Floodplain aquatic productivity: the current state of science

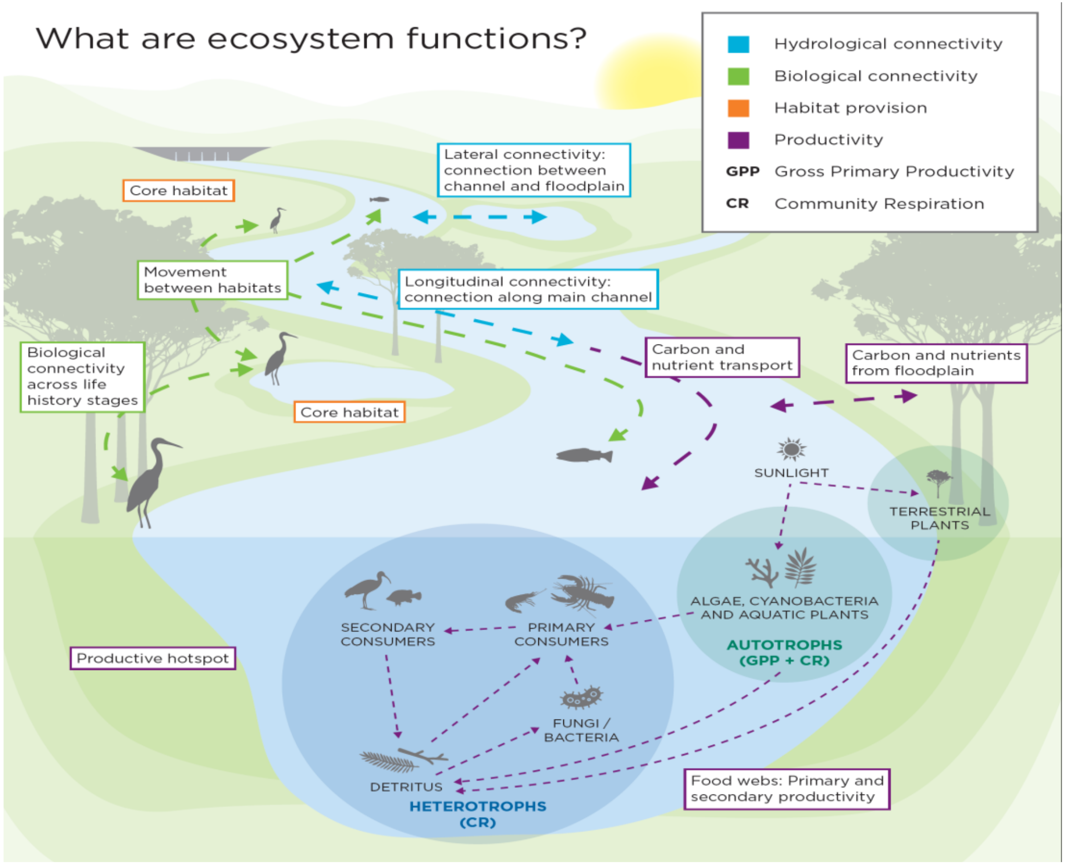
Paul McInerney, Darren Giling, Ben Wolfendon and Ashmita Sengupta

Productivity Theme | November 2022

Australia's National Science Agency

Productivity

- Productivity refers to the rate of generation of new biomass in an ecosystem
- It is usually expressed in units of mass per unit space (surface area or volume) per unit time (e.g. g m^{-2} d^{-1})
- GPP - transformation of solar energy from the sun into organic matter by autotrophs
- ER - use of that energy by autotrophs and heterotrophs



