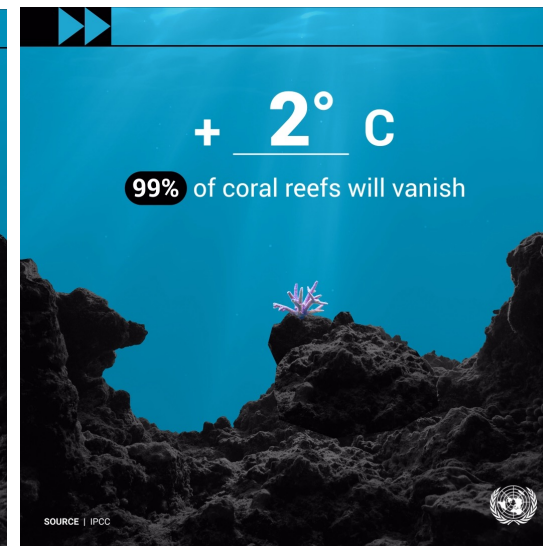
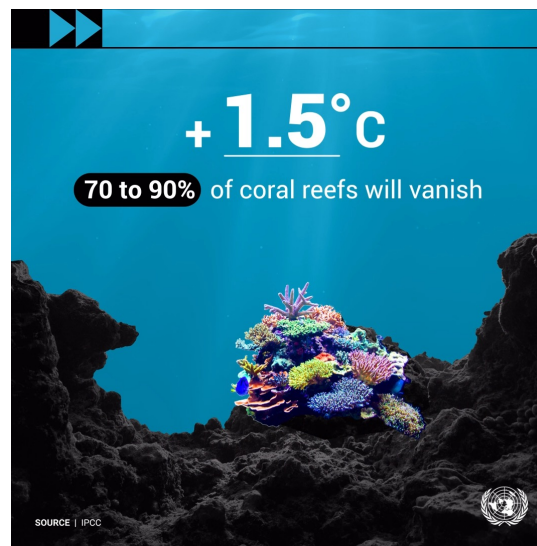
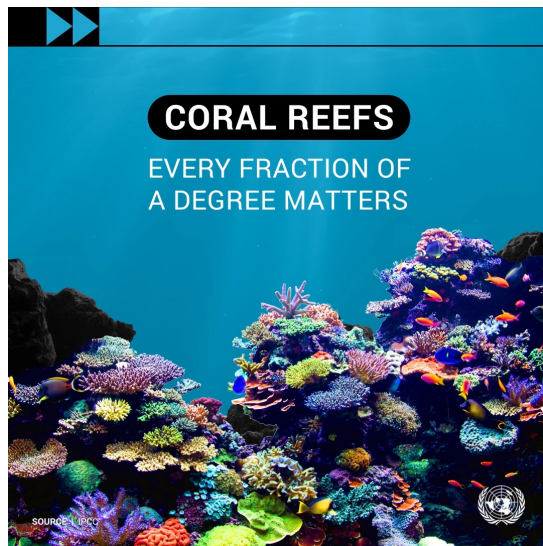


Climate change impacts and mitigation in coastal ecosystems: from tipping points to blue carbon and reserve networks

Frederic Guichard
McGill University



Marine protected areas as dynamic networks

Marine Protected Areas | Help the oceans to mitigate and adapt to climate change by promoting intact and complex ecosystems with high diversity and abundance of species.

Blue carbon

MPAs promote genetic diversity that provides raw material for adaptation to climate change.

Protecting coastal habitats maintains carbon sequestration and storage processes and prevents loss of stored carbon.

MPAs prevent the release of carbon from sediments disturbed by habitat modifying fishing gear.

Reduction of human stressors in MPAs promotes ecosystem recovery and prevents biodiversity loss enhancing livelihoods and ecosystem services.

MPAs protect apex predators that confer increased stability to coastal habitats that buffer climate-induced instabilities.

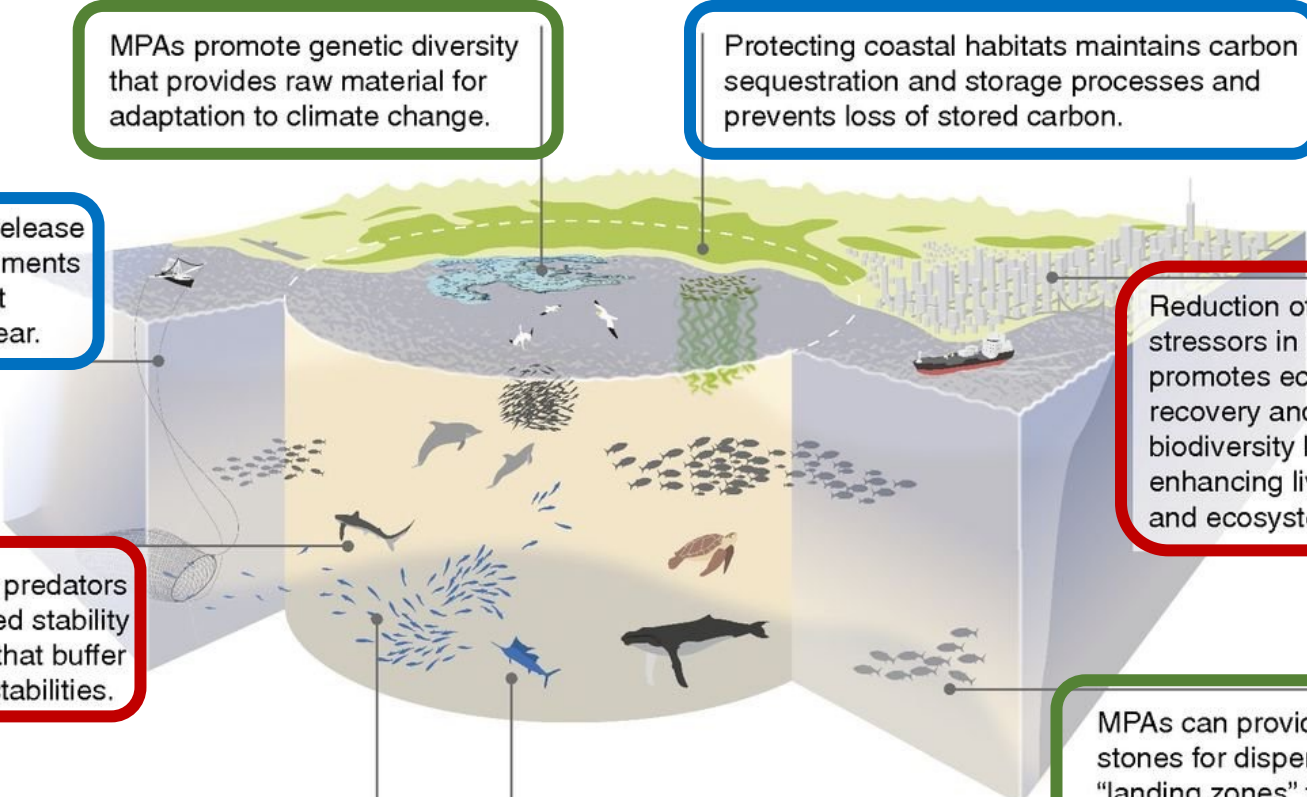
Connectivity & adaptation

MPAs can provide stepping stones for dispersal and safe "landing zones" for climate migrants.

