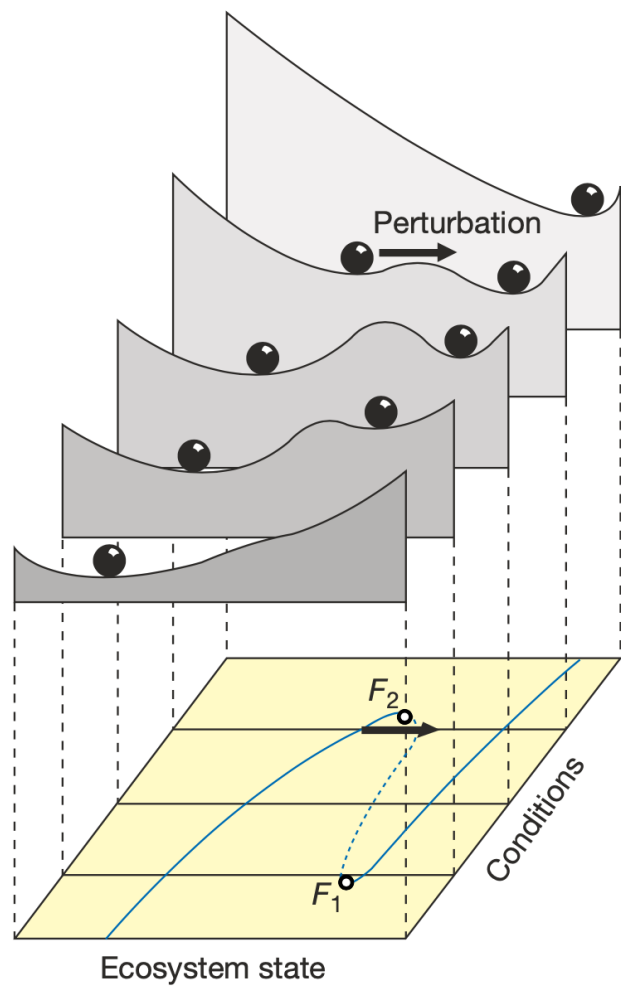


Regime shifts in river deltas (?)



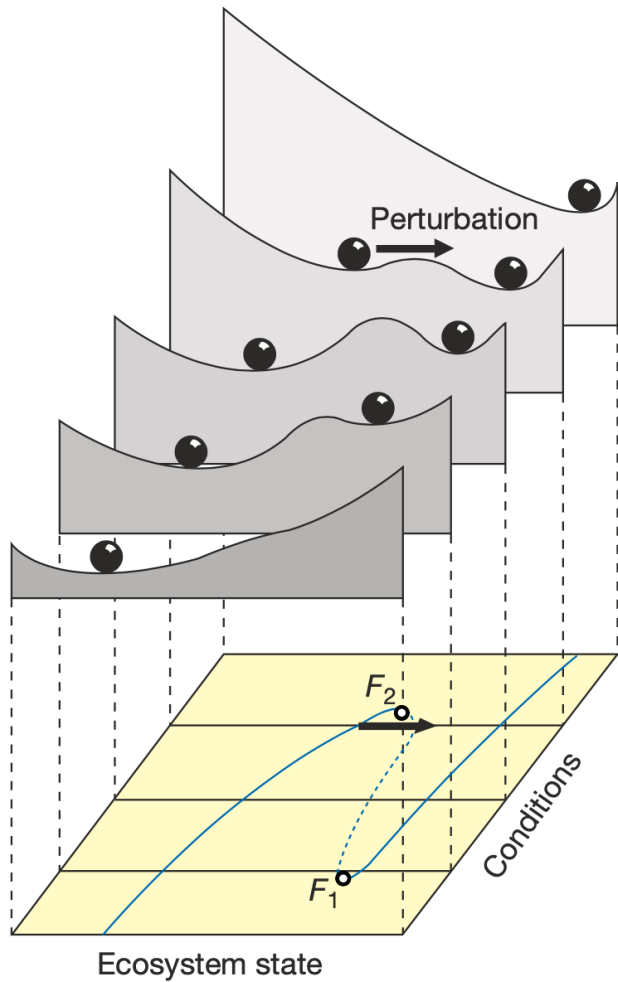
Potentially catastrophic shifts



Scheffer et al. (2001, Nature)

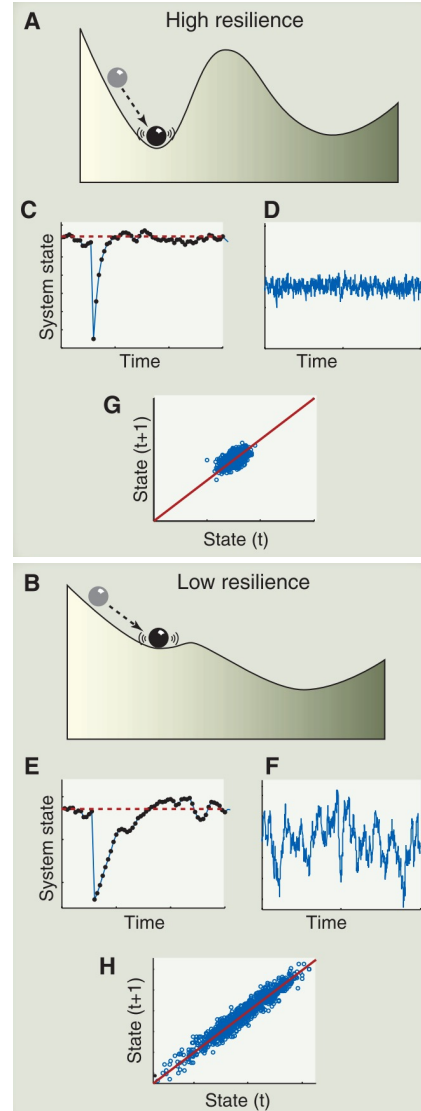
Why study regime shifts in river deltas?

Potentially catastrophic shifts



Scheffer et al. (2001, Nature)

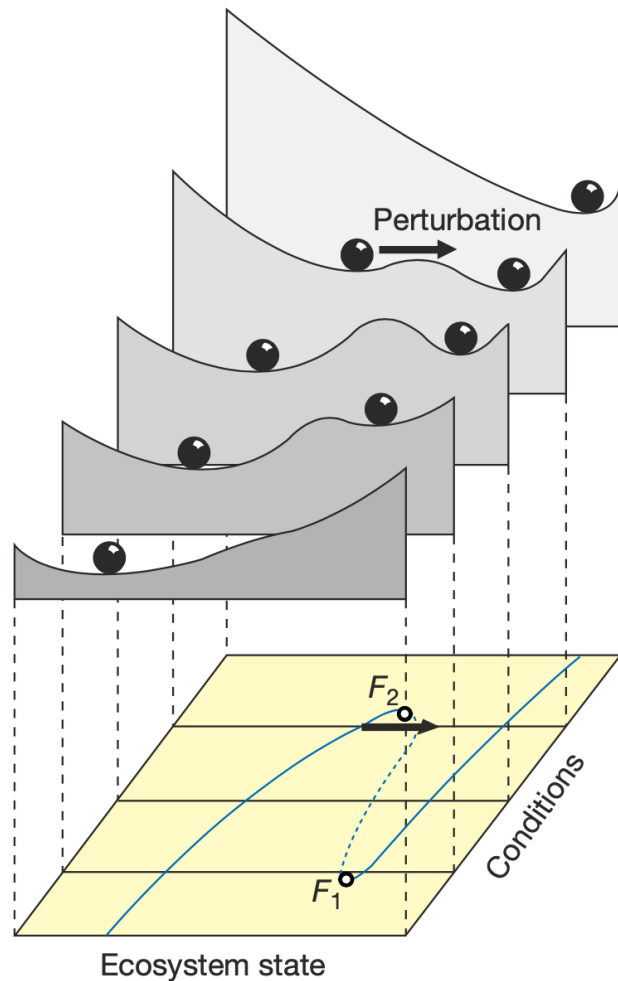
Prediction is essential



Scheffer et al. (2012, Science)

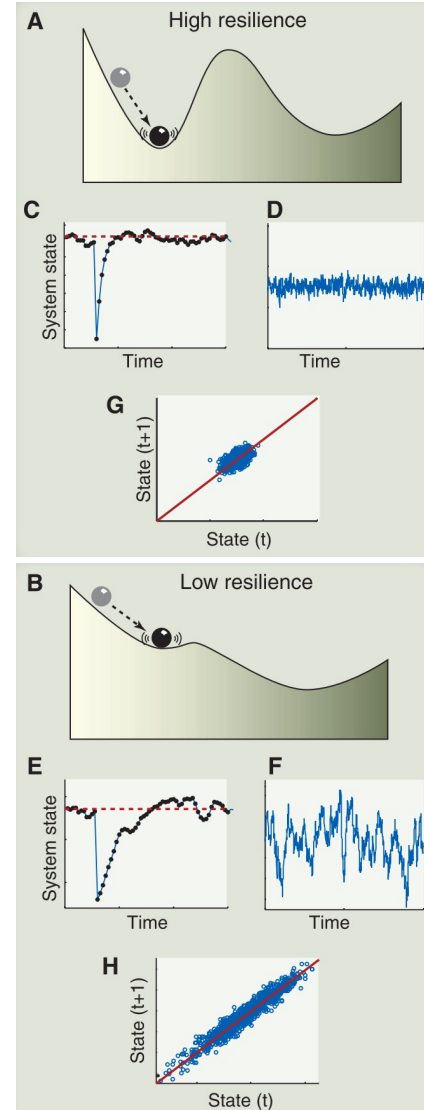
Why study regime shifts in river deltas?