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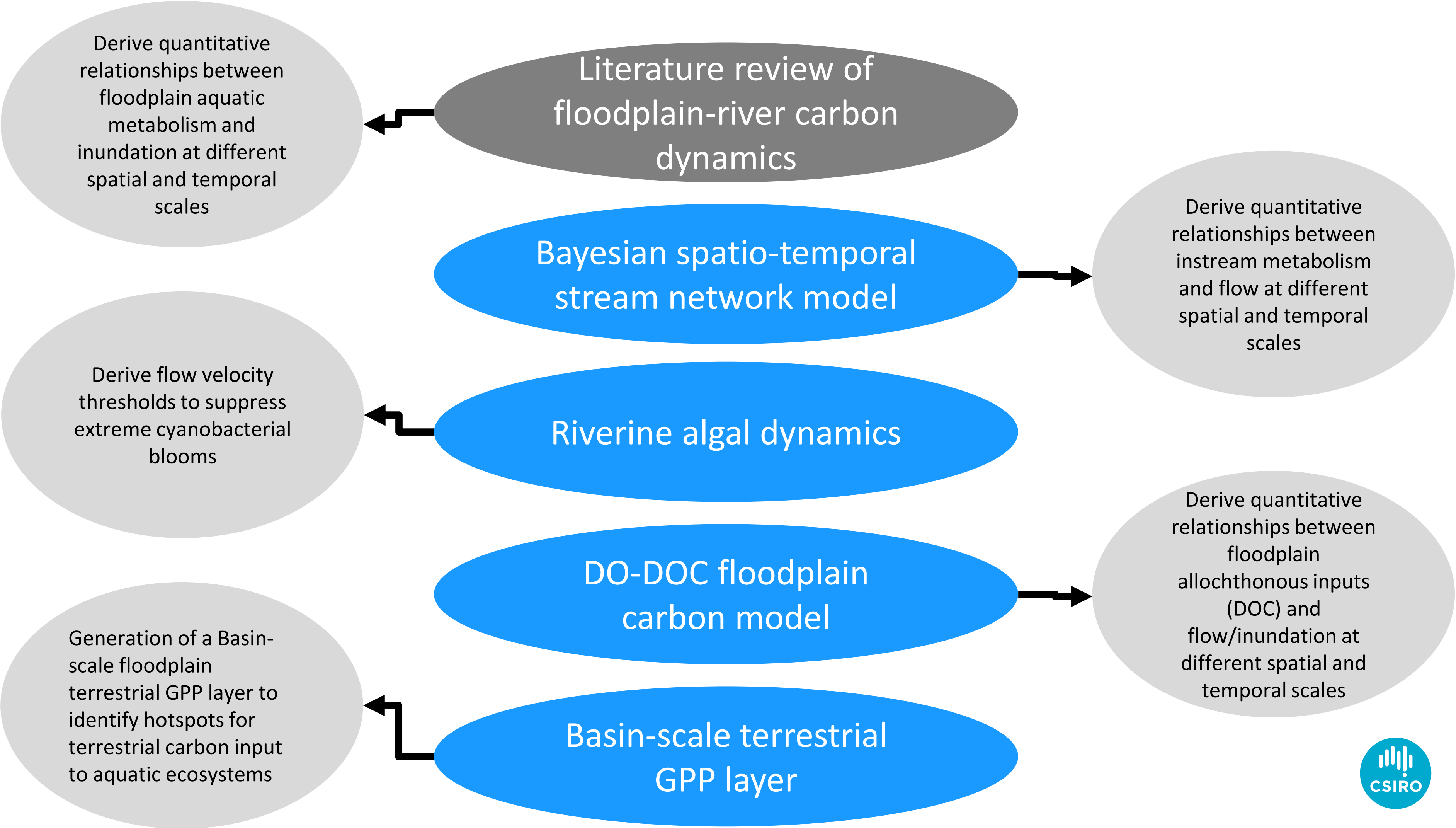

Literature review of floodplain-river carbon dynamics
Derive quantitative relationships between floodplain aquatic metabolism and inundation at different spatial and temporal scales
Bayesian spatio-temporal stream network model
Derive quantitative relationships between instream metabolism and flow at different spatial and temporal scales
Riverine algal dynamics
Derive flow velocity thresholds to suppress extreme cyanobacterial blooms
DO-DOC floodplain carbon model
Derive quantitative relationships between floodplain allochthonous inputs (DOC) and flow/inundation at different spatial and temporal scales
Basin-scale terrestrial GPP layer
Generation of a Basin-scale floodplain terrestrial GPP layer to identify hotspots for terrestrial carbon input to aquatic ecosystems
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Floodplain aquatic productivity

- Knowledge gap - complex relationship between the functioning of floodplains and rivers
- Consistent rates of production in space and time, are unlikely given the high level of structural and functional spatial heterogeneity of floodplains
- Difficulty in data collection
- Importance for riverine function
- Could quantitative general principles be scaled to the Basin?