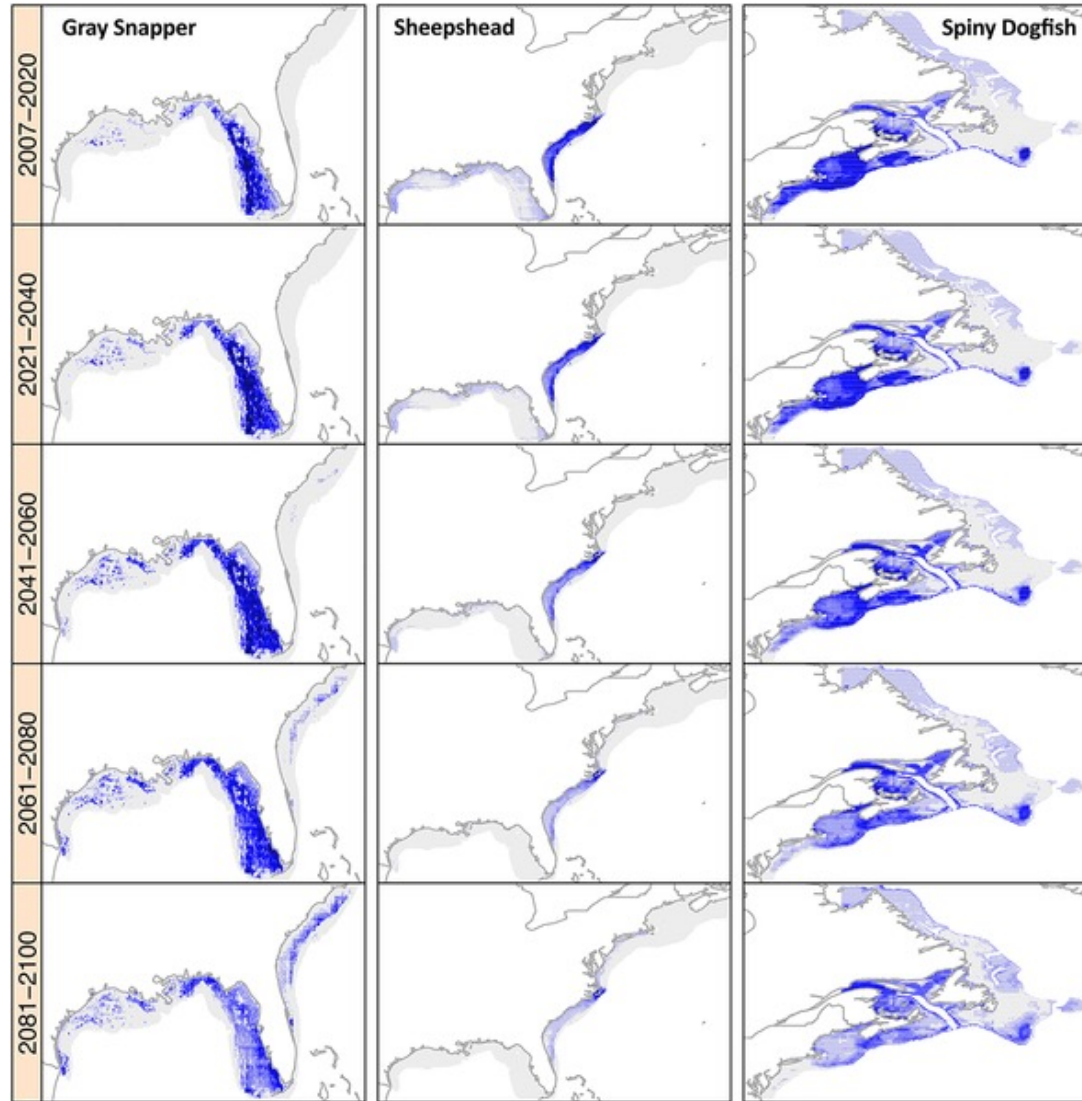
Trophic regulation and tipping points

Large populations with greater reproductive output often found in MPAs will be more resistant to extinction as climate stress increases.

High abundance of mesopelagic fish in open ocean MPAs may enhance CO2 absorption and buffer acidification near the surface through excretion of gut carbonates.

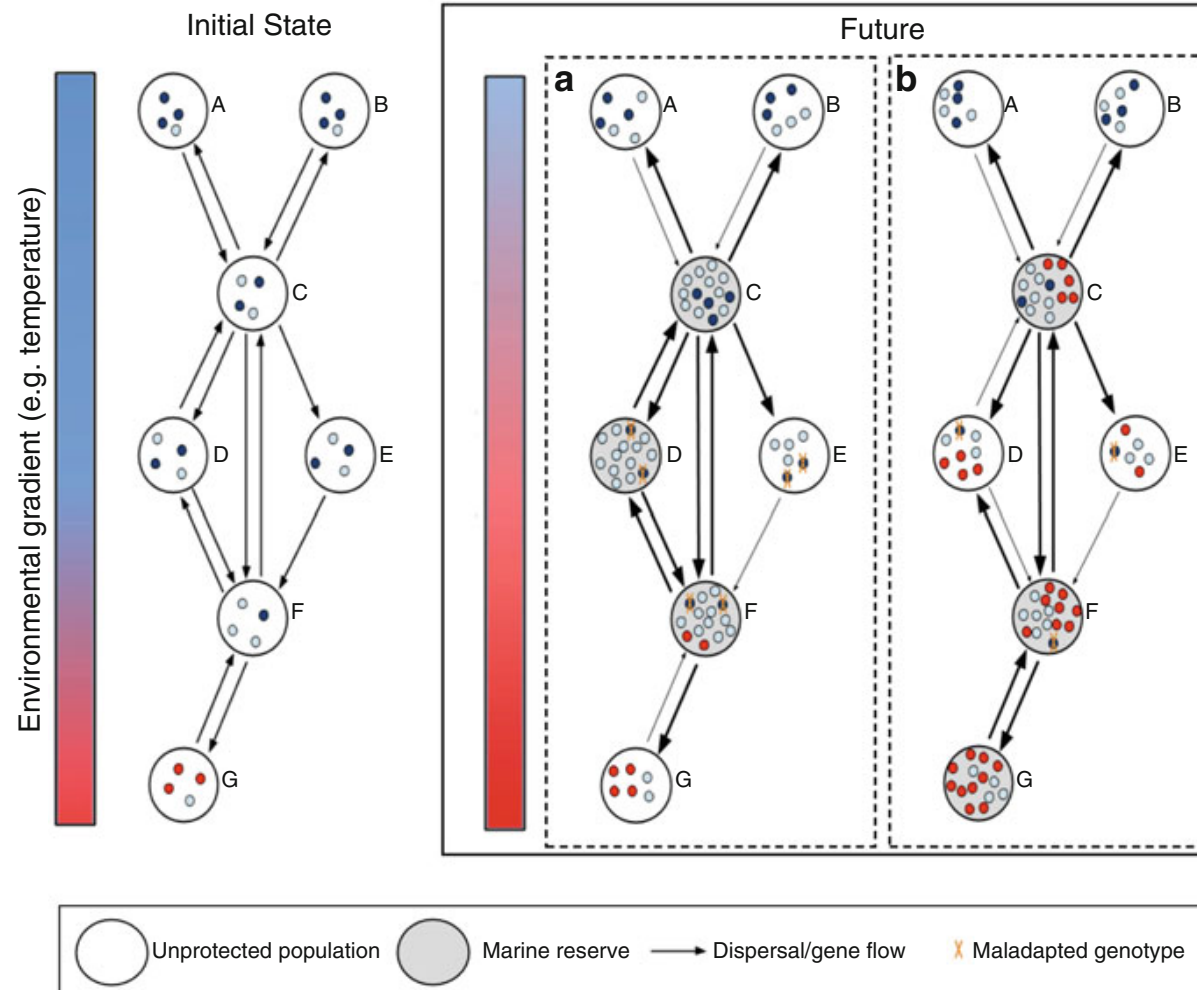


Dynamics of climate change: range shifts



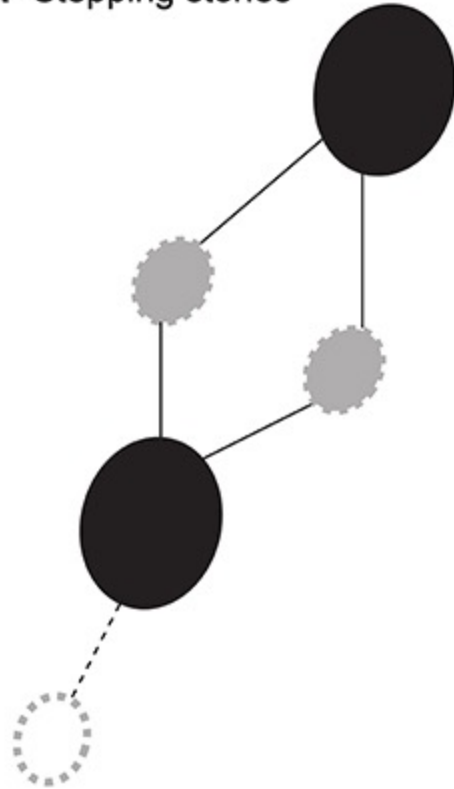
Morley JW, Selden RL, Latour RJ, Frölicher TL, Seagraves RJ, et al. (2018) Projecting shifts in thermal habitat for 686 species on the North American continental shelf. PLOS ONE 13(5): e0196127