Potentially catastrophic shifts



Scheffer et al. (2001, Nature)

Prediction is essential



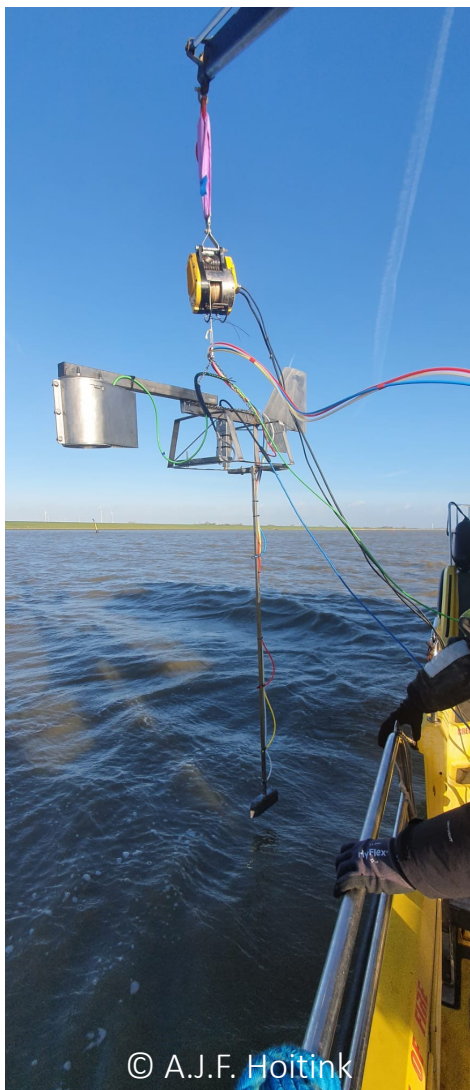
Scheffer et al. (2012, Science)

Dynamic Systems Theory: for **deltas** relatively **unexplored**

Field	Phenomenon	Indicator	Signal	References
Chemistry	Critical slowing down	Recovery rate/ return time	+	(39)
Physics	Critical slowing down	Return time/ dominant eigenvalue	+	(40)
		Rate of change of amplitude	+	(41)
		Autocorrelation at lag 1	+	(42)
Engineering Tectonics	Critical slowing down	Autocorrelation/	+	(43)
	Not specified	spatial correlation	+	(43)
Climate	Critical slowing down	Autocorrelation at lag 1	+	(23, 44, 45)
			0	(44, 46)
		Detrended fluctuation analysis	+	(27, 44)
			-	(44)
	Increasing variability	Variance	+	(44)
			0	(44, 46)
	Skewed responses	Skewness	0	(47)
	Ecology	Critical slowing down	Return time/dominant eigenvalue	+
Autocorrelation at lag 1			+	(22)
Spectral reddening			0	(48)
Spatial correlation			+	(48, 49, 51, 52)
Increasing variability		Variance	+	(48, 49, 52, 53)
			0	(22, 54)
		Spatial variance	+	(48, 49, 55, 56)
Skewed responses		Skewness	+	(48, 49)
Microbiology	Critical slowing down	Autocorrelation at lag 1	+	(57)
		Variance	+	(57)
		Return time	+	(57)
		Skewness	0	(57)
Physiology	Critical slowing down	Recovery rate/ return time	+	(58)
Epilepsy	Critical slowing down	Correlation	+	(59, 60)
	Increasing variability	Variance	+	(61)
Behavior	Critical slowing down	Recovery rate/ return time	+	(62, 63)
Sociology	Critical slowing down	Autocorrelation at lag 1	+/0	(64)
		Variance	+/0	(64, 65)
		Fisher information	+	(64)
Finance	Not specified	Correlation	Scheffer et al. (2012, Science)	

Scheffer et al. (2012, Science)

Unknowns



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Ways forward

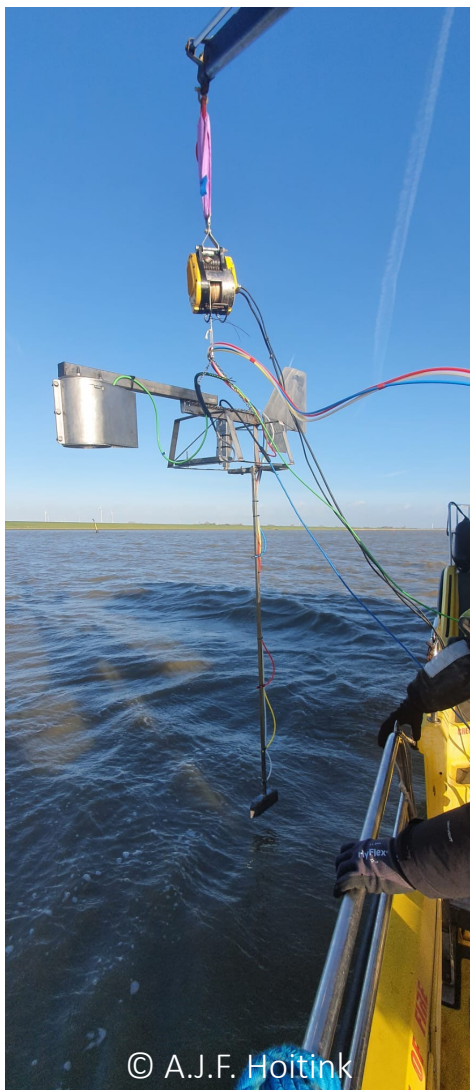


van de Vijzel (2021, PhD Thesis)



van de Vijzel et al. (2020, ESPL)

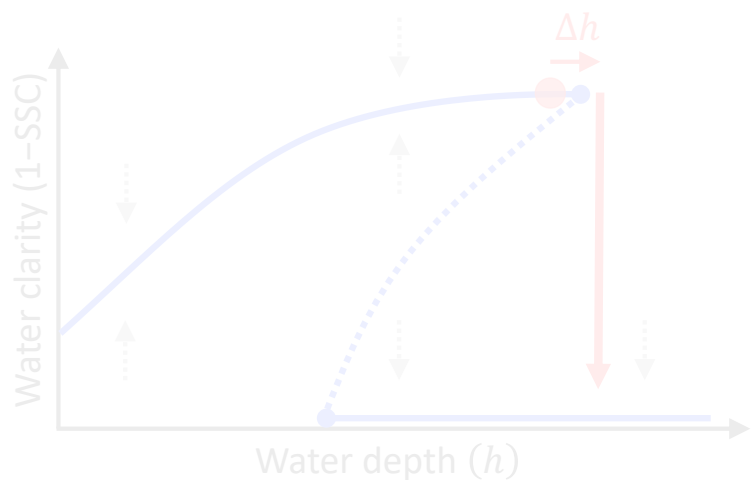
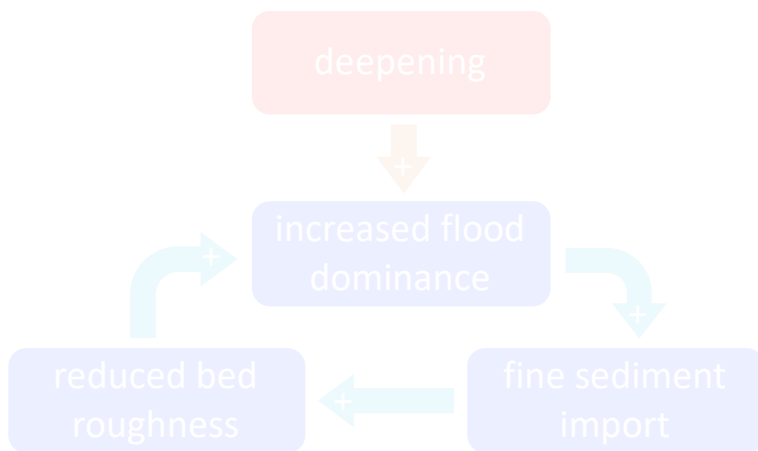
Unknowns



Ways forward

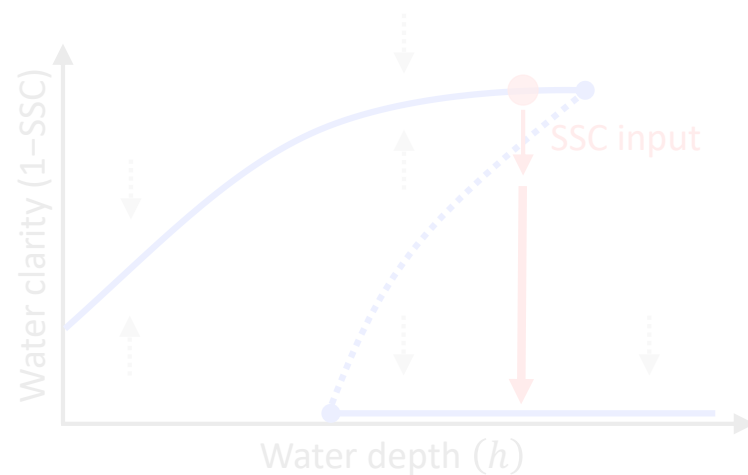
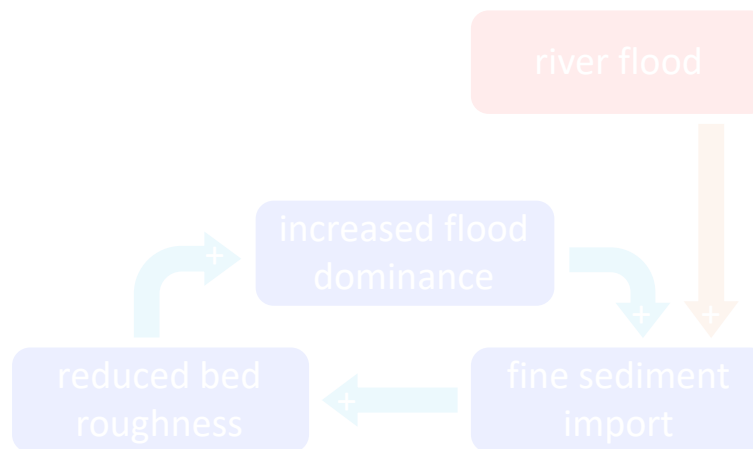


Bifurcation-induced tipping



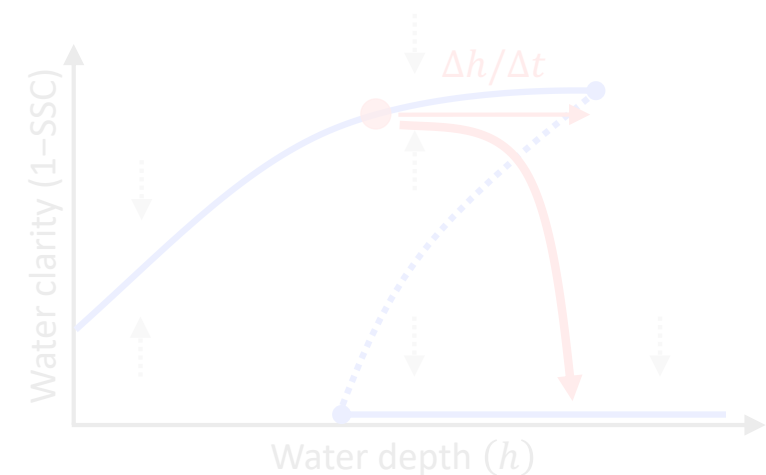
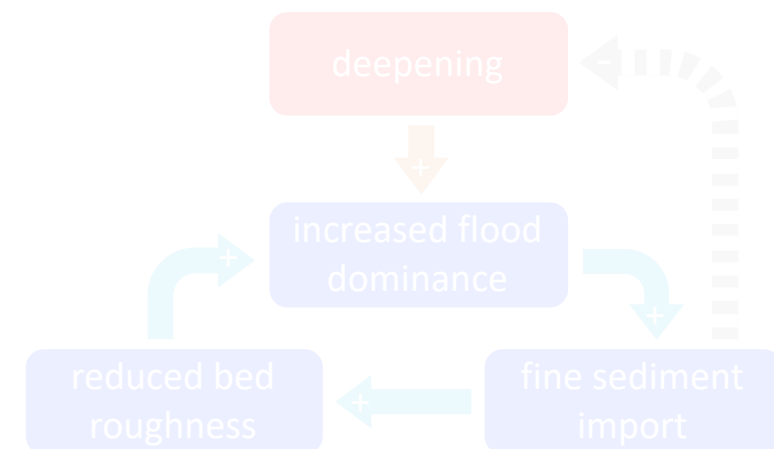
van Maren et al. (2015, Ocean Dynamics)