Objective

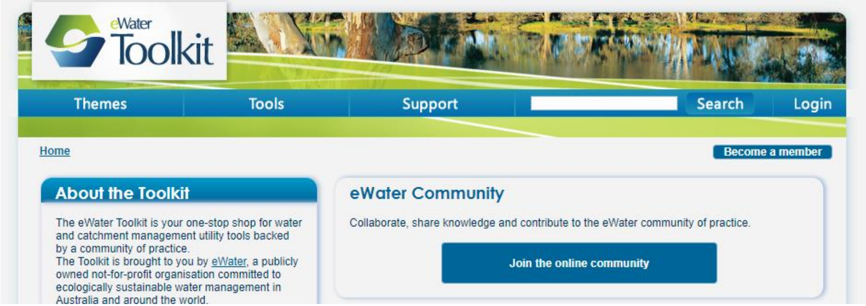
- Derive quantitative relationships among the (1) magnitude, (2) frequency, and (3) duration of floodplain inundation and aquatic ecosystem metabolism and carbon flux

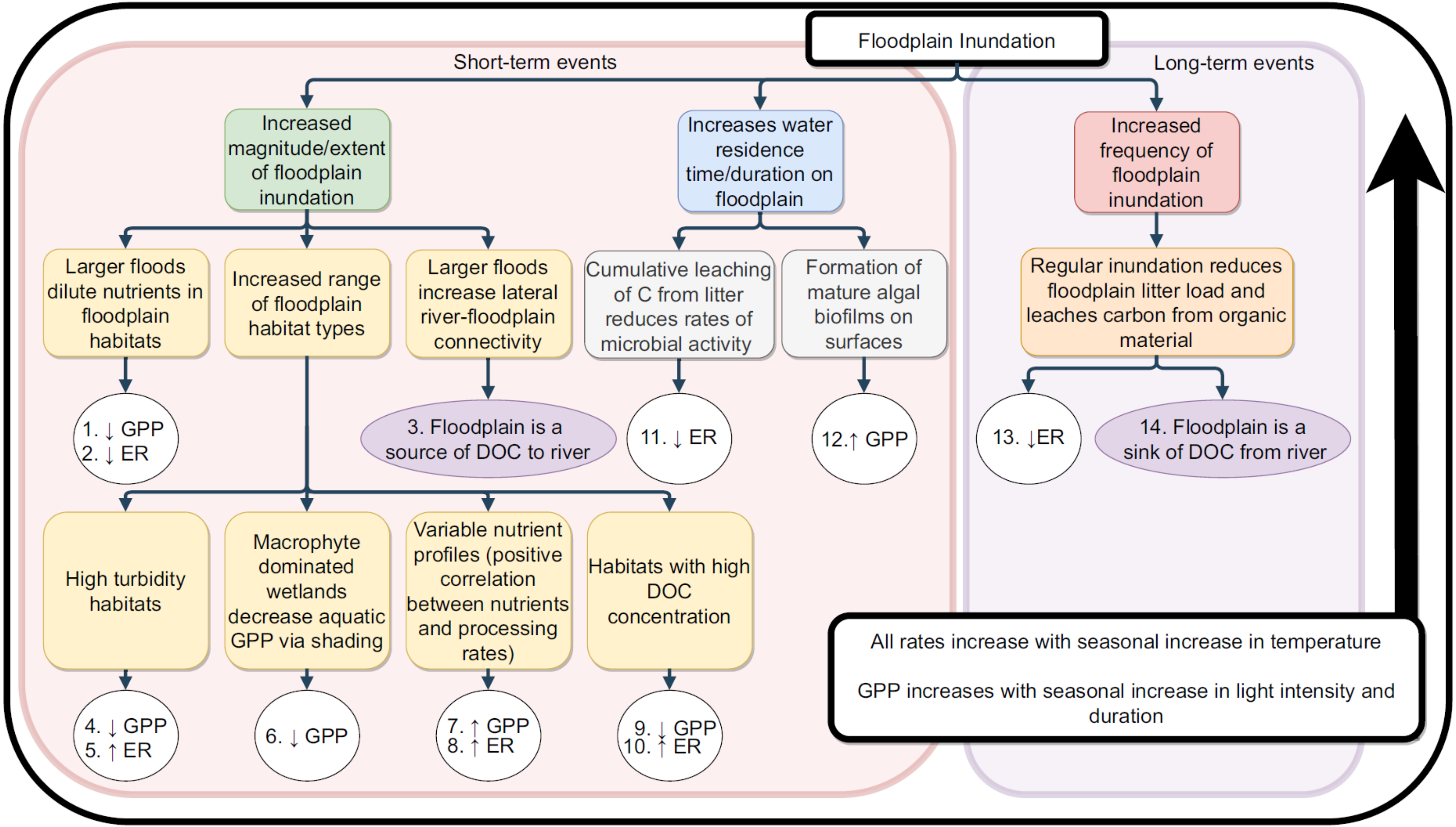
- Identify current knowledge gaps to inform future research