Networks of protected areas: connectivity and adaptation

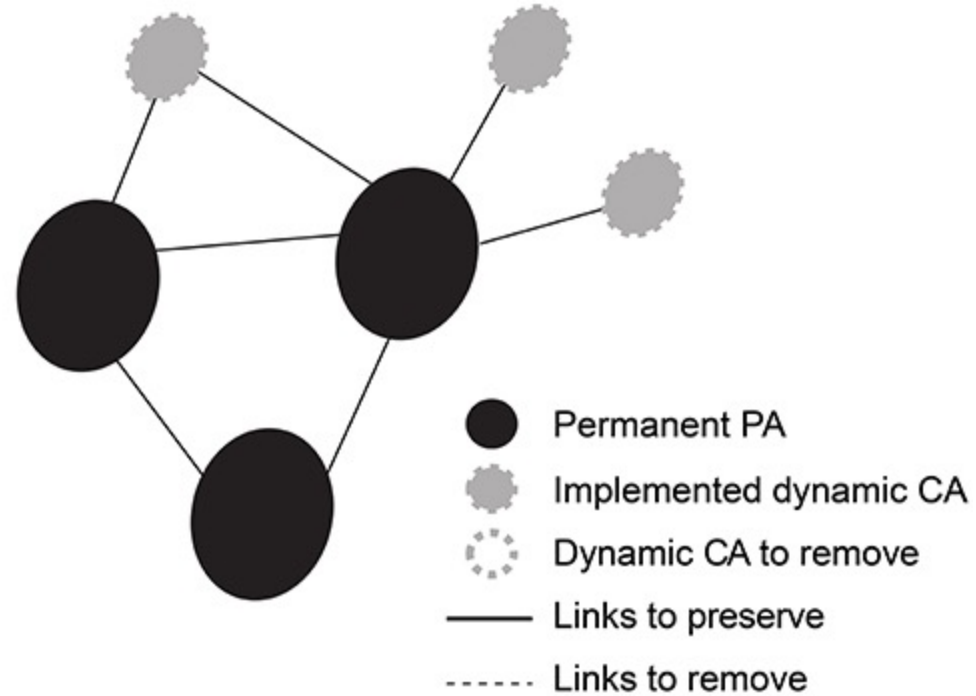


Integration of permanent and dynamic conservation areas

A Stepping stones



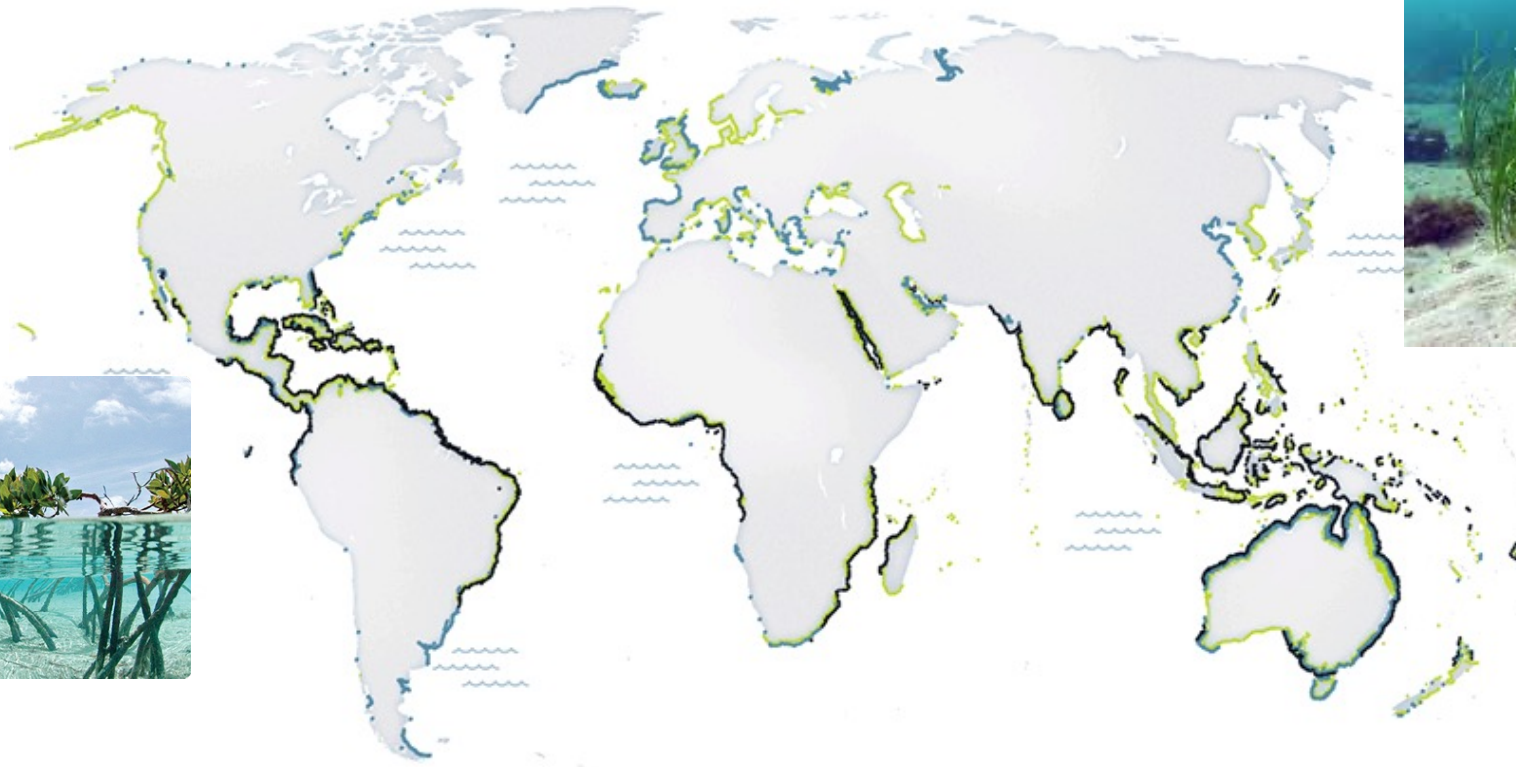
B Peripheral nodes



Blue carbon: carbon stored in coastal and marine ecosystems

‘Ecosystem engineers’ contribute to carbon sequestration

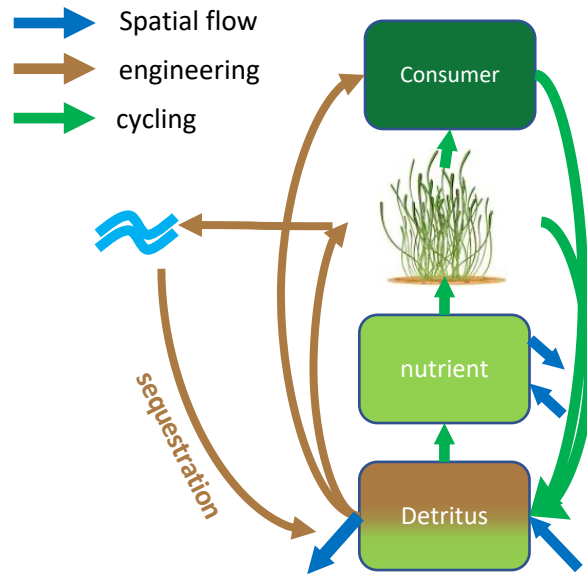
Global Distribution of **Blue Carbon Ecosystems**