Noise-induced tipping



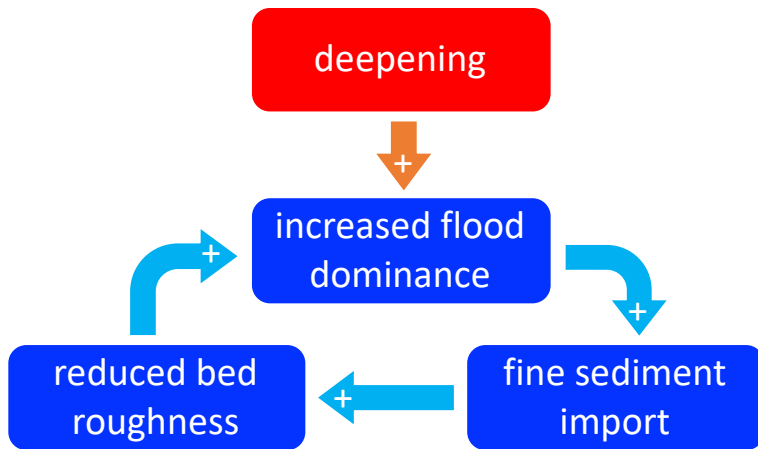
Wang et al. (2014, Ocean Dynamics)

Rate-induced tipping

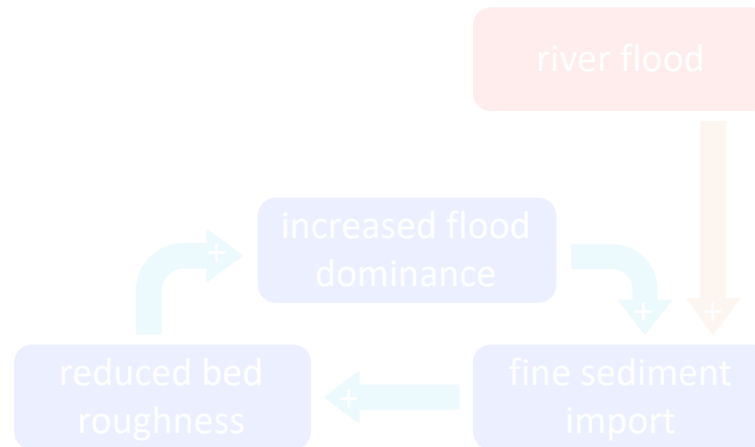


van Maren et al. (2015, Continental Shelf Research)

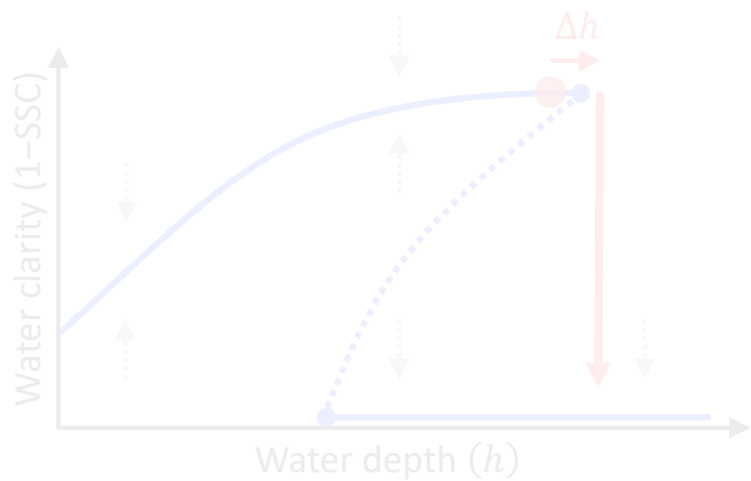
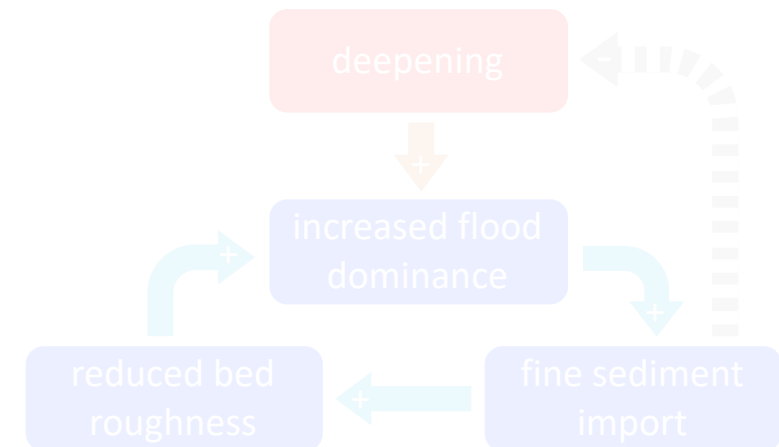
Bifurcation-induced tipping



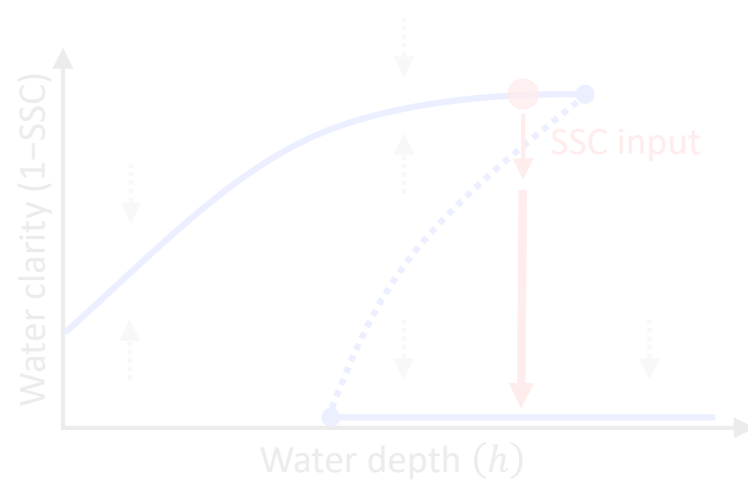
Noise-induced tipping



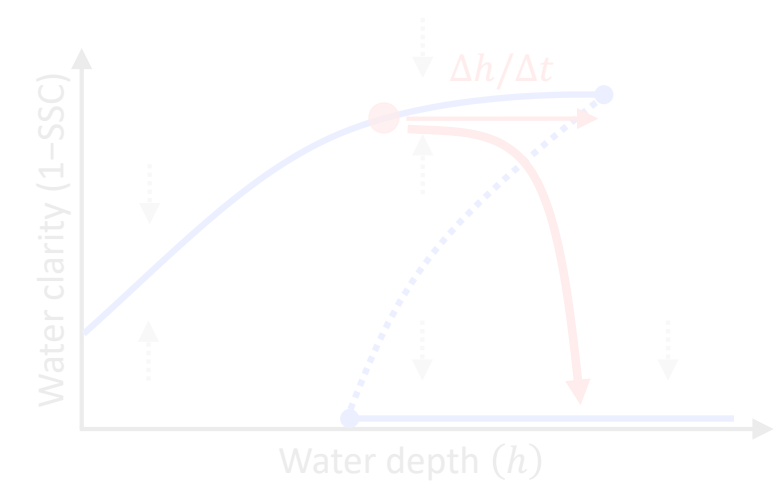
Rate-induced tipping



van Maren et al. (2015, Ocean Dynamics)

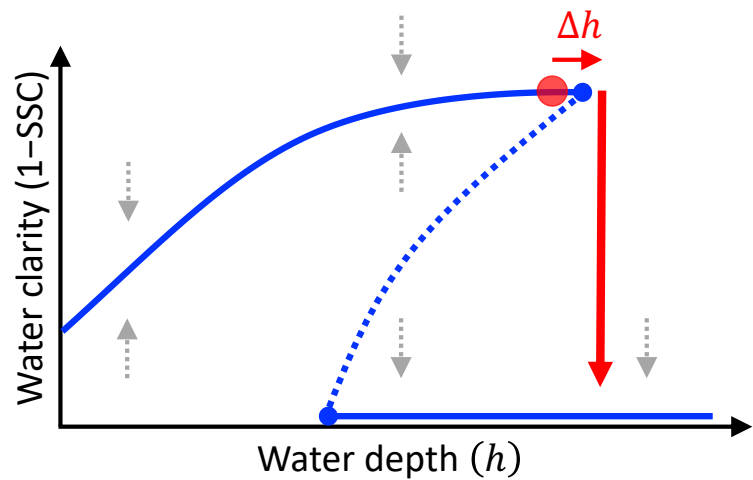
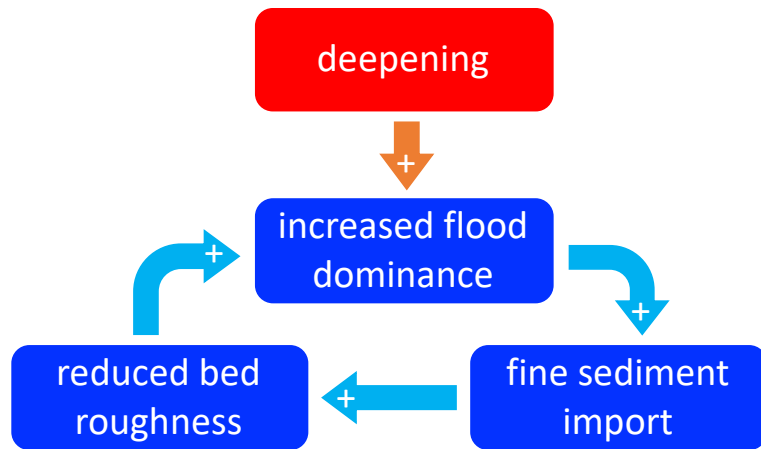


Wang et al. (2014, Ocean Dynamics)



