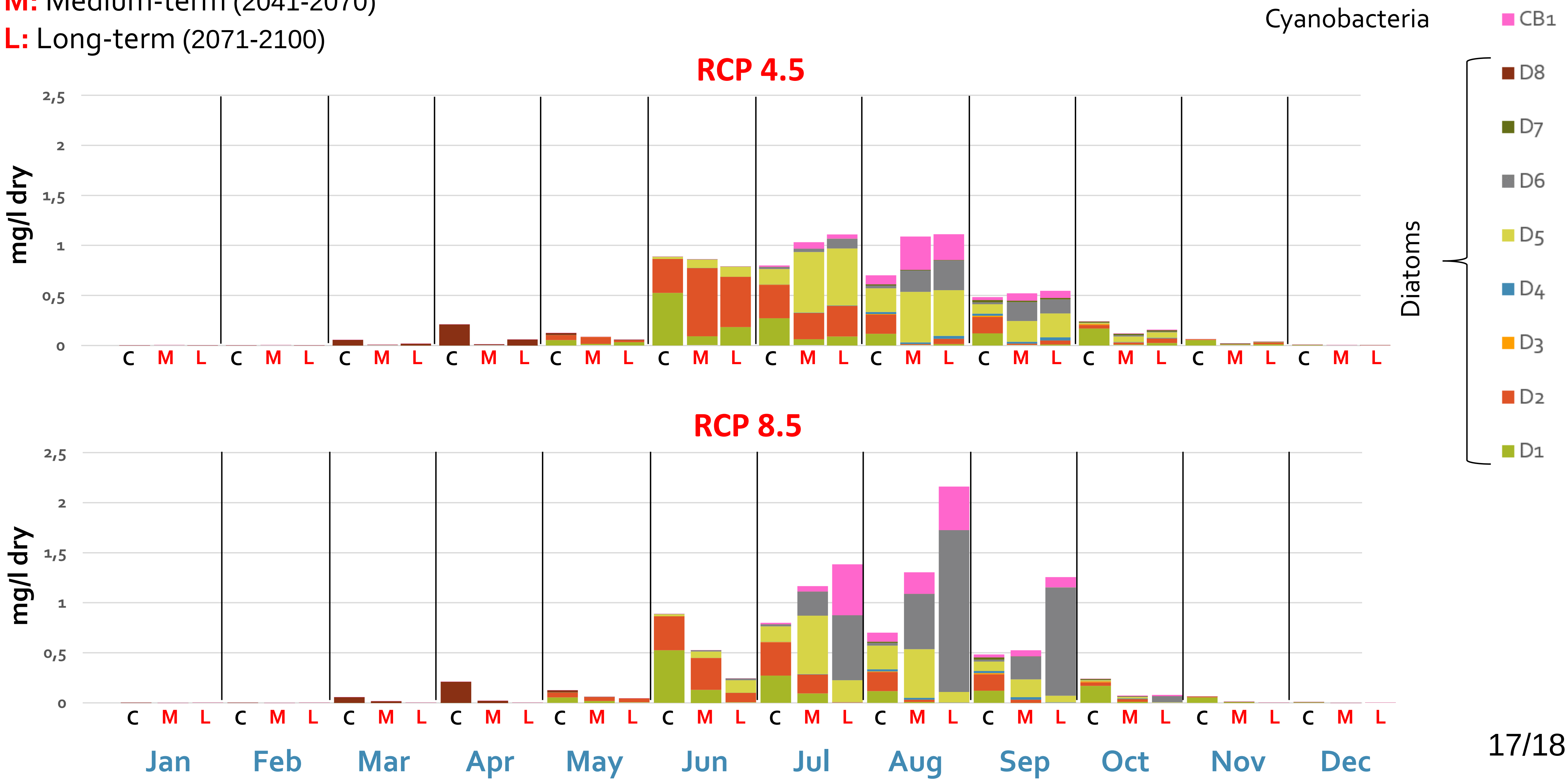


1983 - 2012   2041 - 2070   2071 - 2100

ECO-TOXICOLOGICAL MODELLING: AQUATOX

C: Control (1983-2012)
M: Medium-term (2041-2070)
L: Long-term (2071-2100)

30-year monthly mean Phytoplankton composition



CONCLUSIONS

Climate change will have important effects on the quality of waters and the ecosystems of transitional waterbodies (e.g. coastal lagoons). Changes by 2100:

- **Climate conditions: predicted** mean temperature increase from 2.7 to 5.1 °C; precipitation considerably increases in winter (+60 to +170 mm) and drecrease in summer (-81 to -156 mm)
- **Nutrient loadings:** exacerbation of current conditions. Loadings will increase in winter and reduce in summer
- **Coastal Phytoplankton:** changes in the dynamics and composition of phytoplankton will be mainly driven by changes in temperatures. Changes in the concentration on nutrients might have a minor role in the future.

