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Seasonality in agricultural-associated river pollution: a global multi-pollutant modelling approach

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Introduction

Worldwide, **agricultural activities** are important for **food security**, but emit multiple pollutants including **nutrients** and **herbicides** into our rivers. Pollutant cocktails in rivers, and their interactions, are affected by **temporal patterns** in land use, hydrology, and climate. However, current knowledge is still poor in understanding the **monthly changes in pollutant inputs to rivers**. This especially holds for a **global scale** taking a **multi-pollutant** perspective. This challenges formulations of effective management strategies to ensure clean water for ecosystems and society throughout the year.

Objective

This study aims to better understand how seasonal patterns in agricultural activities, hydrology, and climate affect monthly inputs of nutrients and herbicides to rivers worldwide.

Seasonal Model to Assess River Inputs of pollutaNts to seAs (Seasonal MARINA-Multi)

Inputs

Human activities
- Population, urbanization
- Animal manure**
- Synthetic fertilizers**
- Atmosperic N deposition**
- Biological N fixation**
- Herbicide application**

Sub-basin characteristics
- Soil characteristics*
- Land use**
- Climate*

Seasonal MARINA-MULTI model

10,226 sub-basins

Outputs (sub-basin scale)

Monthly pollutant inputs to rivers
- Nutrients
  - Dissolved inorganic nitrogen (DIN)
  - Dissolved organic nitrogen (DON)
- Herbicides
  - Glyphosate
  - Aminomethylphosphonic Acid
  - Atrazine
- Source attribution

MARINA-Multi

Development of the new Seasonal MARINA-Multi model

1. Developing seasonal modelling approaches for multiple pollutants
2. Downscaling and preparing model inputs
3. Model runs & analysing monthly pollution patterns
4. Model evaluation using the building trust modelling approach

* Seasonally driven, (raw) input data are available at a monthly time-step

** Seasonally driven, (raw) input data are available at an annual time-step from the MARINA-Multi model (Micella et al., 2024; Zhang et al., under review), but require downscaling approaches. For downscaling approaches, we are building forward on approaches and lessons learned from McCrackin et al. (2014) for DIN and Maggi et al. (2023) for herbicides.
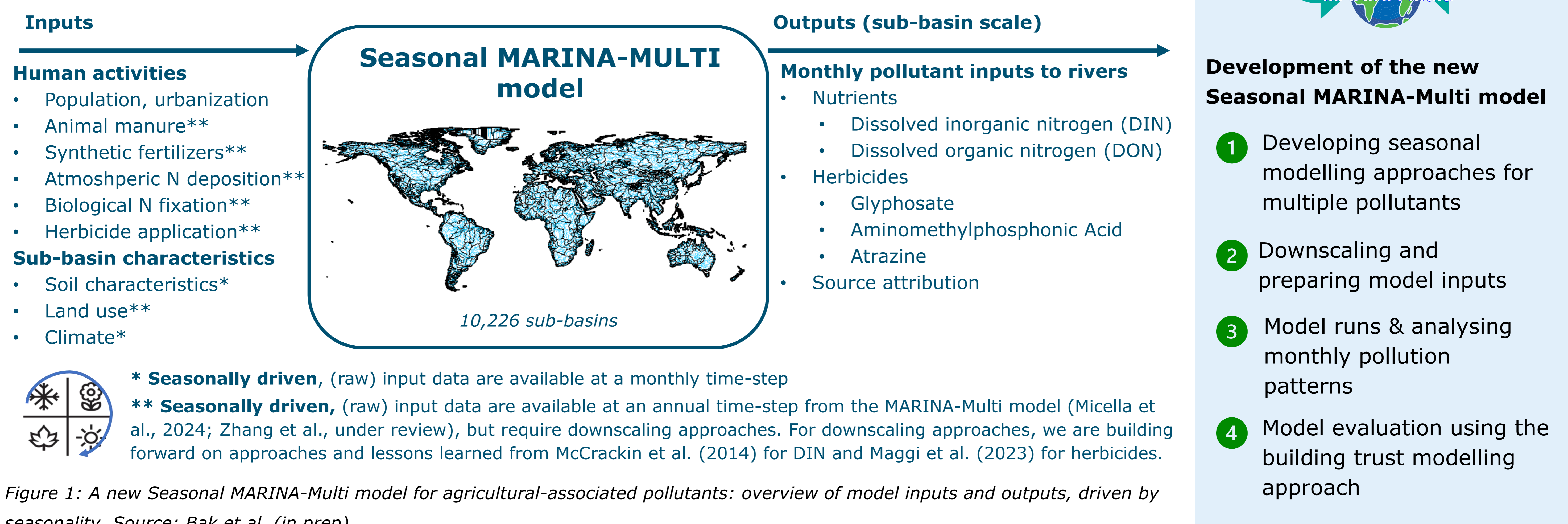
Figure 1: A new Seasonal MARINA-Multi model for agricultural-associated pollutants: overview of model inputs and outputs, driven by seasonality. Source: Bak et al. (in prep)