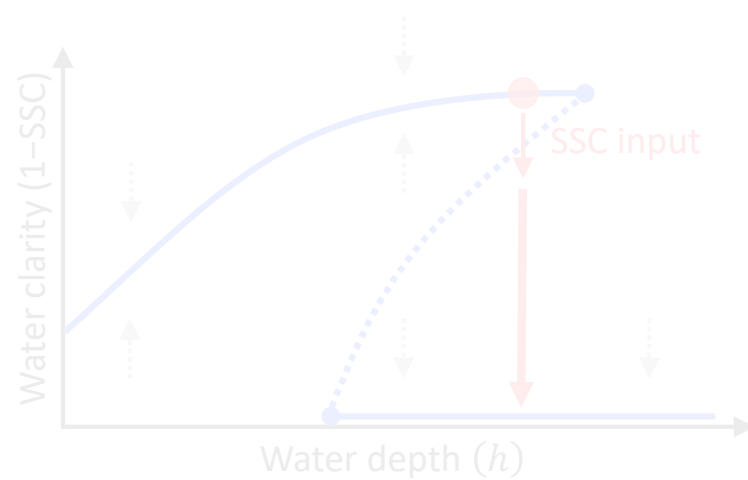
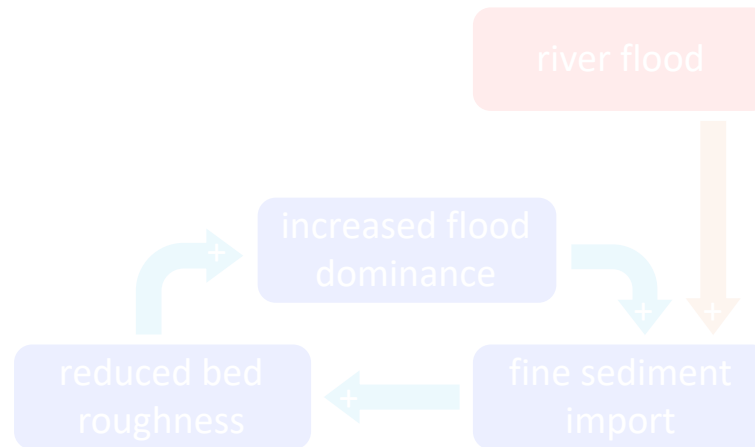
van Maren et al. (2015, Continental Shelf Research)

Bifurcation-induced tipping



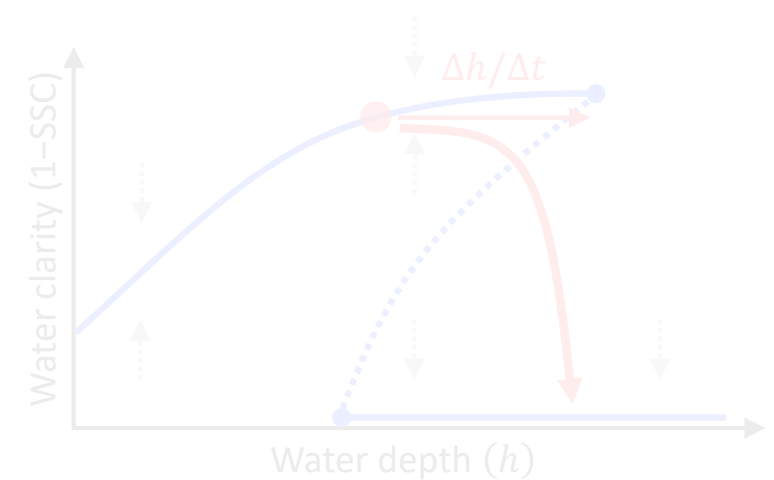
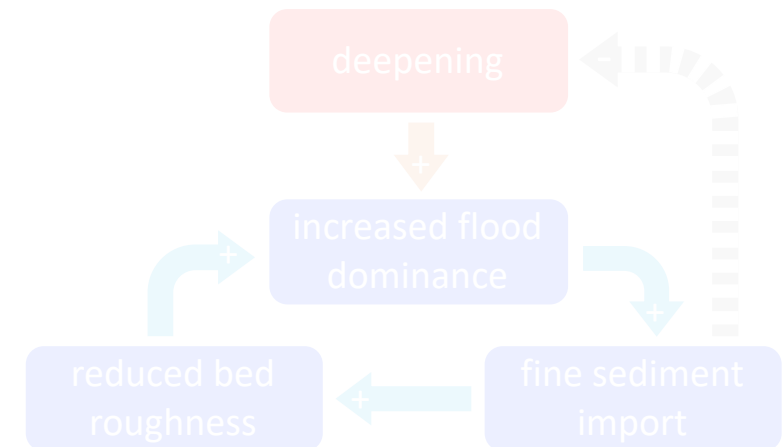
van Maren et al. (2015, Ocean Dynamics)

Noise-induced tipping



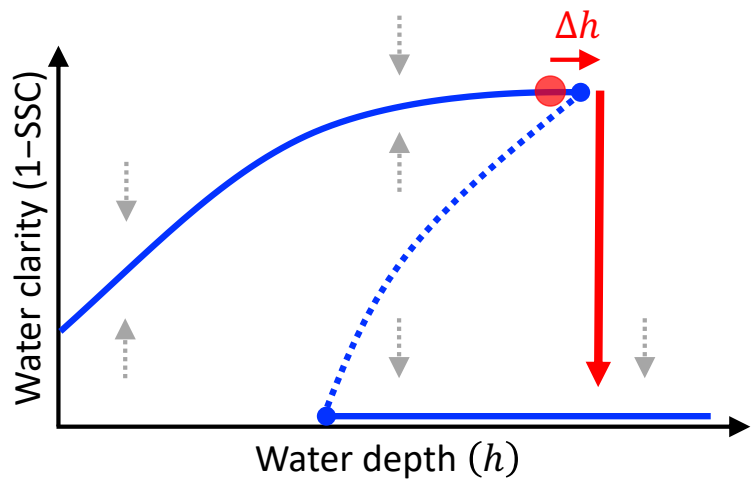
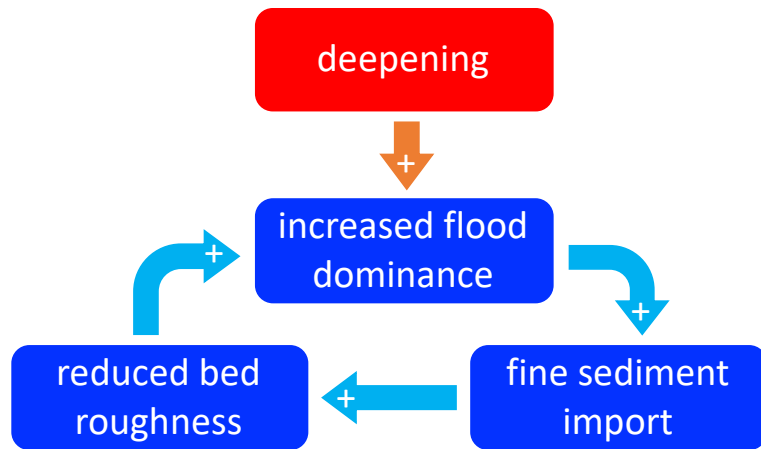
Wang et al. (2014, Ocean Dynamics)

Rate-induced tipping



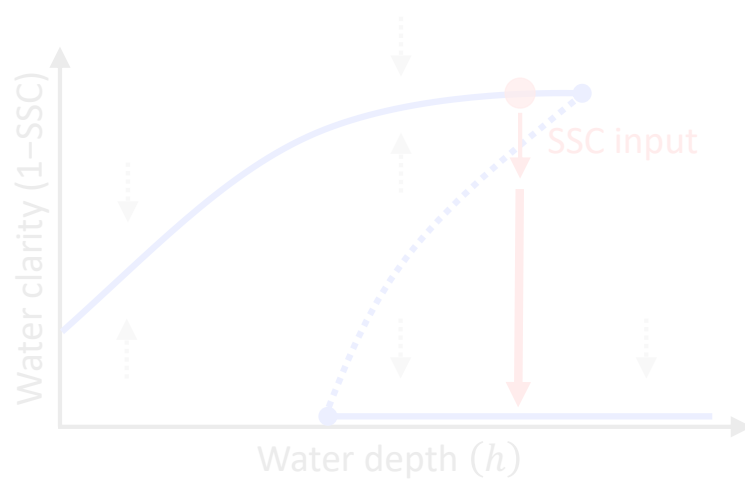
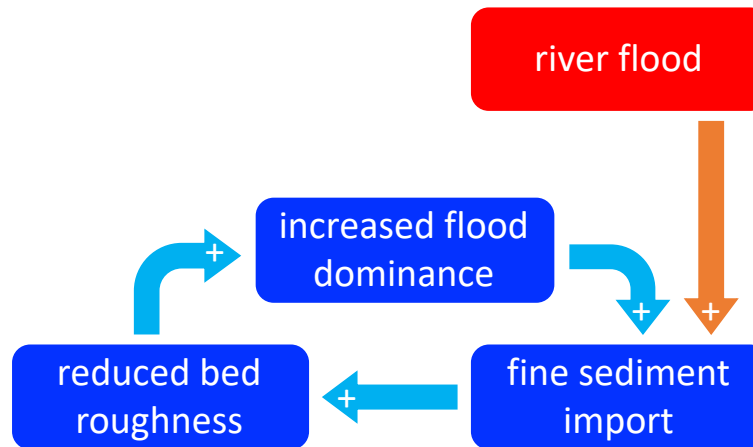
van Maren et al. (2015, Continental Shelf Research)

Bifurcation-induced tipping



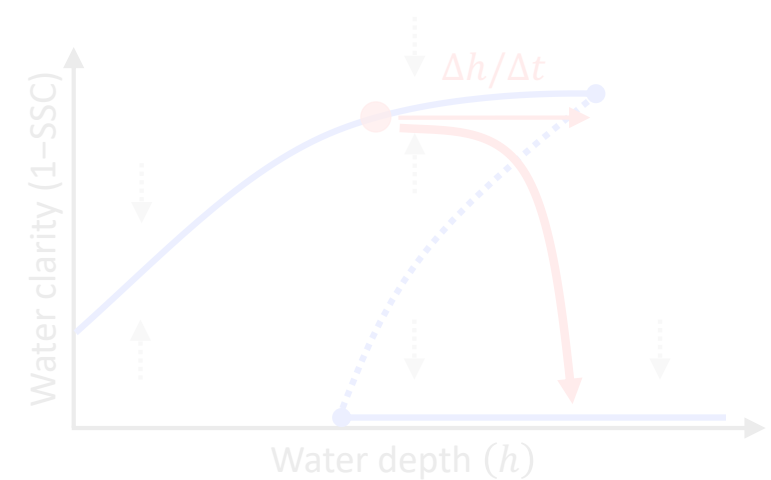
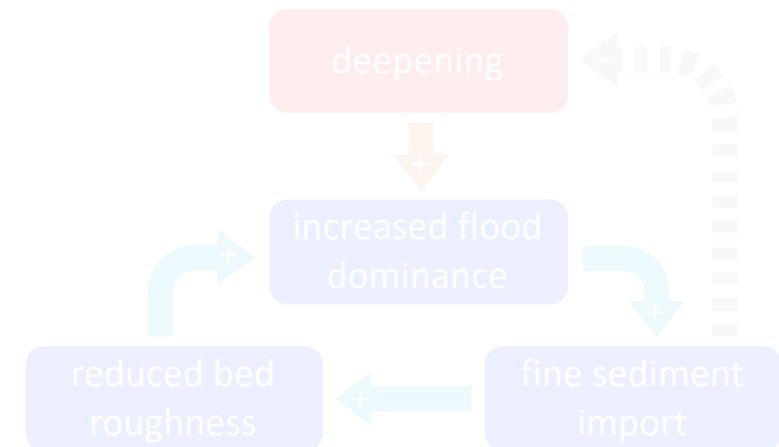
van Maren et al. (2015, Ocean Dynamics)