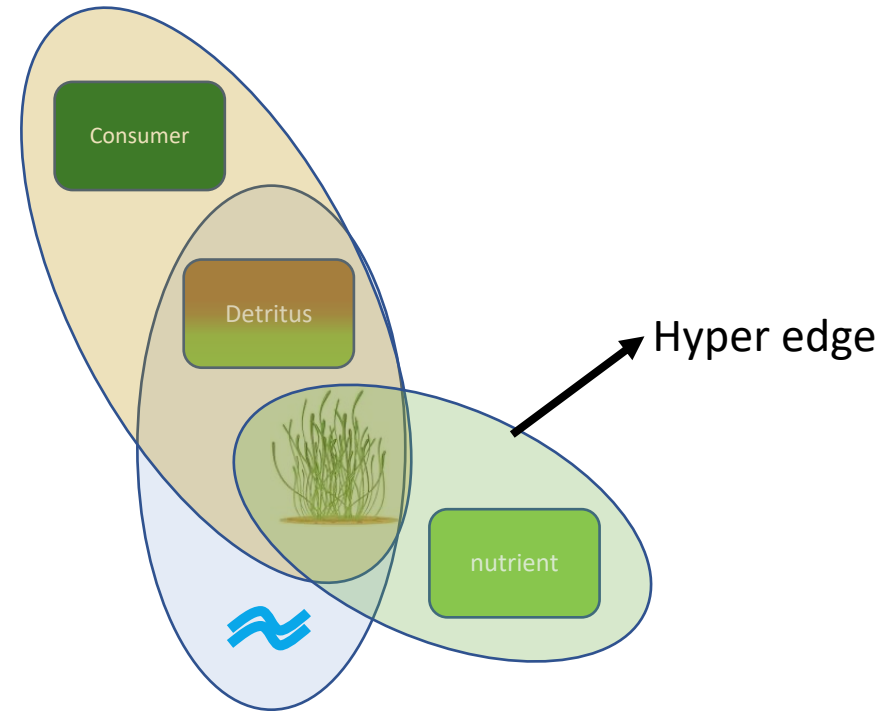
 Mangroves  Salt Marsh  Seagrass



Ecosystem engineering: higher-order interactions and hypergraphs

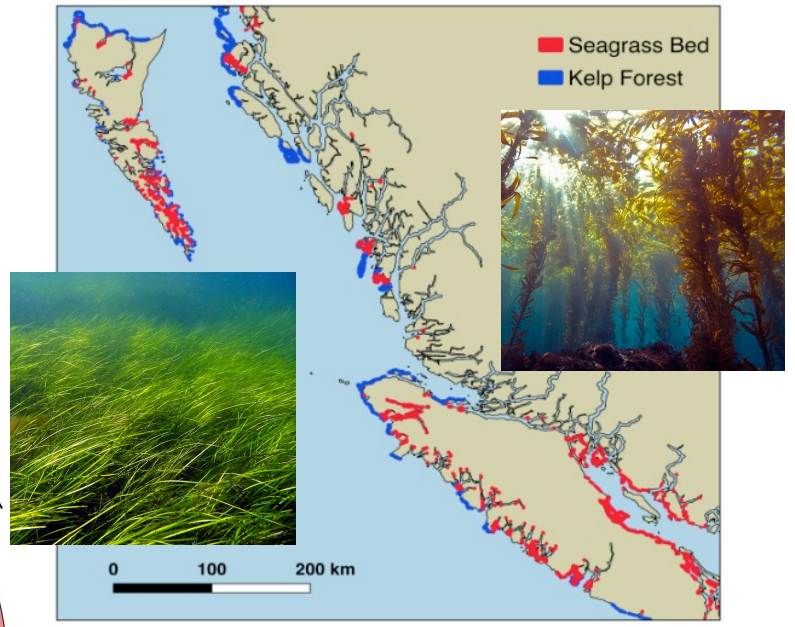
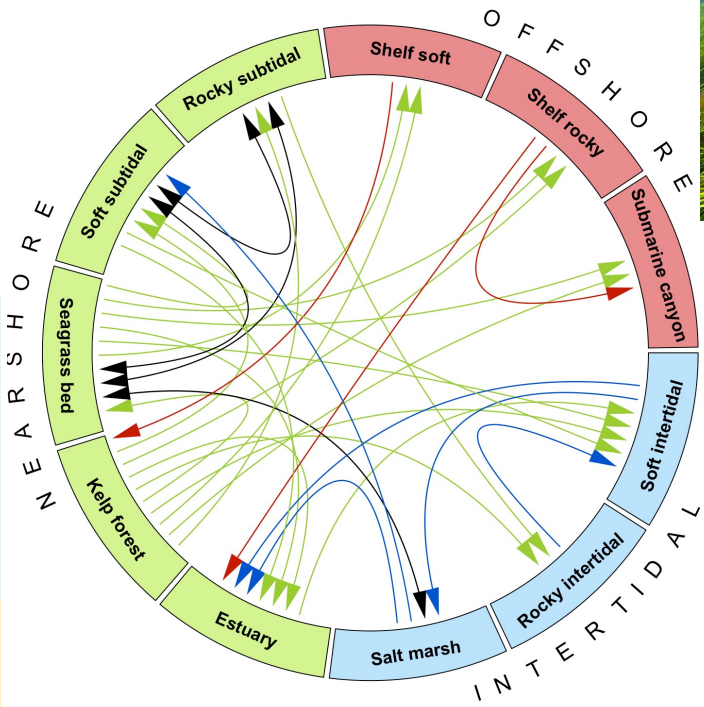
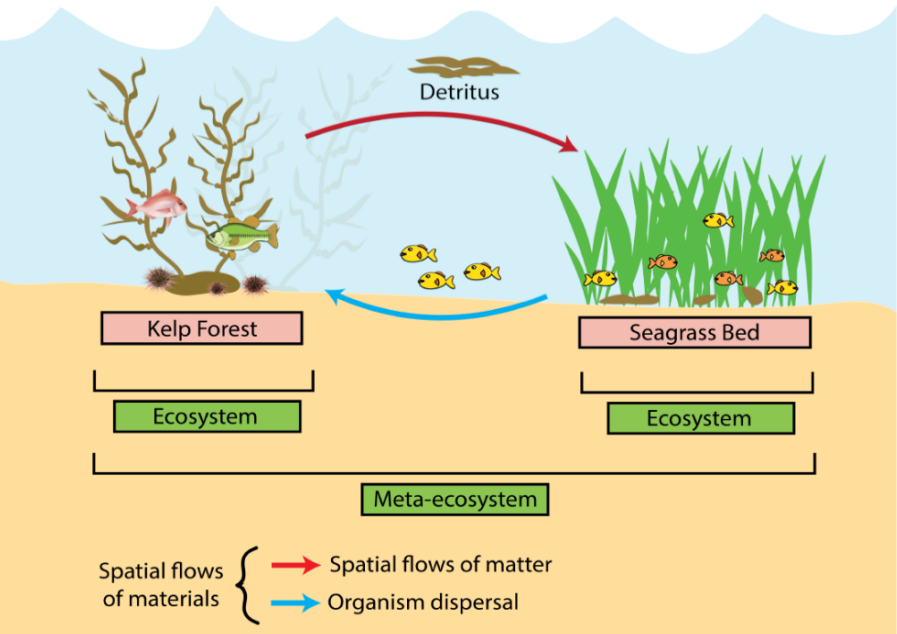