Concept of using crop calendars to downscale model inputs

Crop calendar	J	F	M	A	M	J	J	A	S	O	N	D

Cropping system & Spatial variation

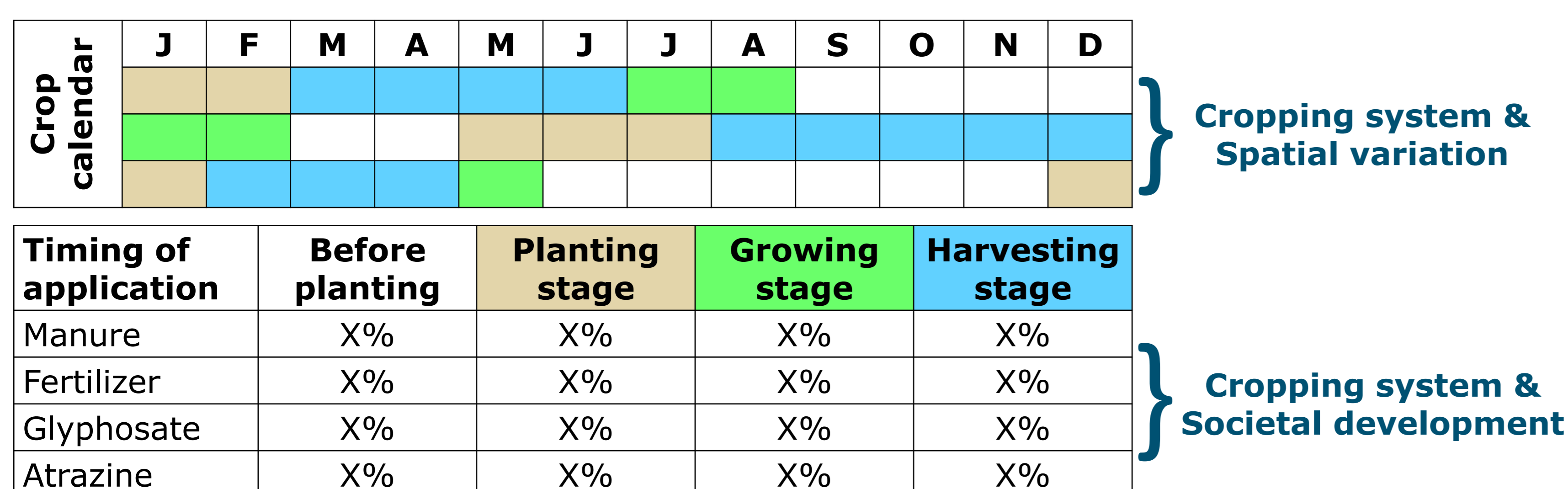| Timing of application	Before planting	Planting stage	Growing stage	Harvesting stage
Manure	X%	X%	X%	X%
Fertilizer	X%	X%	X%	X%
Glyphosate	X%	X%	X%	X%
Atrazine	X%	X%	X%	X%

Cropping system & Societal development

Figure 2: Conceptual framework of downscaling annual manure, fertilizer and glyphosate applications to monthly applications by sub-basin using a global crop calendar (e.g. Sacks et al., 2010)

Ideas for model framework

Existing knowledge

Key references

- Bak, M. P., et al., (in prep) Seasonality in agricultural-associated river pollution: a global multi-pollutant modelling approach
- Maggi, F., et al., (2023). Agricultural pesticide land budget and river discharge to oceans. Nature, 620(7976), 1013-1017.
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- Micella, I., et al., (2024). Causes of coastal waters pollution with nutrients, chemicals and plastics worldwide. Marine Pollution Bulletin, 198, 115902.
- Sacks, W. J., et al., (2010). Crop planting dates: an analysis of global patterns. Global ecology and biogeography, 19(5), 607-620.
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