Noise-induced tipping



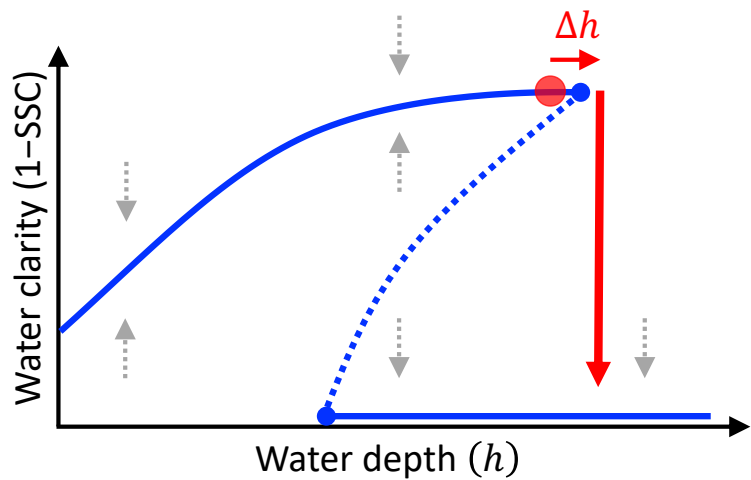
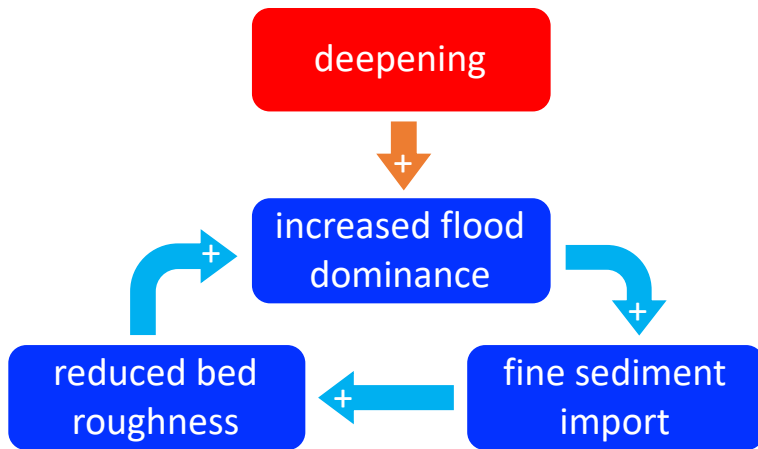
Wang et al. (2014, Ocean Dynamics)

Rate-induced tipping



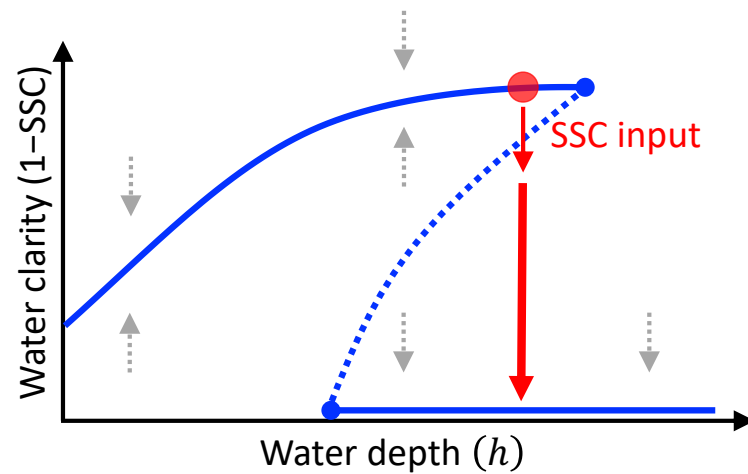
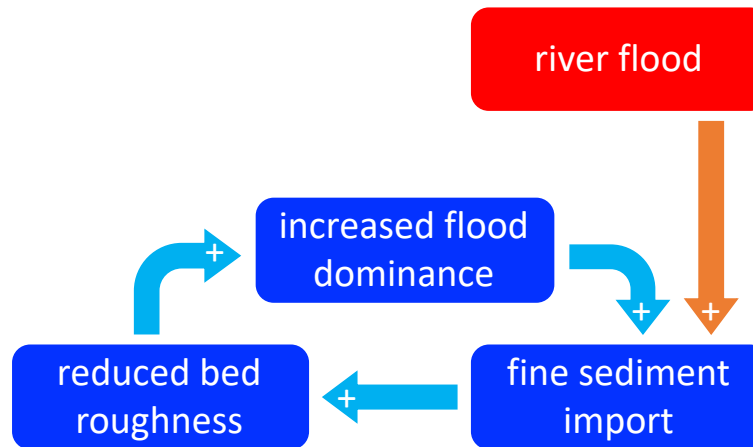
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Bifurcation-induced tipping



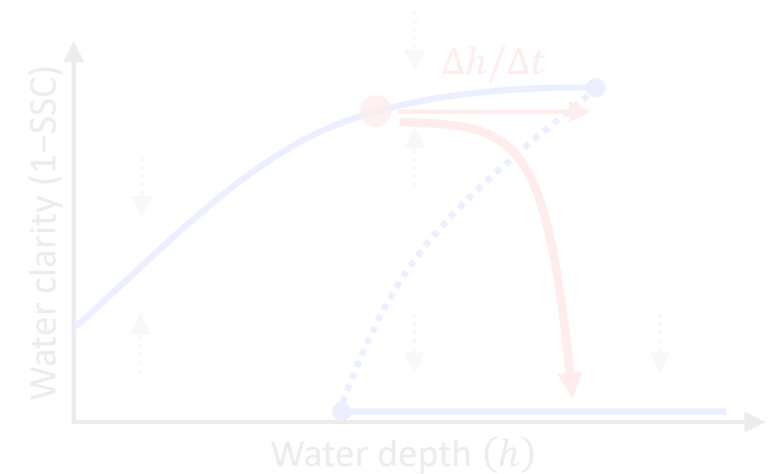
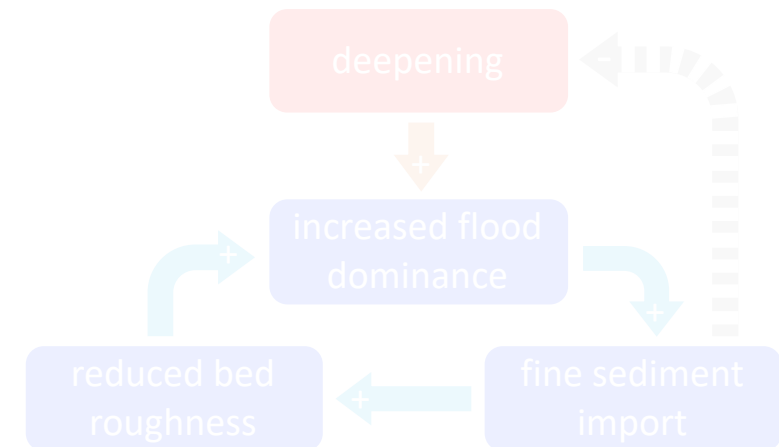
van Maren et al. (2015, Ocean Dynamics)

Noise-induced tipping



Wang et al. (2014, Ocean Dynamics)

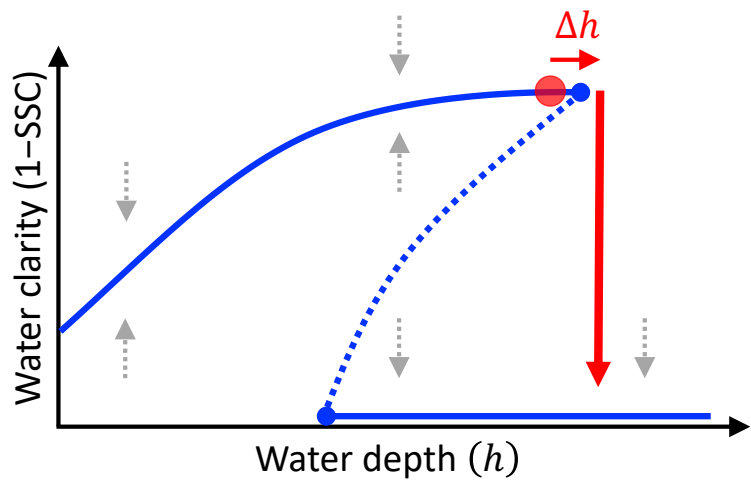
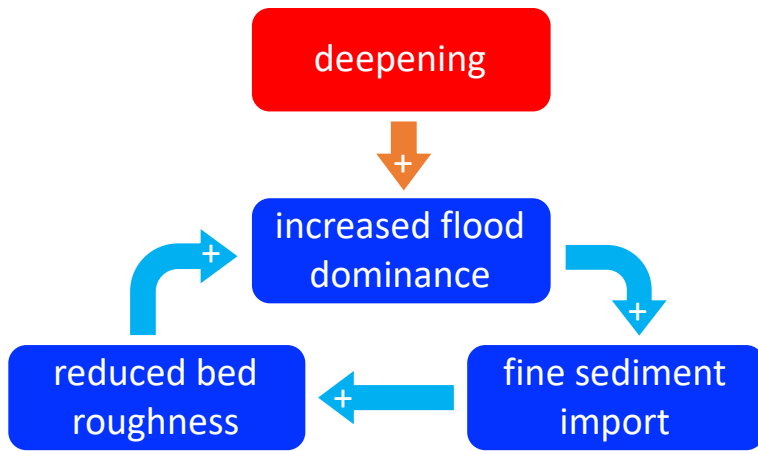
Rate-induced tipping



van Maren et al. (2015, Continental Shelf Research)