non-trophic (higher-order) interactions

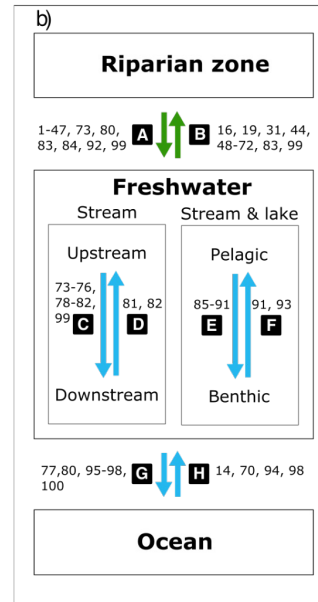
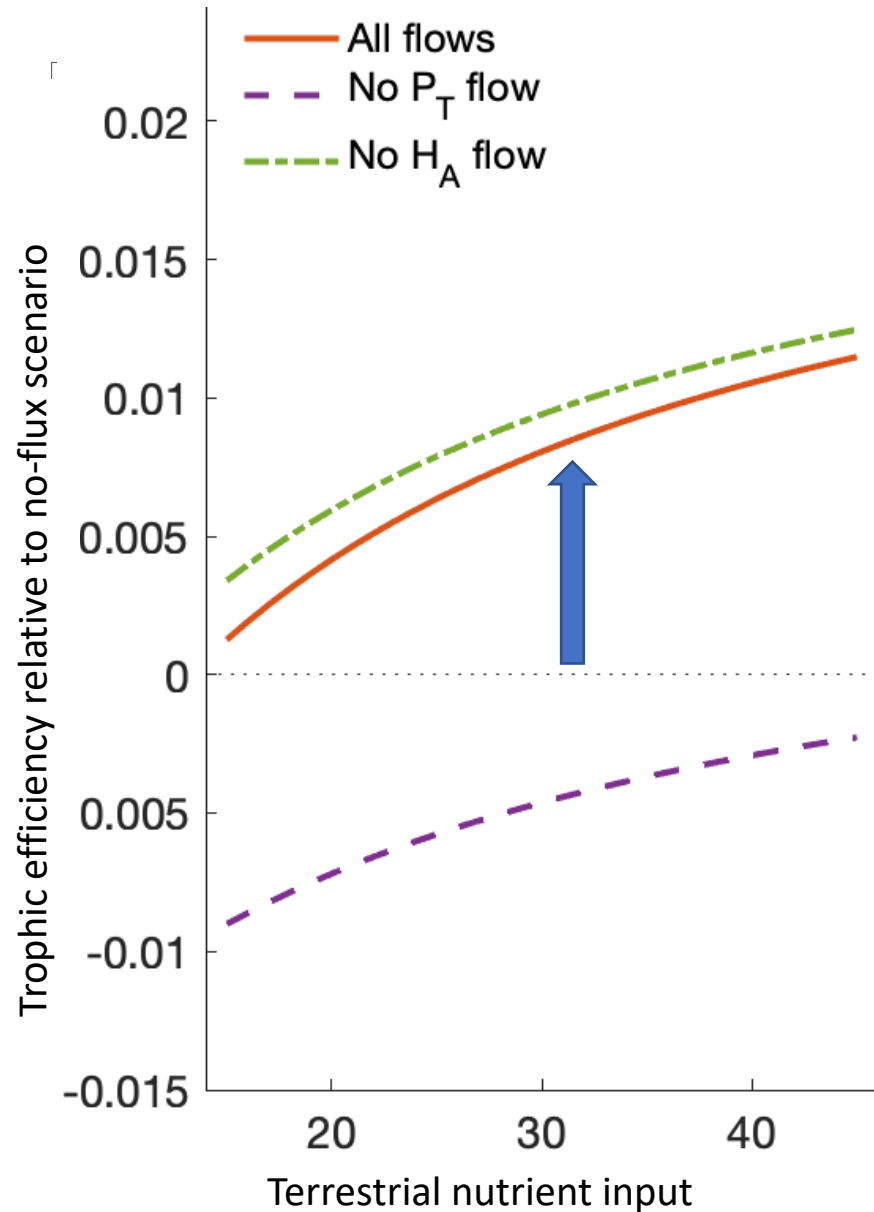


(annotated) Hypergraph representation

Meta-ecosystem engineering: spatial subsidies (detritus) in coastal ecosystems

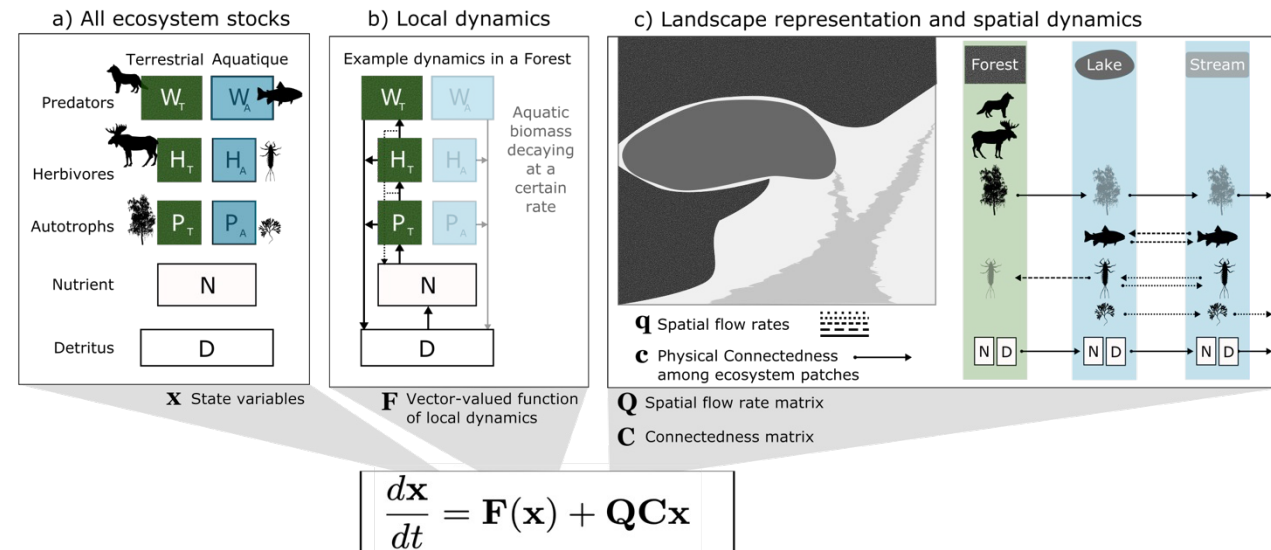


Cross-ecosystem fluxes increase meta-ecosystem efficiency



$$C = \bigoplus_{k=1}^m (C_k)^T = \begin{pmatrix} (C_1)^T & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & (C_2)^T & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & (C_m)^T \end{pmatrix}$$

$$Q = Q' \otimes I_{(n,n)} = \begin{pmatrix} q_1 I_{(n,n)} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & q_2 I_{(n,n)} & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \dots & q_m I_{(n,n)} \end{pmatrix}$$