- **Future developments:**
  - ✓ Extension of the investigation to pesticides (Glyphosate and Metolachlor)
  - ✓ Integration of land-use change scenarios
  - ✓ Implementation of a complete trophic network to study the effects on higher trophic levels

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THANK YOU

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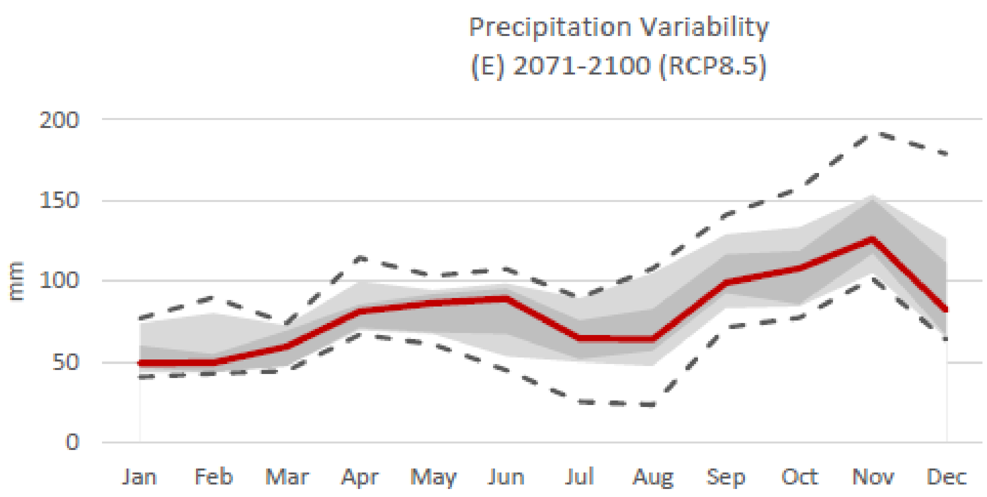
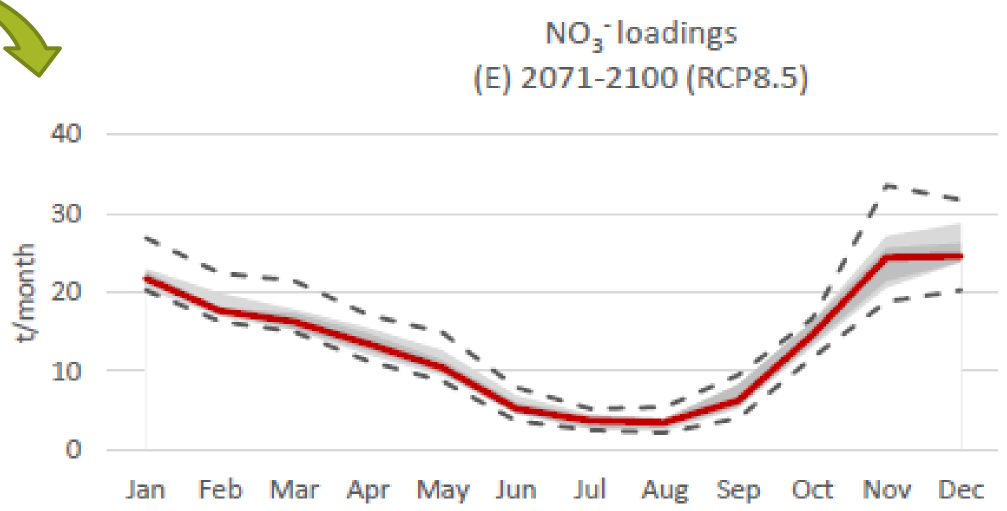
cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici

UNCERTAINTY ASSOCIATED WITH CLIMATE IMPACT STUDIES

CLIMATE SCENARIOS



HYDROLOGICAL MODELLING



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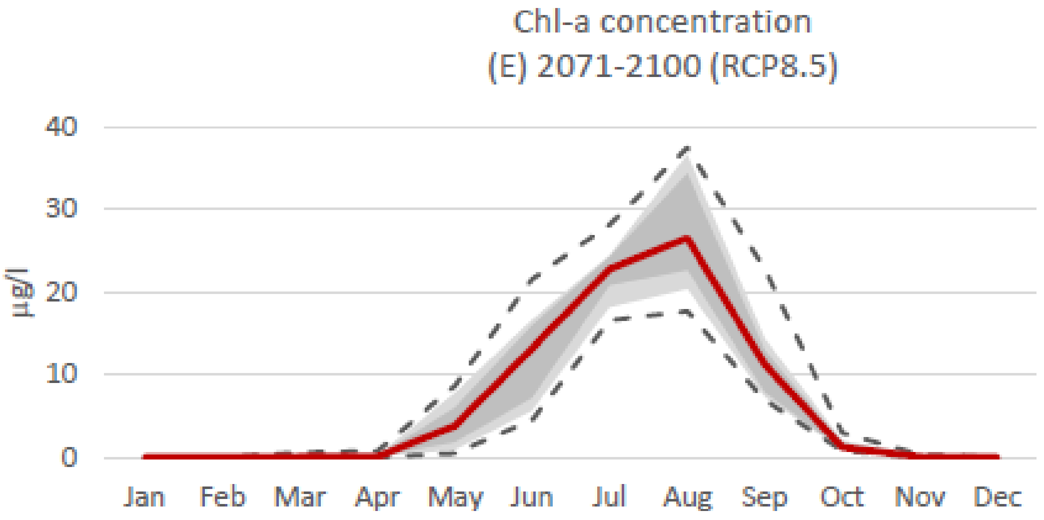

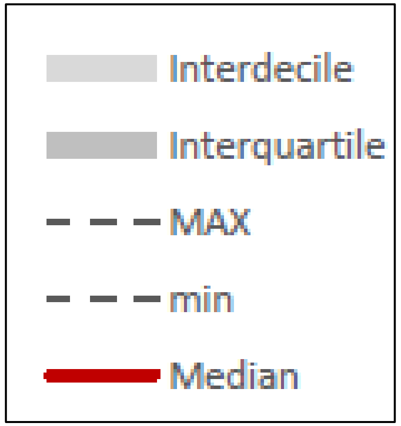

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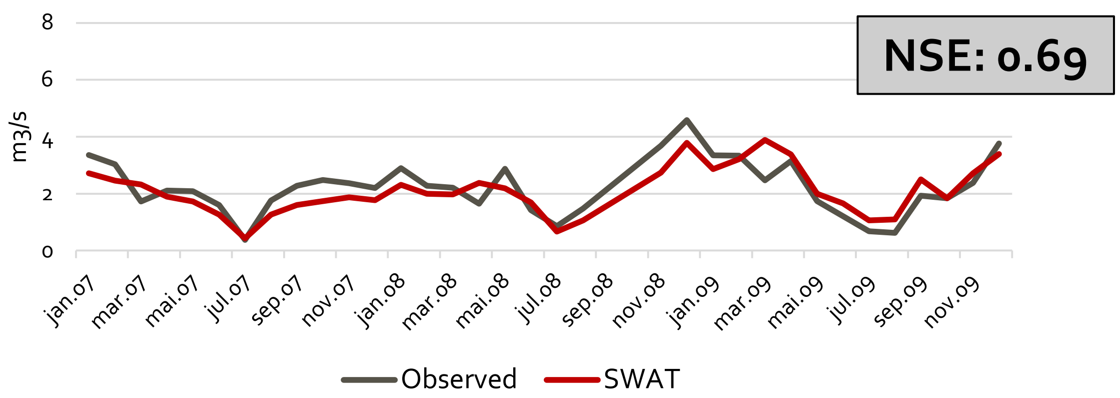