- Global literature review

Literature review of floodplain-river carbon dynamics

- CCA approach using Ecoevidence
- Epidemiology - method to deal with a lack of experimental data/weak inference of causal relationships
- Defensible technique that weights evidence based on the strength of its experimental design
- Scope -published, peer-reviewed studies that investigated ecosystem metabolism and carbon flux in floodplain habitats
- One of four conclusions: support for hypothesis, support for alternate hypothesis, inconsistent evidence, and insufficient evidence

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Macrophyte dominated wetlands decrease aquatic GPP via shading
Variable nutrient profiles (positive correlation between nutrients and processing rates)
Habitats with high DOC concentration
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7. ↑ GPP
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10. ↑ ER
All rates increase with seasonal increase in temperature
GPP increases with seasonal increase in light intensity and duration

Effect (hypotheses)	Search terms TS = ((floodplain OR "temporary wetland" OR "ephemeral wetland" OR wetland OR riparian) AND ("metabolism" OR "primary producti*" OR "GPP" OR "community respiration" OR "CR" OR "ecosystem respiration" OR ER) AND (flow OR flood OR flooding OR "environmental flows" OR "environmental water" OR inundation)	Web of Science literature search hits
H1—↑ surface water (volume) → ↓ GPP	AND (magnitude OR dilution OR nutrients))	392
H2—↑ surface water (volume) → ↓ ER	AND (magnitude OR dilution OR nutrients))	
H3—↑ surface water (volume) → ↑ dissolved organic matter	AND (magnitude OR "dissolved organic carbon"))	172
H4—↑ water quality (turbidity) → ↓ GPP	AND (magnitude OR turbidity))	101
H5 - ↑ water quality (turbidity) → ↑ ER	AND (magnitude OR turbidity))	
H6—↑ vegetation (abundance) → ↓ GPP	AND (magnitude OR macrophytes OR shading))	194
H7—↑ water quality (nutrients) → ↑ GPP	AND (magnitude OR nutrients))	386
H8—↑ water quality (nutrients) → ↑ ER	AND (magnitude OR nutrients))	
H9—↑ dissolved organic matter → ↓ GPP	AND (magnitude OR "dissolved organic carbon" OR "light attenuation"))	174
H10—↑ dissolved organic matter → ↑ ER	AND (magnitude OR "dissolved organic carbon" OR leaching))	191
H11—↑ surface water (duration) → ↓ ER	AND (duration OR leaching OR labile))	125
H12—↑ surface water (duration) → ↑ GPP	AND (duration OR "algae biomass"))	80
H13—↑ surface water (frequency) → ↓ ER	AND (frequency OR litter))	143
H14—↑ surface water (frequency) → ↓ dissolved organic matter	AND (frequency OR "dissolved organic carbon"))	164
	Total	2122

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Final filtering returned 41 peer reviewed publications

55 individual evidence items that contributed to the testing of our 14 hypotheses

Causal linkages relating to magnitude:

Increased magnitude of inundation dilutes nutrients in floodplain habitats:

H1—↑ surface water (volume) → ↓ GPP—leading to decreased GPP
H2—↑ surface water (volume) → ↓ ER—leading to decreased ER

Increased magnitude of inundation increases river-floodplain connectivity:

H3—↑ surface water (volume) → ↑ dissolved organic matter—floodplain becomes a source of carbon to the river main channel

Increased magnitude of inundation increases the number of different habitat types:

H4— ↑ water quality (turbidity) → ↓ GPP—in high turbidity habitats GPP is decreased due to increased light attenuation limiting photosynthesis
H5—↑ water quality (turbidity) → ↑ ER—in high turbidity habitats ER is increased due to elevated carbon availability in the water column from suspended organic matter
H6—↑ vegetation (abundance) → ↓ GPP—in macrophyte dominated habitats aquatic GPP is decreased due to shading of submerged autotrophs
H7—↑ water quality (nutrients) → ↑ GPP—there is a positive correlation between nutrients and GPP
H8—↑ water quality (nutrients) → ↑ ER—there is a positive correlation between nutrients and ER
H9—↑ dissolved organic matter → ↓ GPP—in high DOC habitats GPP is decreased due to light attenuation
H10—↑ dissolved organic matter → ↑ ER—in high DOC habitats ER is increased due to higher metabolic substrate availability

Causal linkages relating to duration:

Increased duration of inundation leaches C from litter:

H11—↑ surface water (duration) → ↓ ER—daily ER rate is reduced over time

Increased duration of inundation leads to formation of algal biofilms:

H12—↑ surface water (duration) → ↑ GPP—GPP is increased

Causal linkages relating to frequency:

Increased frequency of inundation leaches C from litter:

H13—↑ surface water (frequency) → ↓ ER—reduces ER occurring in any single, subsequent event

H14—↑ surface water (frequency) → ↓ dissolved organic matter—floodplain becomes a C sink for riverine DOC

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Causal linkages related to magnitude:

H3 – Support for hypothesis 👍

15 evidence items – 14 in favour, 1 against

- well represented in the literature
- strong relationships among litter loads, floodplain inundation area, and DOC concentration in adjacent rivers have been established
- antecedent conditions, flooding frequency and the ability to predict responses remain an active area of research

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Causal linkages related to magnitude:

H3 – Support for hypothesis
H4 – Support for hypothesis

6 evidence items – 5 in favour, 1 against

- photic depth limitation in high turbidity habitats reduces GPP
- direct comparisons of turbidity/GPP relationships in floodplain ecosystems are few
- high spatial variation and stratification within lentic waters

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Causal linkages related to magnitude:

H3 – Support for hypothesis 👍
H4 – Support for hypothesis 👍
H6 – Inconsistent evidence 🤔

9 evidence items – 3 in favour, 6 against

- negative influence on aquatic autotrophs of decreased light from macrophyte shading
- positive influence of structural support for periphyton growth
- importance likely to co-vary strongly with a range of other variables

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Causal linkages related to magnitude:

H3 – Support for hypothesis 👍
H4 – Support for hypothesis 👍
H6 – Inconsistent evidence 🤔
H7 – Support for hypothesis 👍

7 evidence items – 6 in favour, 1 against

- nutrients regulate GPP
- low context dependency and can be applied broadly to floodplain ecosystems