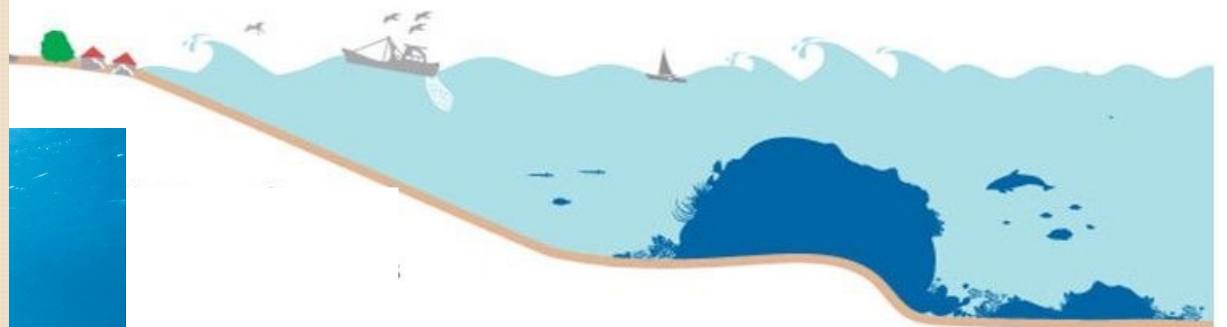
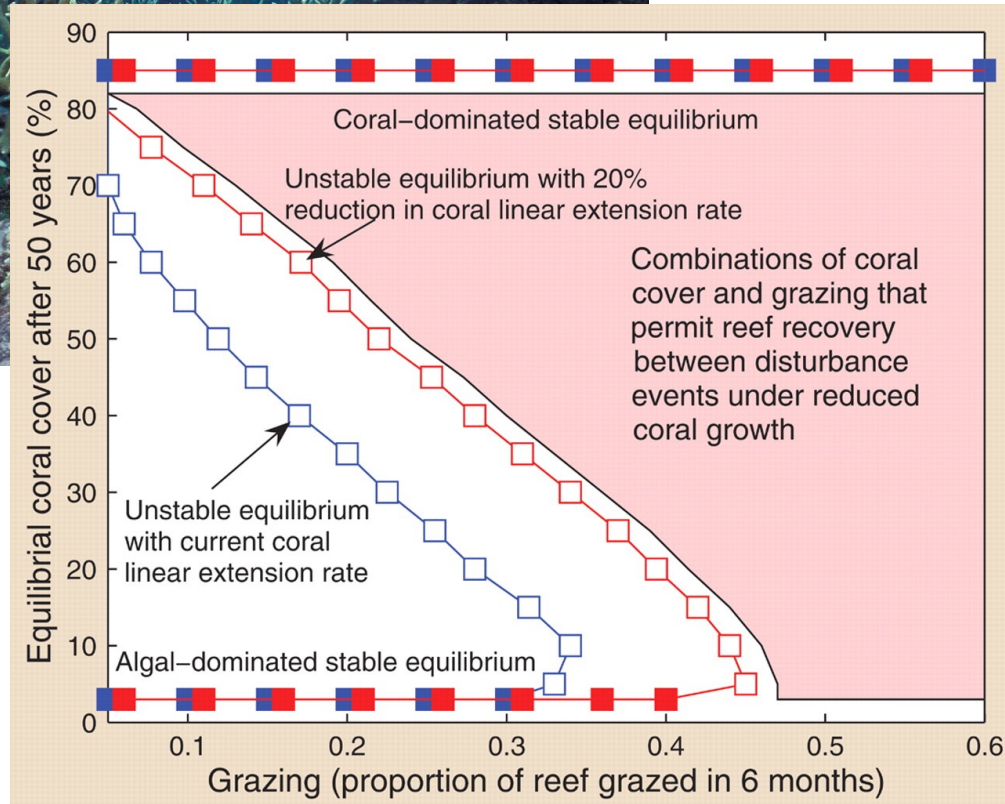
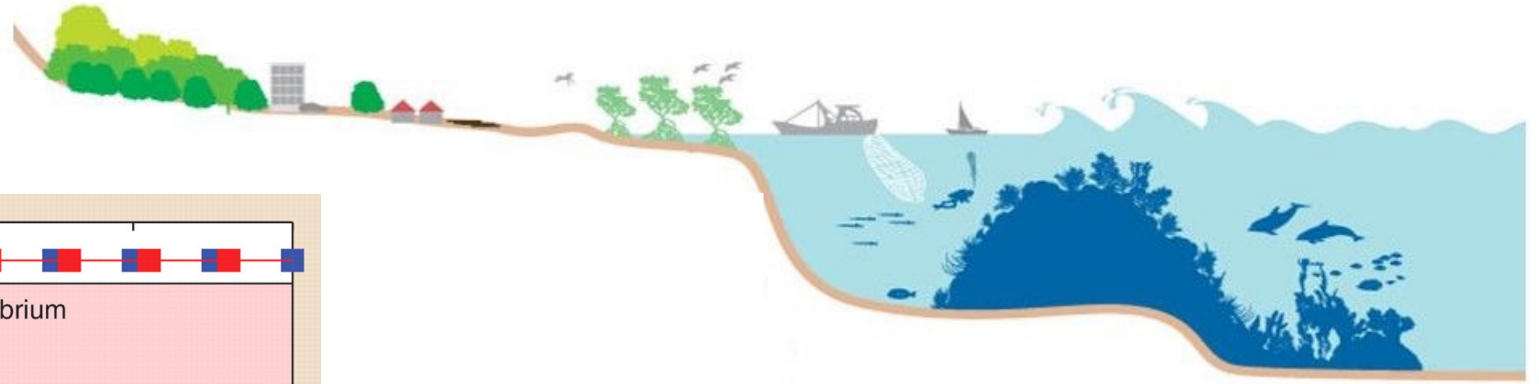
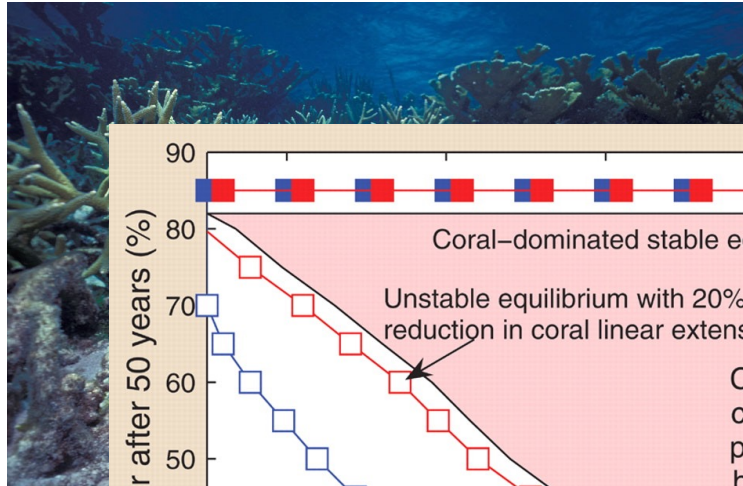