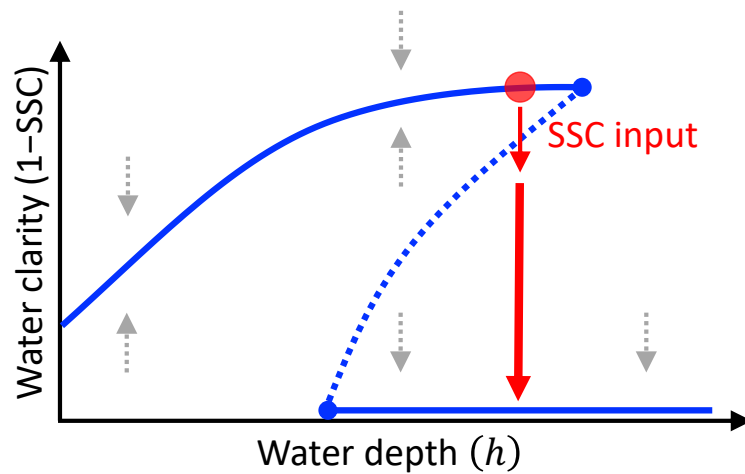
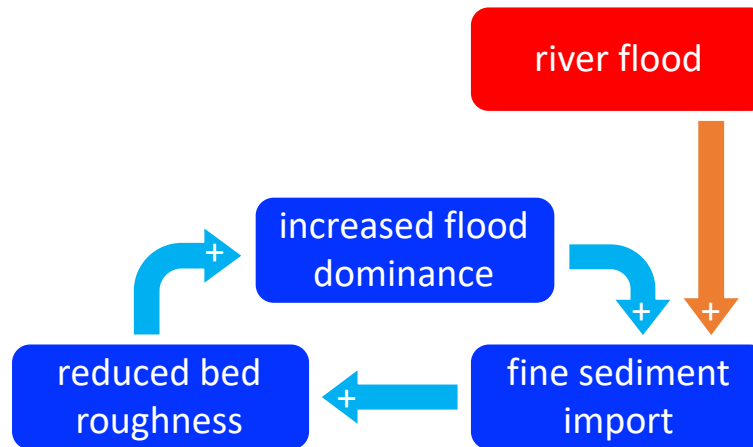
Unknowns: Estuarine hyperturbidity as example

Bifurcation-induced tipping



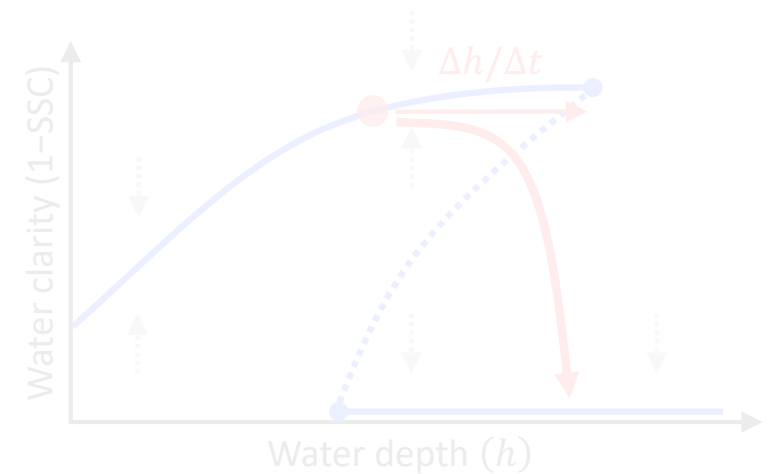
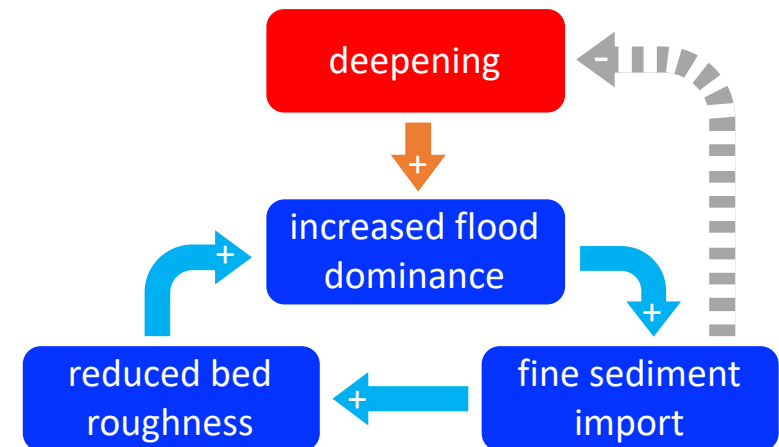
van Maren et al. (2015, Ocean Dynamics)

Noise-induced tipping



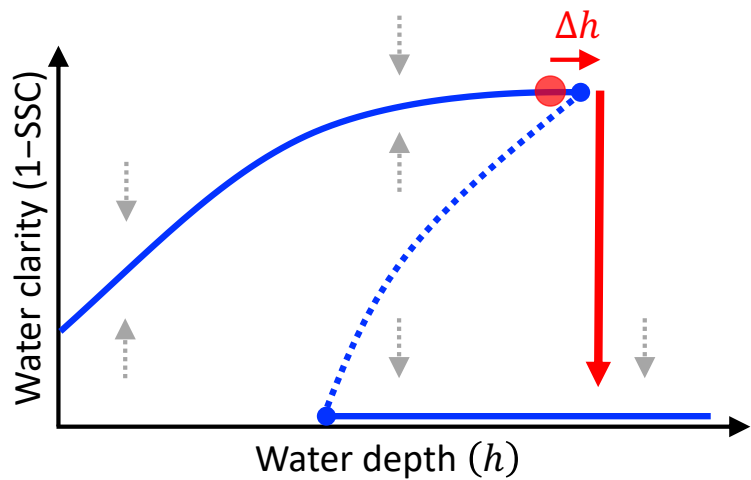
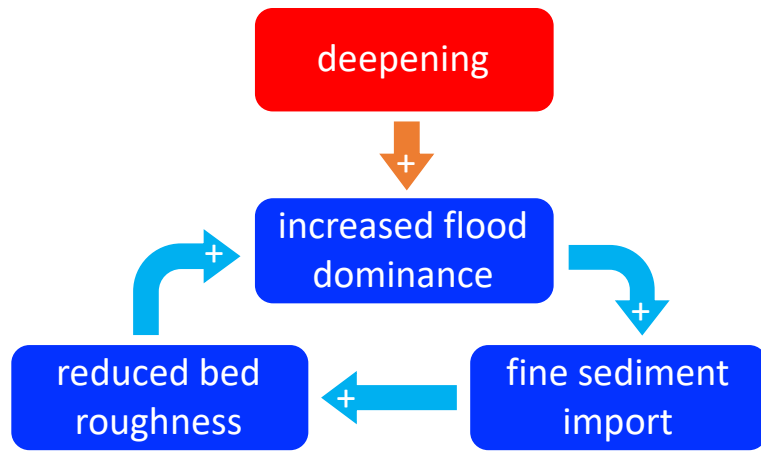
Wang et al. (2014, Ocean Dynamics)

Rate-induced tipping



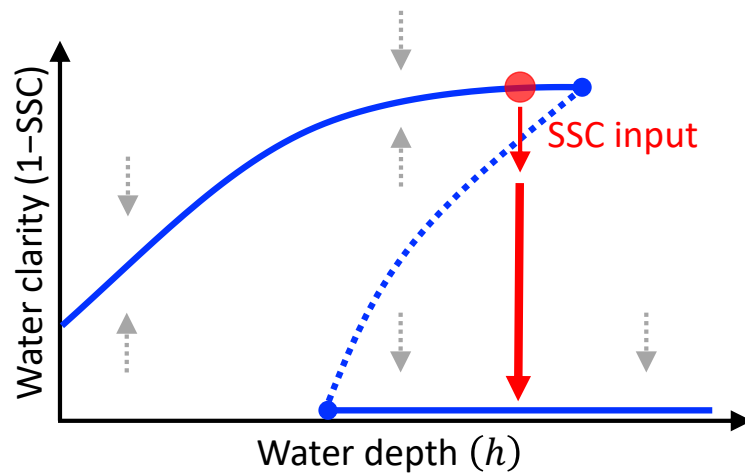
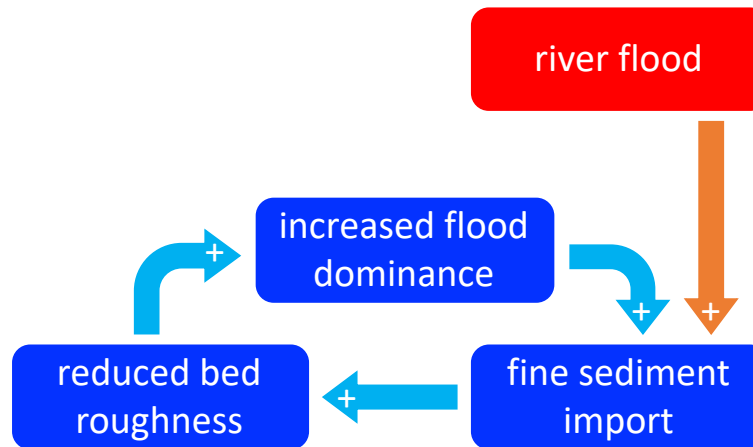
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Bifurcation-induced tipping



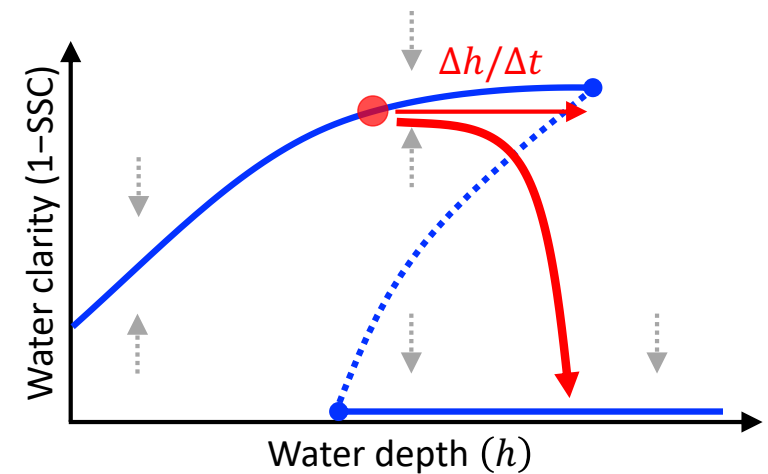
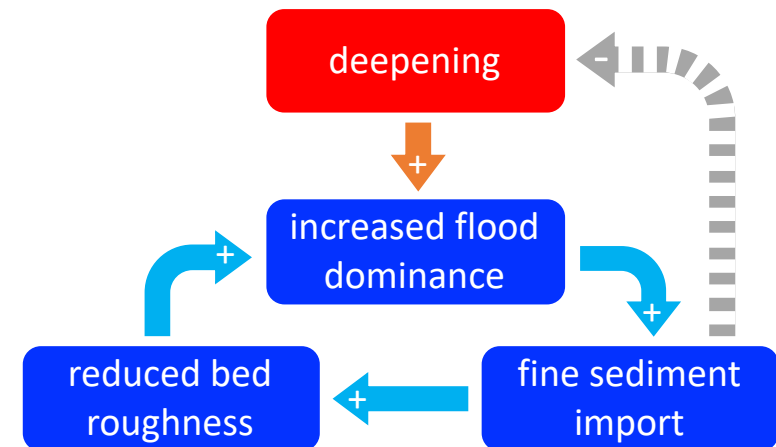
van Maren et al. (2015, Ocean Dynamics)