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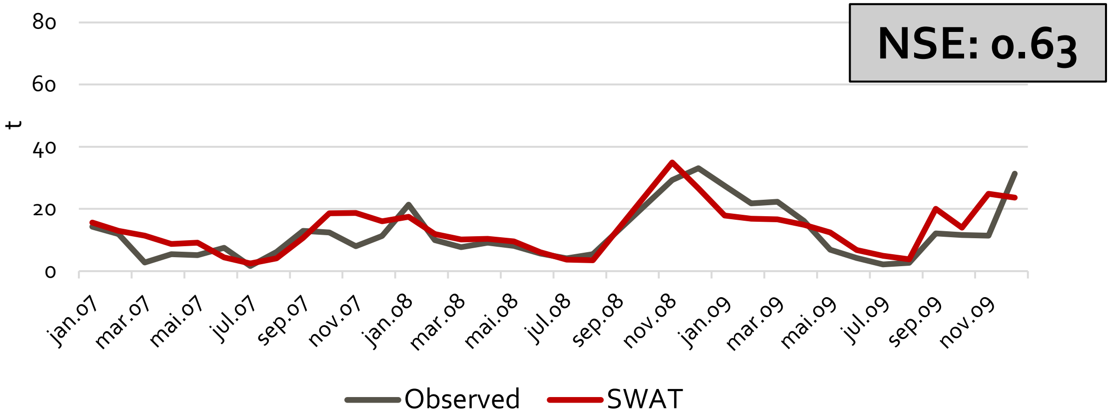

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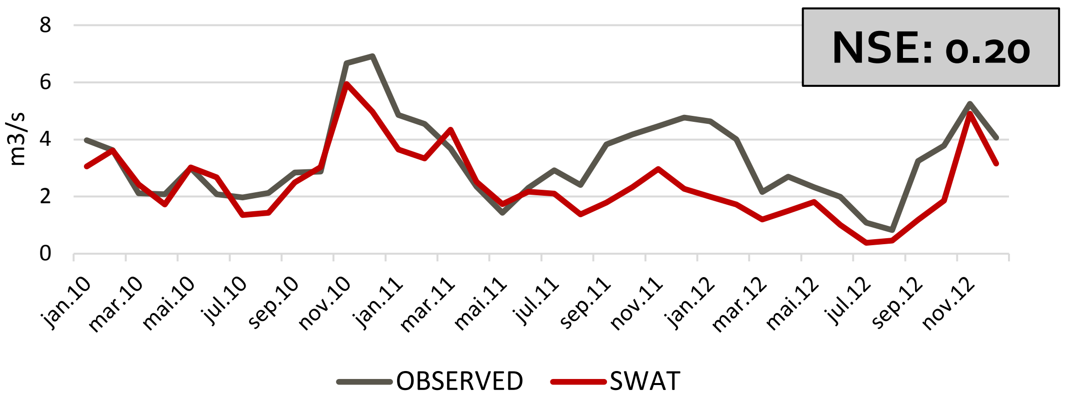

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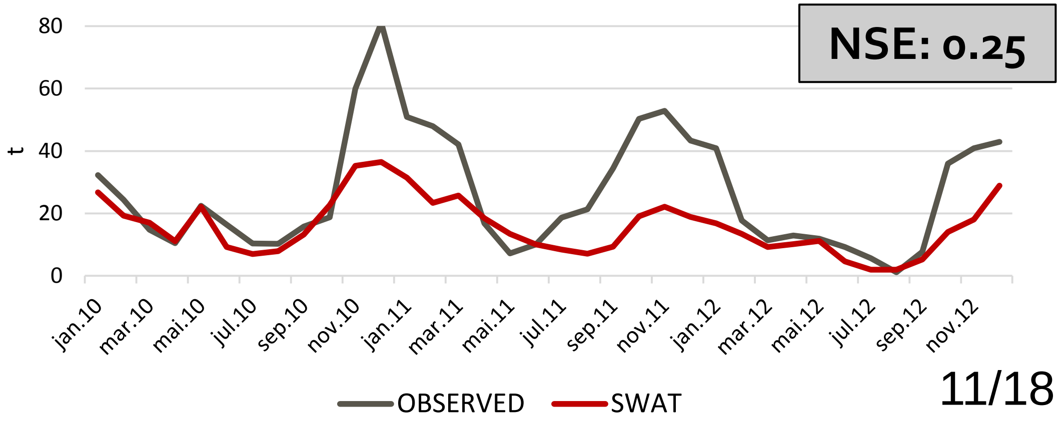