$$\frac{dx}{dt} = F(x) + QCx$$

d) Mathematical matrix-based meta-ecosystem framework

Tipping points: coral reef ecosystems

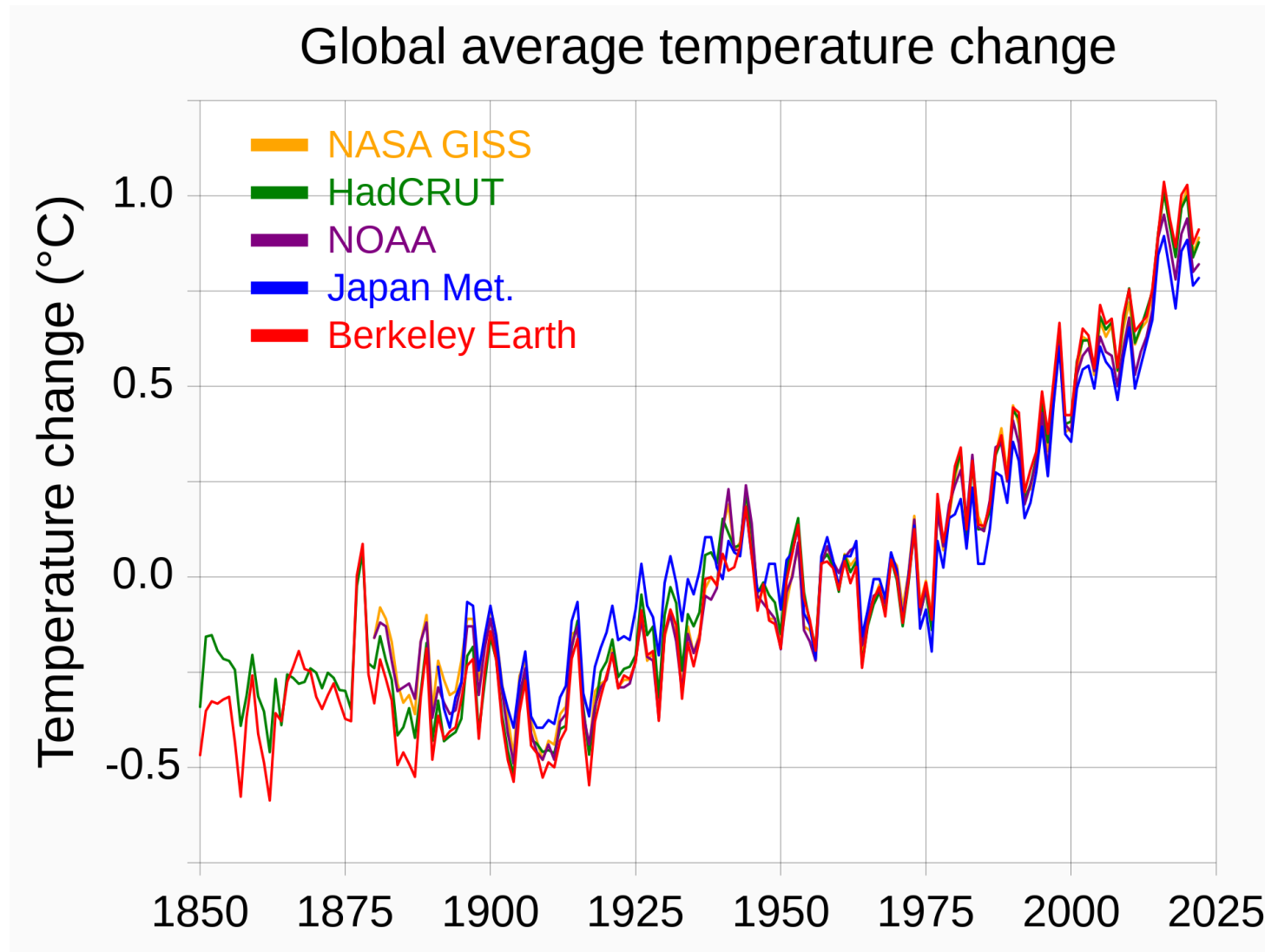
1980



Hoegh-Guldberg et al. (2008, Science)