Noise-induced tipping



Wang et al. (2014, Ocean Dynamics)

Rate-induced tipping



van Maren et al. (2015, Continental Shelf Research)

Unknowns



Ways forward

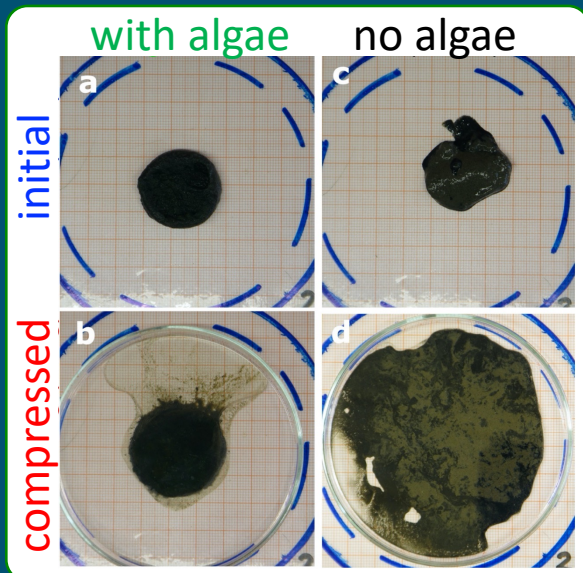


A. Observations



van de Vijssel et al. (2020, ESPL)
van de Vijssel et al. (2021, JGR Biogeosciences)
van de Vijssel (2021, PhD Thesis)

B. Controlled experiments

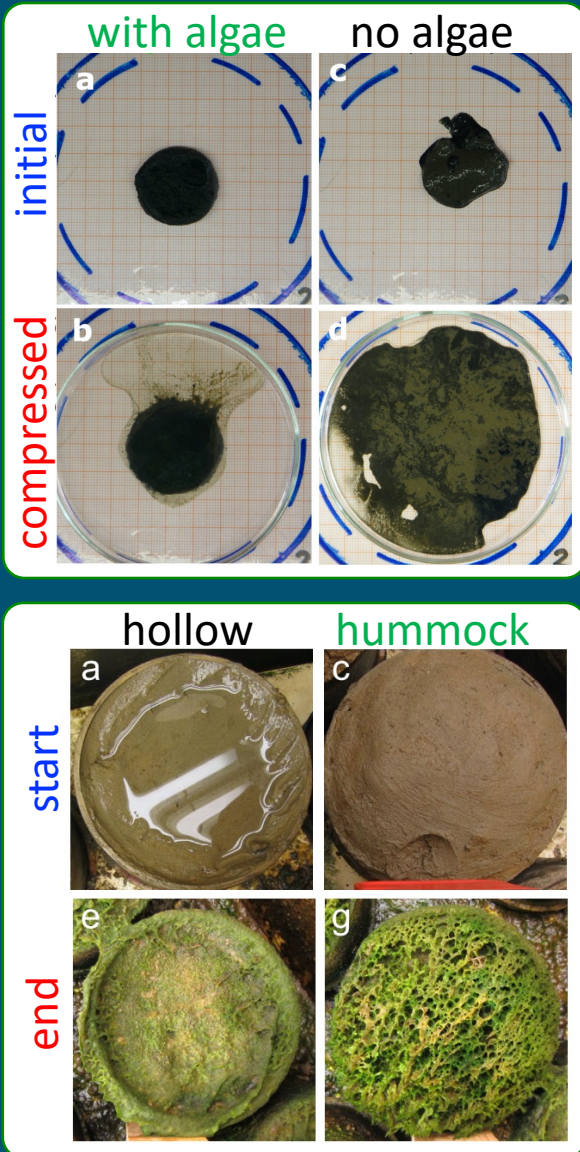


A. Observations



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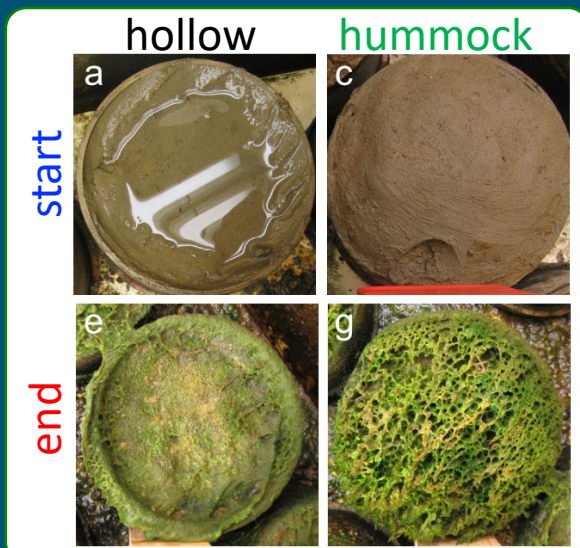
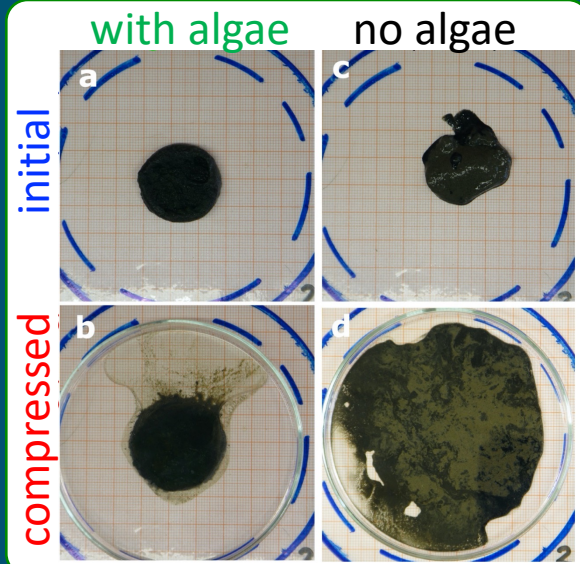


A. Observations

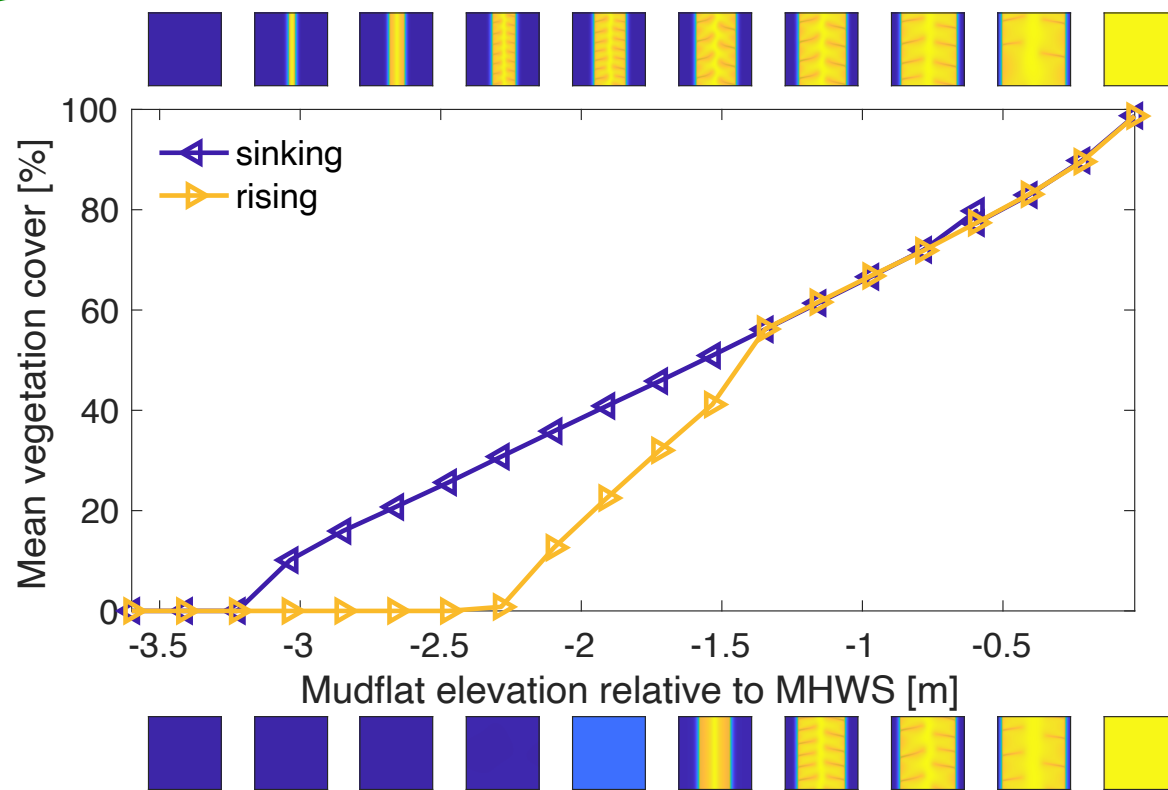


van de Vijssel et al. (2020, ESPL)
van de Vijssel et al. (2021, JGR Biogeosciences)
van de Vijssel (2021, PhD Thesis)