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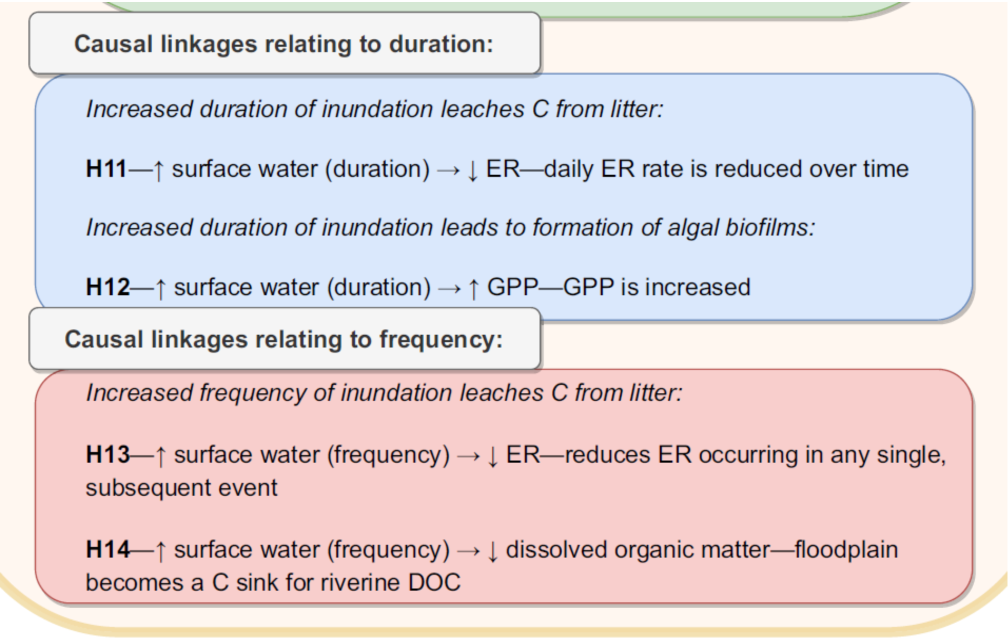
Causal linkages related to magnitude:

H3 – Support for hypothesis 👍
H4 – Support for hypothesis 👍
H6 – Inconsistent evidence 🫤
H7 – Support for hypothesis 👍

Remaining hypotheses – Insufficient evidence 💩



Causal linkages related to duration:

Insufficient evidence – to support any hypotheses 💩

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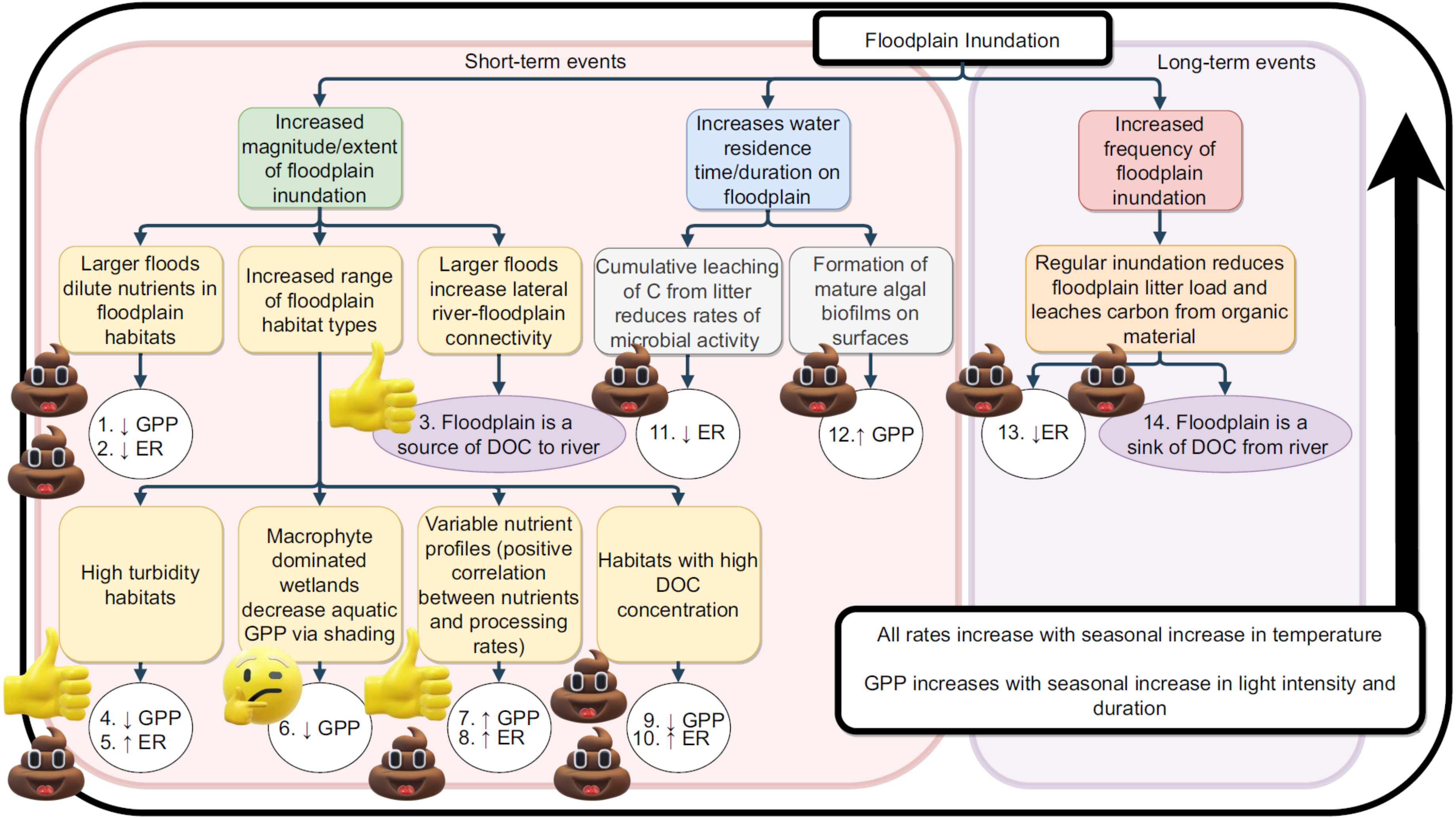