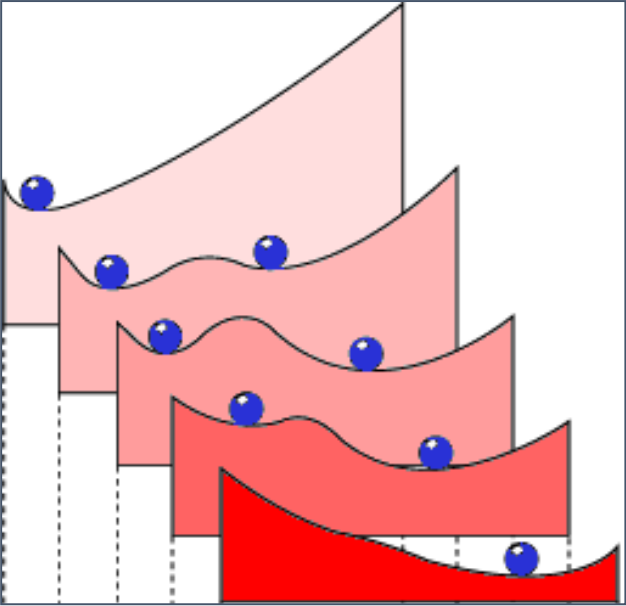


Dynamics of climate change: rate-dependent impacts

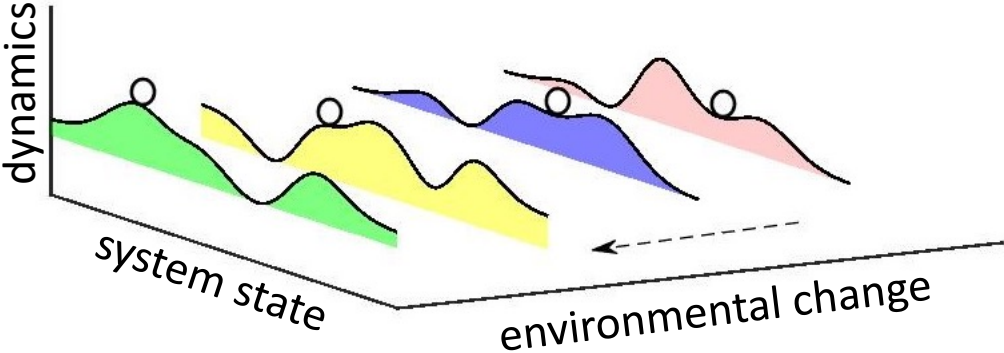


The rate of environmental change can drive ecological response

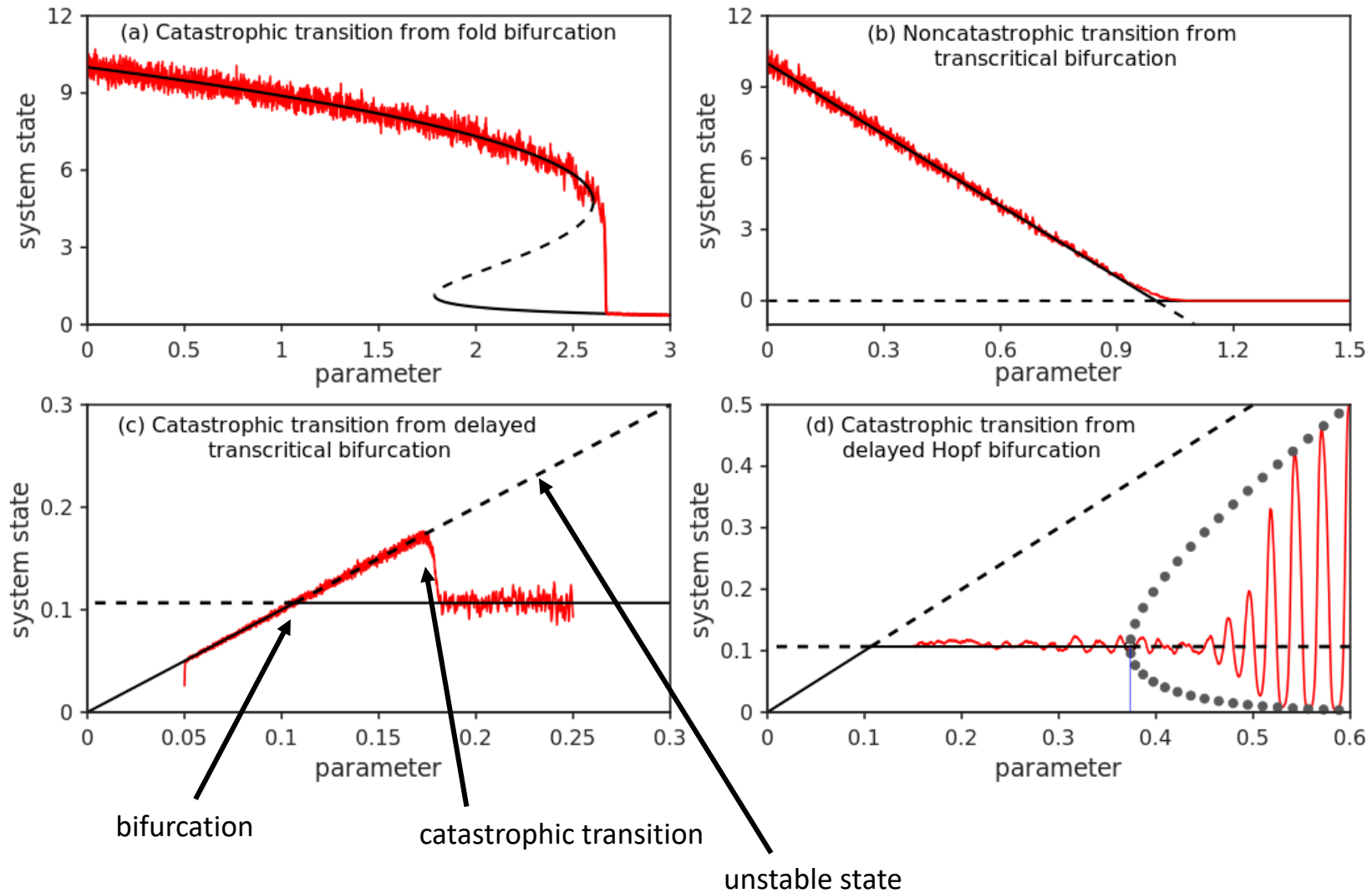
Stability landscape at equilibrium



Non-equilibrium: the ecological states is under a shifting stability 'landscape'

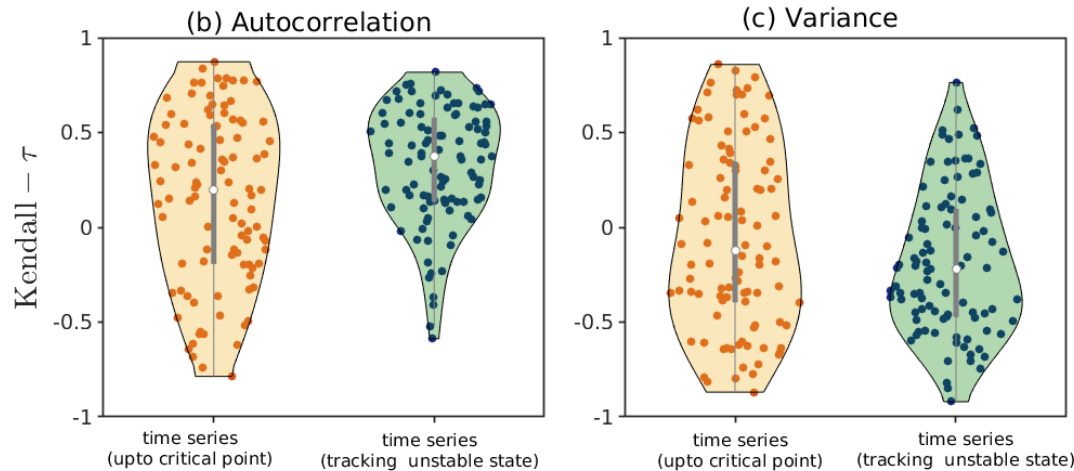
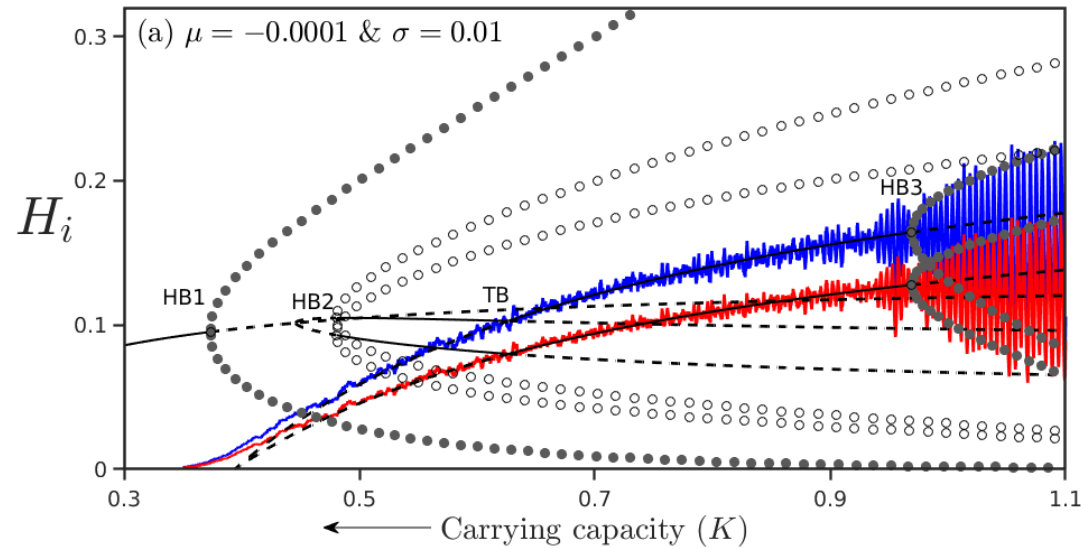


The rate of environmental change can decouple bifurcation and transitions



Early-warning signals of bifurcations vs transitions

- Non-catastrophic transcritical bifurcation leads to extinction

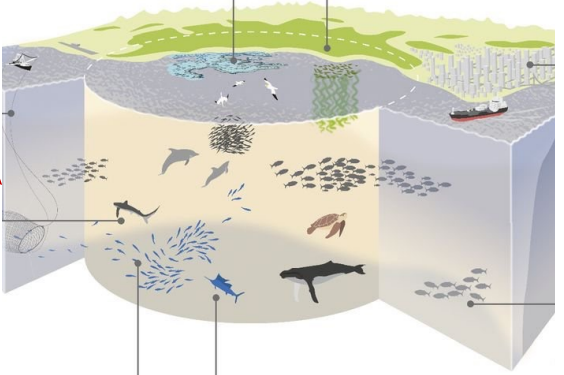
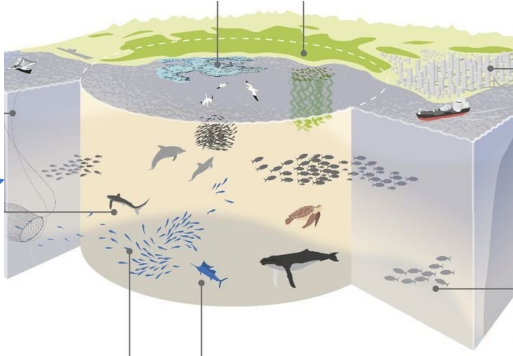
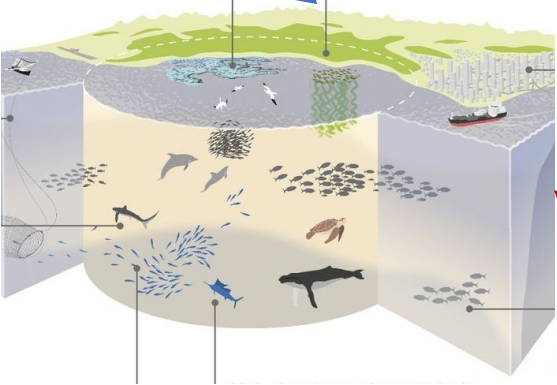


- Variance: false-negative prediction of catastrophic transition
- Transition predicted by autocorrelation but not the bifurcation

Conclusions

Blue carbon:

- Cross system fluxes and non-trophic interactions



Trophic regulation and tipping points:

- Rate-dependent tipping

Connectivity & adaptation:

- Eco-evolutionary dynamics on networks
- Network rewiring
- Dynamic MPA networks