B. Controlled experiments



C. Idealized modelling

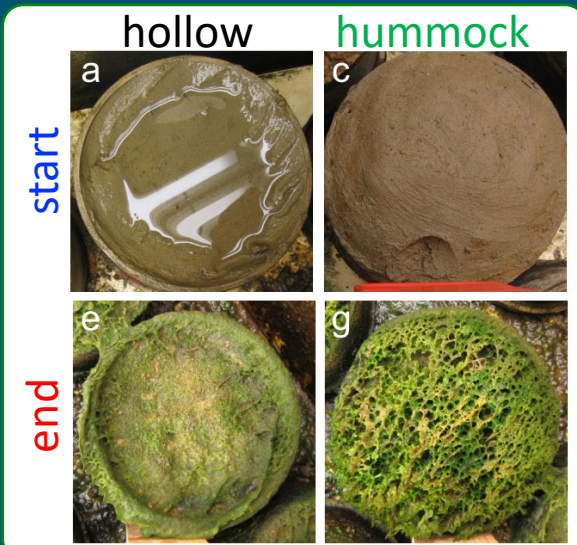
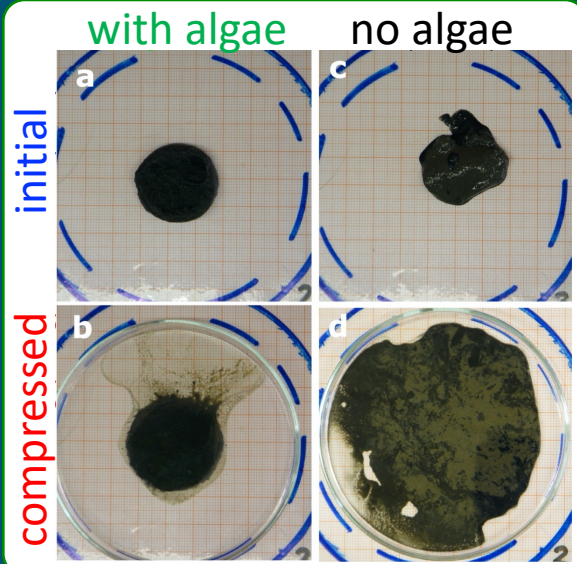


van de Vijssel et al. (2020, ESPL)
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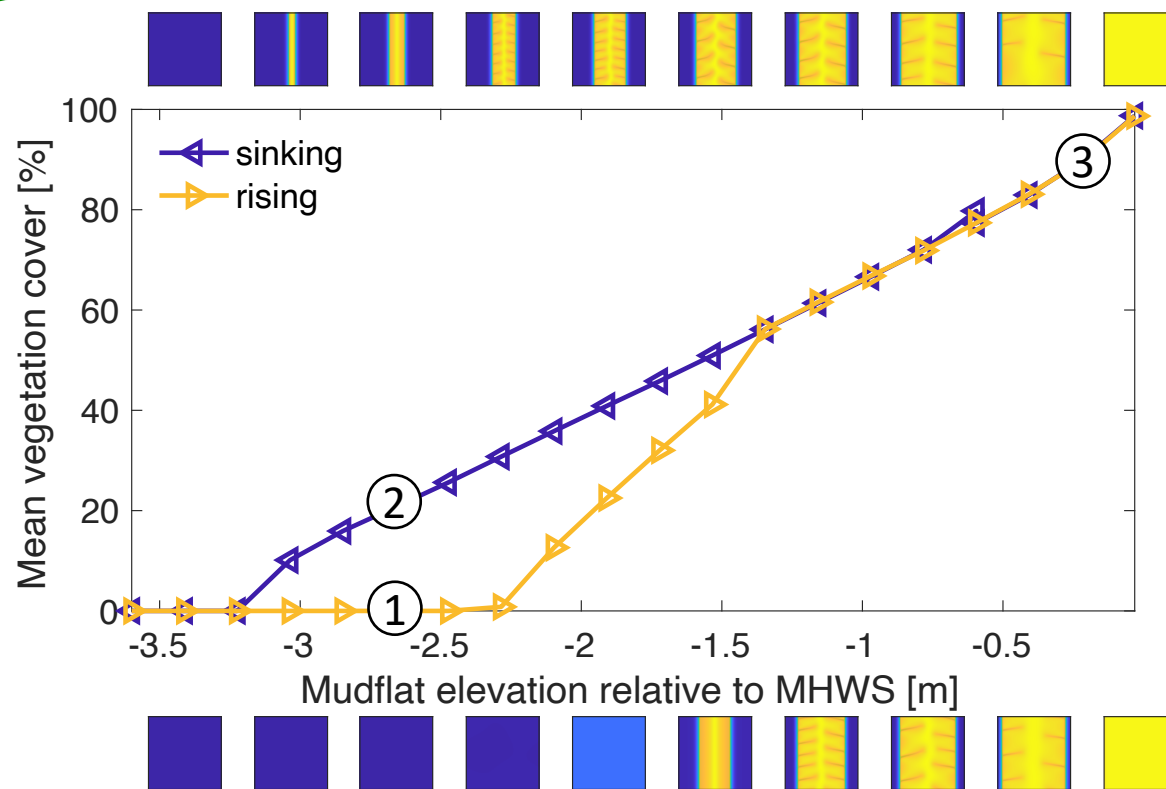
A. Observations



B. Controlled experiments



C. Idealized modelling

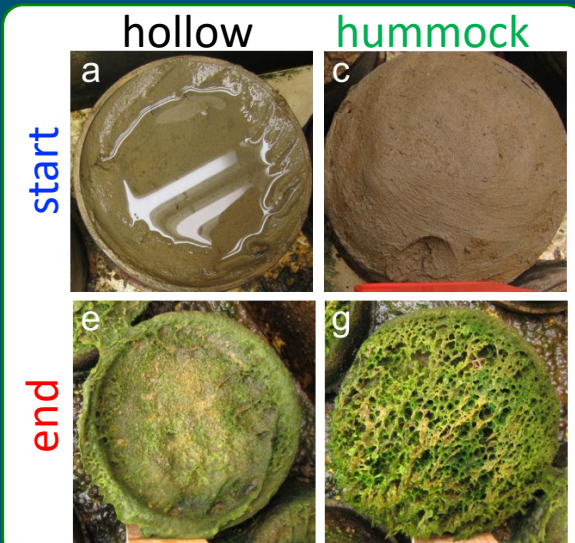
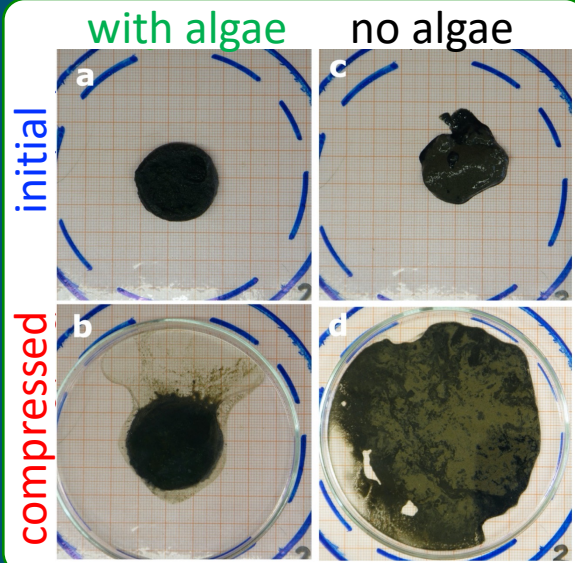


A. Observations

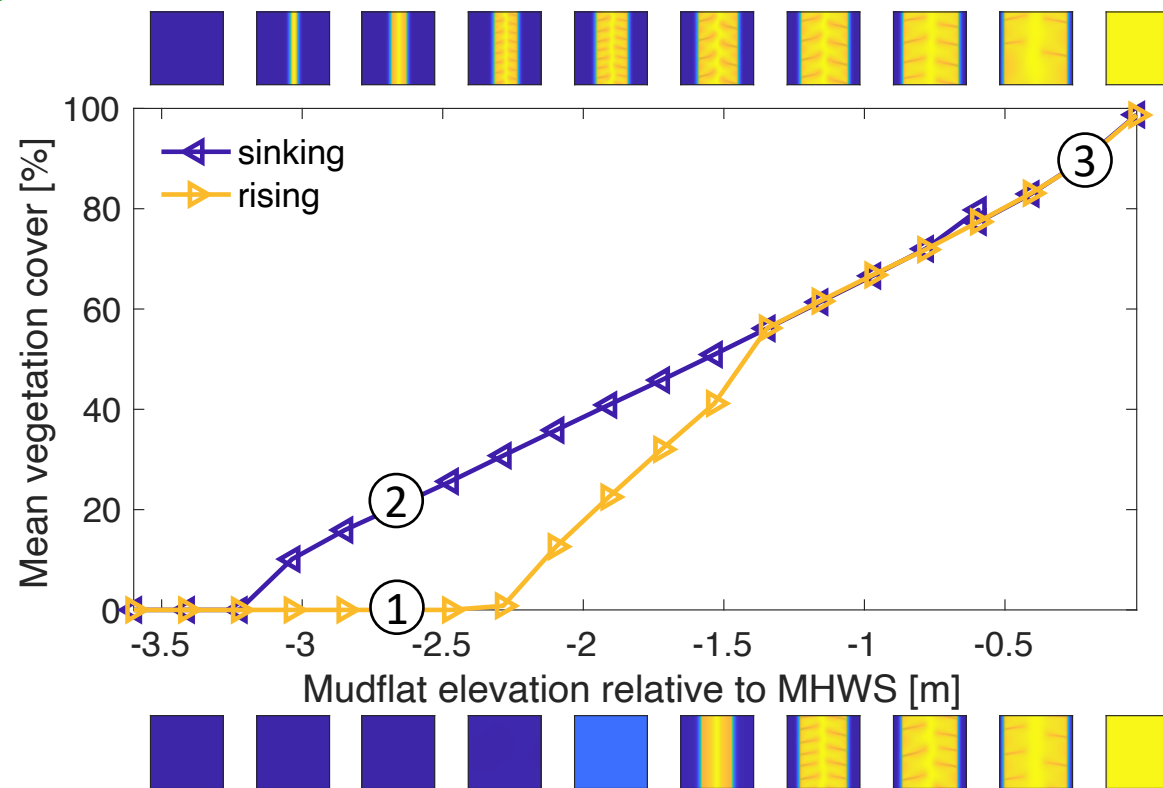


van de Vijssel et al. (2020, ESPL)
van de Vijssel et al. (2021, JGR Biogeosciences)
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B. Controlled experiments



C. Idealized modelling



D. High-complexity modelling

Future work ...

van de Vijssel et al. (2020, ESPL)
van de Vijssel et al. (2021, JGR Biogeosciences)
van de Vijssel (2021, PhD Thesis)

A. Observations



- Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature*, 413(6856), 591-596. <https://doi.org/10.1038/35098000>
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- van de Vijssel, R. C., van Belzen, J., Bouma, T. J., van der Wal, D., & van de Koppel, J. (2021). Algal-induced biogeomorphic feedbacks lay the groundwork for coastal wetland development. *Journal of Geophysical Research: Biogeosciences*, 126, e2021JG006515. <https://doi.org/10.1029/2021JG006515>
- van de Vijssel, R. C., (2021). *Biophysical self-organization of coastal wetlands: Unraveling spatial complexity on tidal flats and marshes, from the Precambrian to today*. University of Groningen. <https://doi.org/10.33612/diss.160081233>
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