THE ROLE OF CLIMATE CHANGE IN THE 21ST CENTURY

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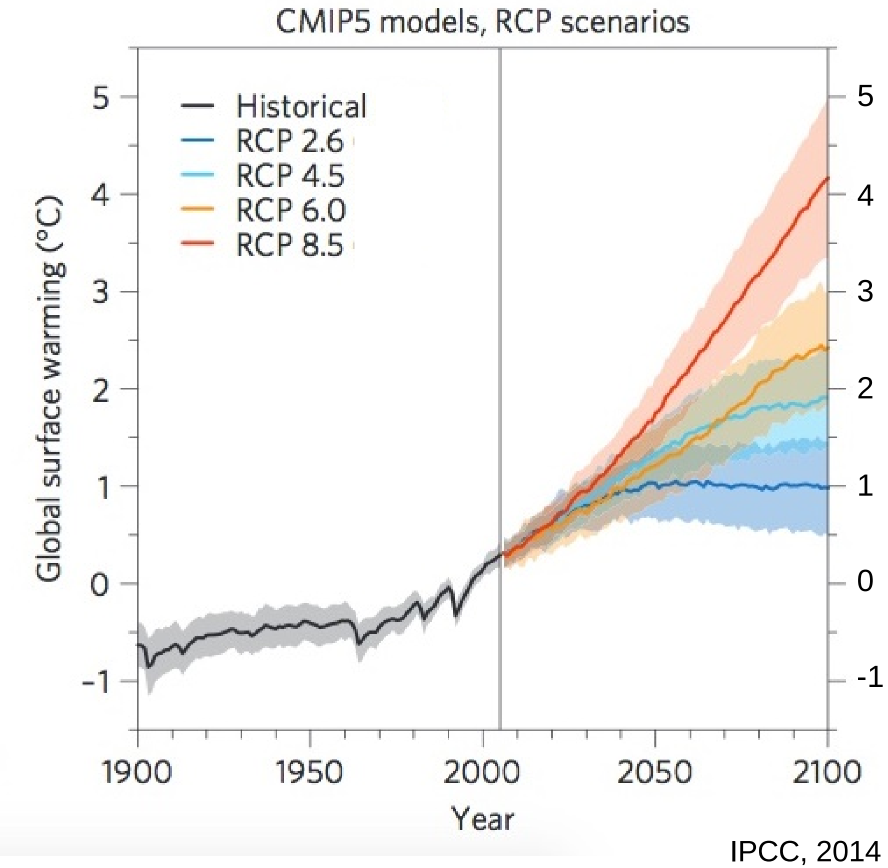

IPCC, 2014

- Frequent and more extended heat waves
- More extreme precipitation events
- Warmer and more acid waters
- Rising sea levels

Climate change will be the **defining characteristic** of the 21st century.

It will **amplify existing risks** and **create new risks** for natural and human systems.

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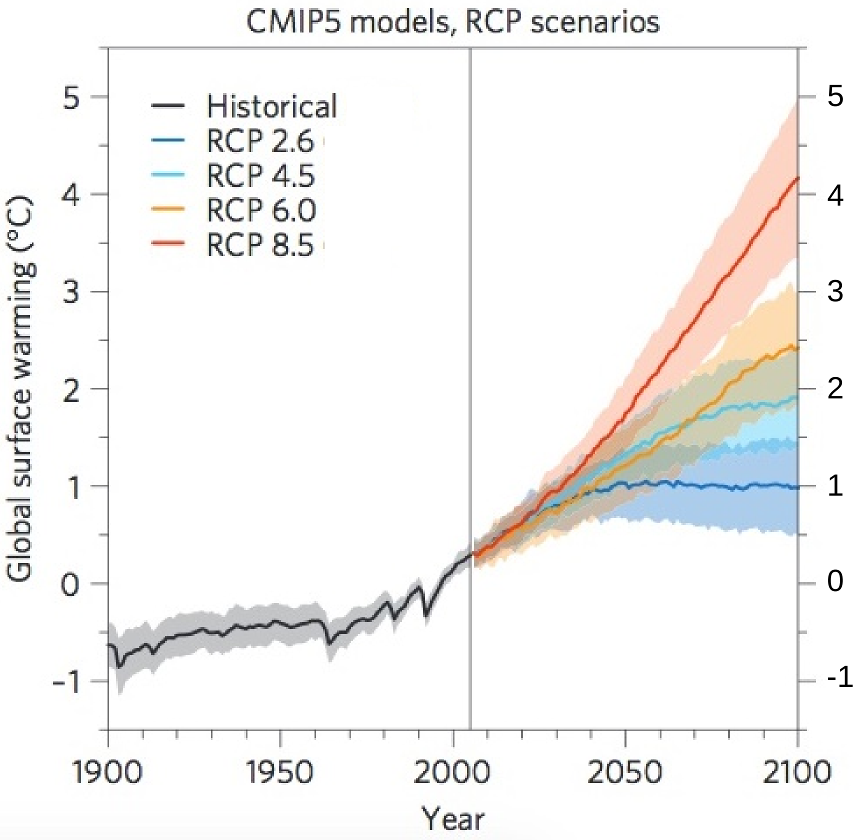