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Literature review of floodplain-river carbon dynamics

Magnitude Example:

- small flood sufficient in size to inundate wetlands and floodplain channels had only a negligible influence on floodplain DOC export
- subsequent ~5 × larger) flood inundated more than 80% of the floodplain, exported 300 tonnes of DOC to the river

(Nielsen et al. 2016)

- Despite an apparent wealth of metabolic studies in riverine ecosystems, floodplain metabolic dynamics remain poorly studied
- Summary of quantitative relationships
- Not all studies that provided evidence presented field or laboratory derived metabolic values to support their findings (e.g., proxy estimates or model predictions) making weighting of the evidence difficult in some cases

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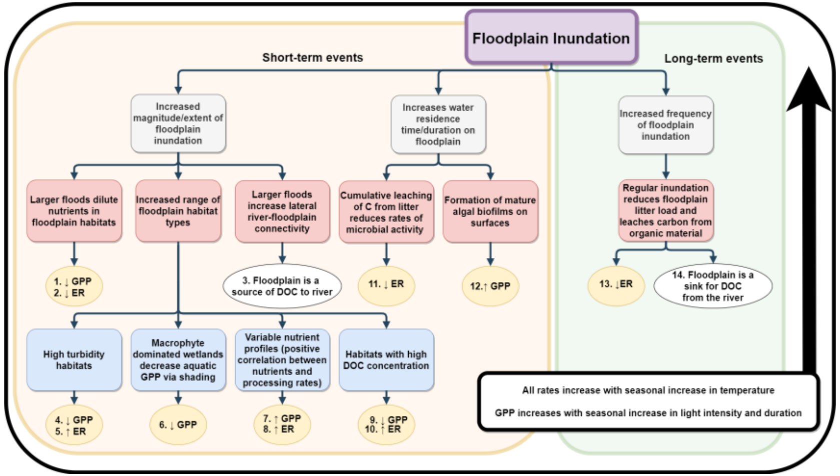
Literature review of floodplain-river carbon dynamics

Significant knowledge gaps remain surrounding floodplain carbon dynamics and inundation duration and frequency

Larger floods transfer more carbon from floodplains to the river channel than small floods via the increase in inundation area leading to more overall leaching of floodplain litter

High level of context dependency due to floodplain habitat and functional heterogeneity associated with floodplain inundation and metabolic responses

Floodplain GPP is reduced in highly turbid habitats and increased in high nutrient habitats



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A synthesis of floodplain aquatic ecosystem metabolism and carbon flux using causal criteria analysis

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- When planning floodplain watering actions, the high level of context dependency for many aspects of floodplain metabolism identified in this review need to be considered in a local perspective – difficult to scale patterns to the Basin or even catchment

- Thus, we acknowledge that more experimental data might not lead to support for general principles, but it will increase our knowledge and understanding of complex floodplain ecosystems

Thank you

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