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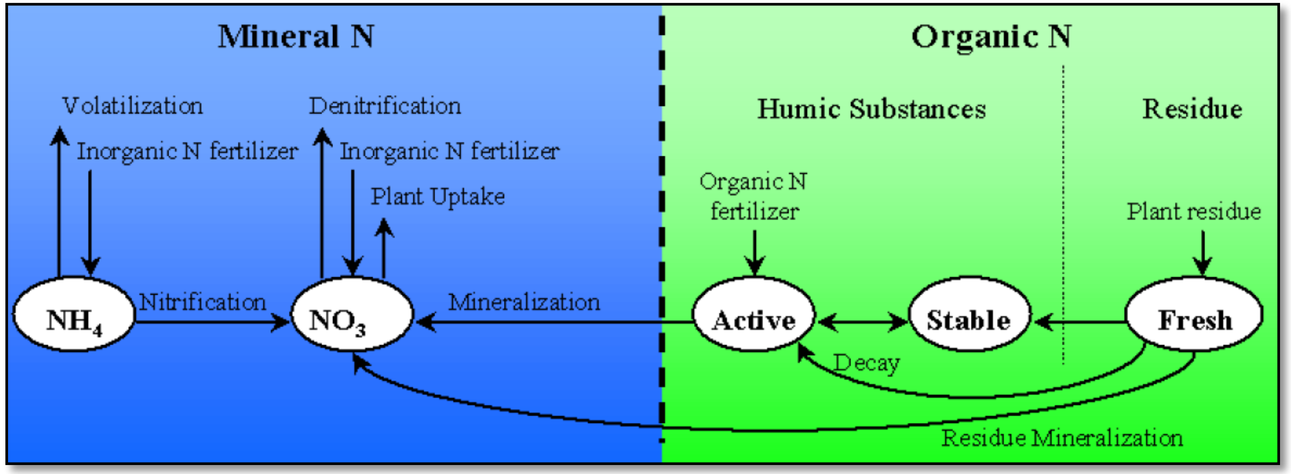
Climate change will be the **defining characteristic** of the 21st century.

It will **amplify existing risks** and **create new risks** for natural and human systems.

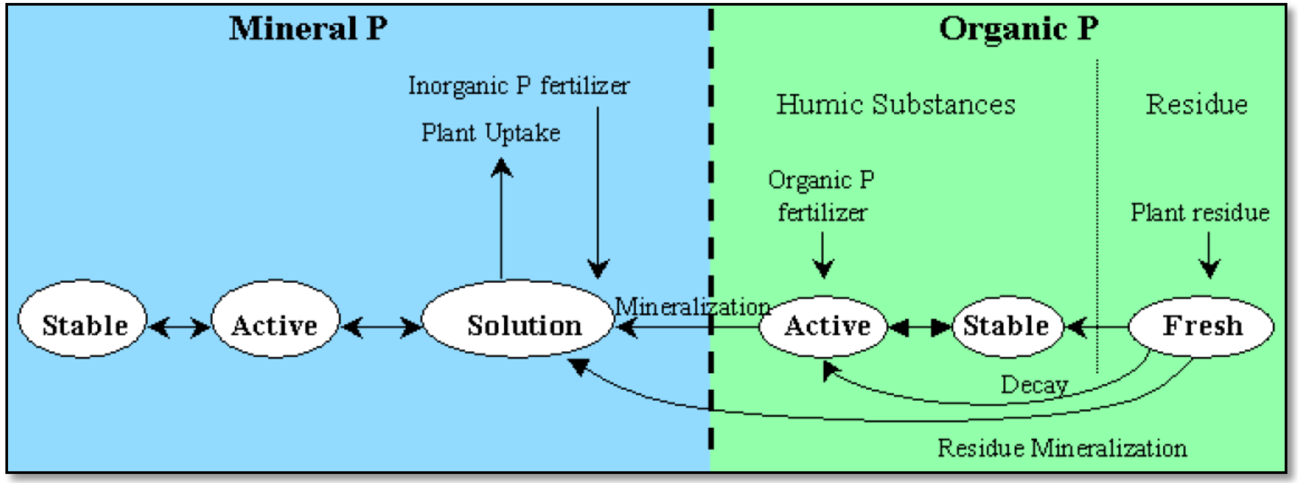
Potential impacts of climate change on nutrients and effects on aquatic ecosystems

2. SWAT Model

Nitrogen routing in land phase



Phosphorus routing in land phase

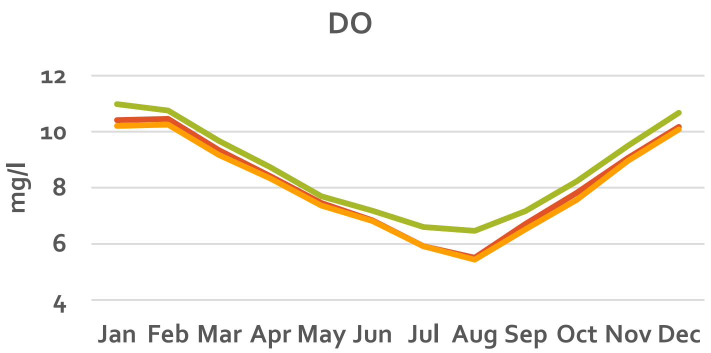


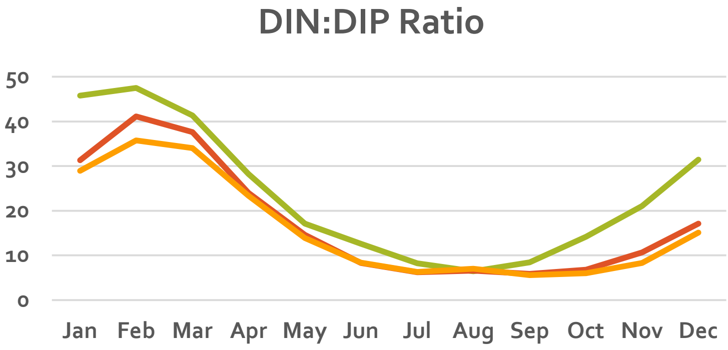
Ecological modelling: AQUATOX

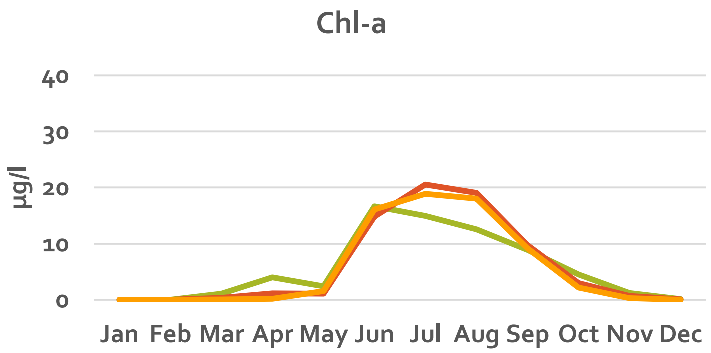
Palude di Cona

30-year monthly mean

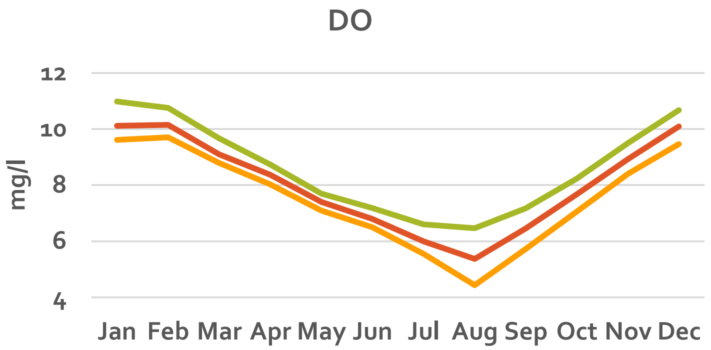
RCP 4.5

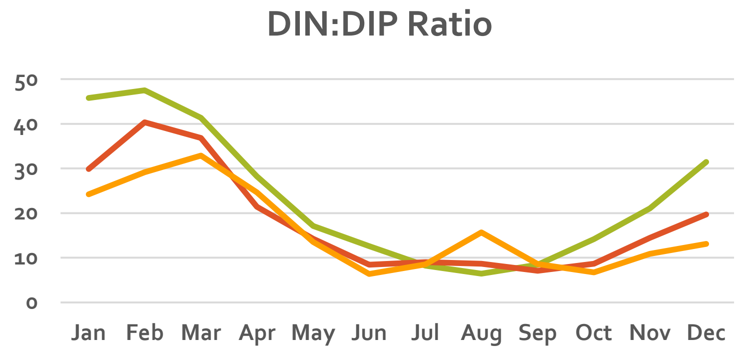


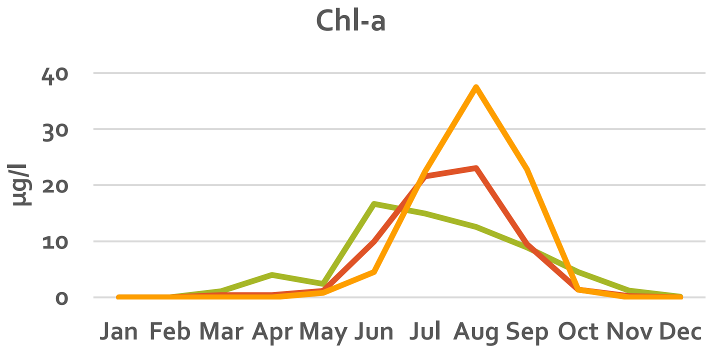




RCP 8.5







ECO-TOXICOLOGICAL MODELLING: AQUATOX

Phytoplankton composition

D1: Navicula -> typical in lagoon of Venice

D2: Cyclotella nana (adapted to 20°C and medium nutrient waters) -> typical in lagoon of Venice

D3: Cyclotella nana (adapted to 20°C and high nutrient waters)

D4: Fragilaria (adapted to 20°C and low nutrient waters)

D5: Cyclotella nana (adapted to warm waters 25°C)

D6: Cyclotella nana (adapted to very warm waters 30°C)

D7: Cyclotella nana (high nutrient and warm waters)

D8: Fragilaria (high nutrient and cold waters) -> representative of the «easter peak» (March/April

CB1: Cyanobacteria Microcystis spp. (adapted to very warm waters 30°C. It proliferates when P concentrations are high because of its nitrogen-fixing properties)

Eco-Toxicological modelling: AQUATOX

Phytoplankton composition

D1: Navicula -> typical in lagoon of Venice -> extremely reduced concentrations in 4.5 and disappear in 8.5

D2: Cyclotella nana (adapted to 20°C and medium nutrient waters) -> typical in lagoon of Venice -> variations in seasonality, manages to survive in every scenarios except long-term 8.5

D3: Cyclotella nana (adapted to 20°C and high nutrient waters) -> implemented to observe the effects of changes in DIN:DIP ratio -> does not proliferate which indicates that the DIN:DIP ratio in the blooming season

D4: Fragilaria (adapted to 20°C and low nutrient waters) -> implemented to observe the effects of changes in DIN:DIP ration

D5: Cyclotella nana (adapted to warm waters 25°C)

D6: Cyclotella nana (adapted to very warm waters 30°C)

D7: Cyclotella nana (high nutrient and warm waters)

D8: Fragilaria (high nutrient and cold waters) -> representative of the «easter peak» (March/April). It disappears/reduces in all future predictions

CB1: Cyanobacteria Microcystis spp. (adapted to very warm waters 30°C. It proliferates when P concentrations are high because of its nitrogen-fixing properties) -> favorable conditions in summer lon-term RCP8.5