Network modularity and the spread of perturbations in macroalgal canopies

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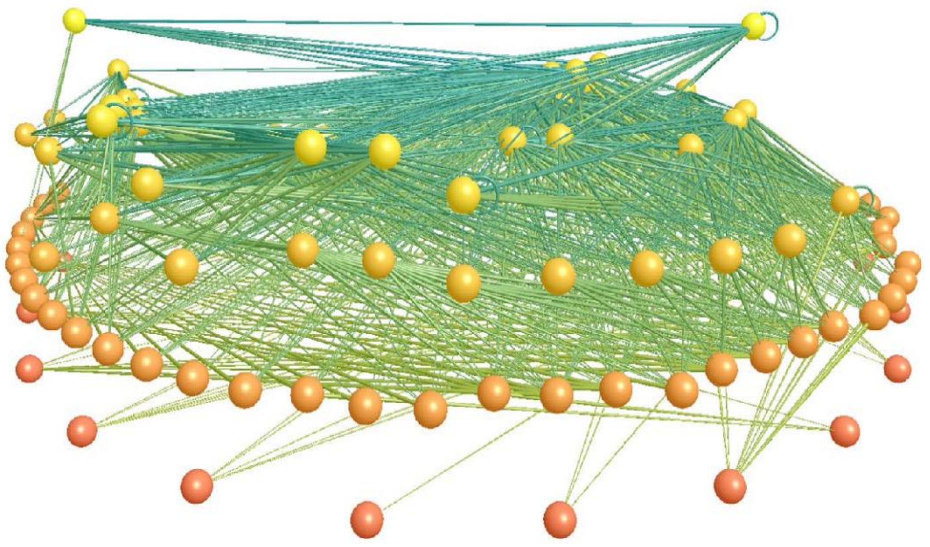
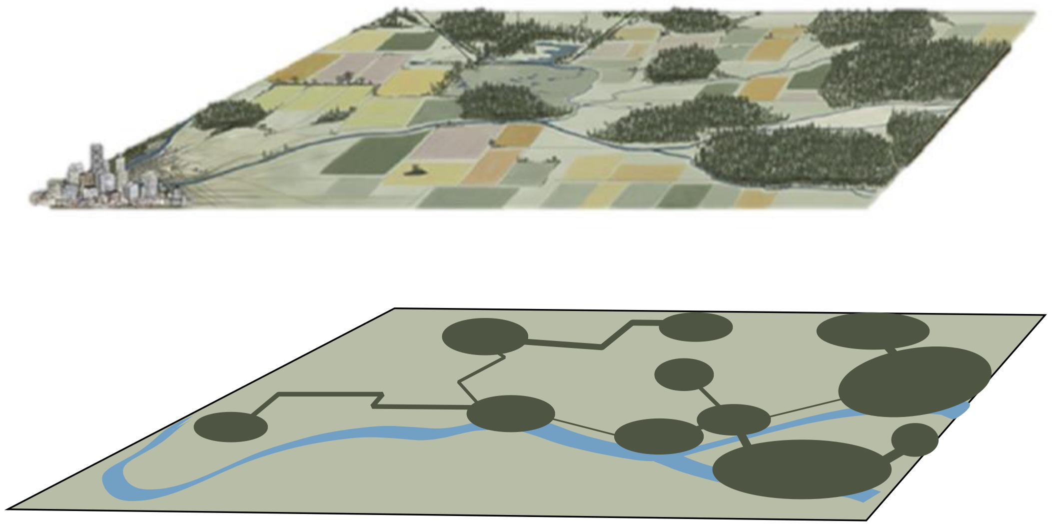
Caterina Mintrone

Network-based approaches in ecology

Networks are graphical representations of systems composed of multiple elements (**nodes**) variably connected through **links**

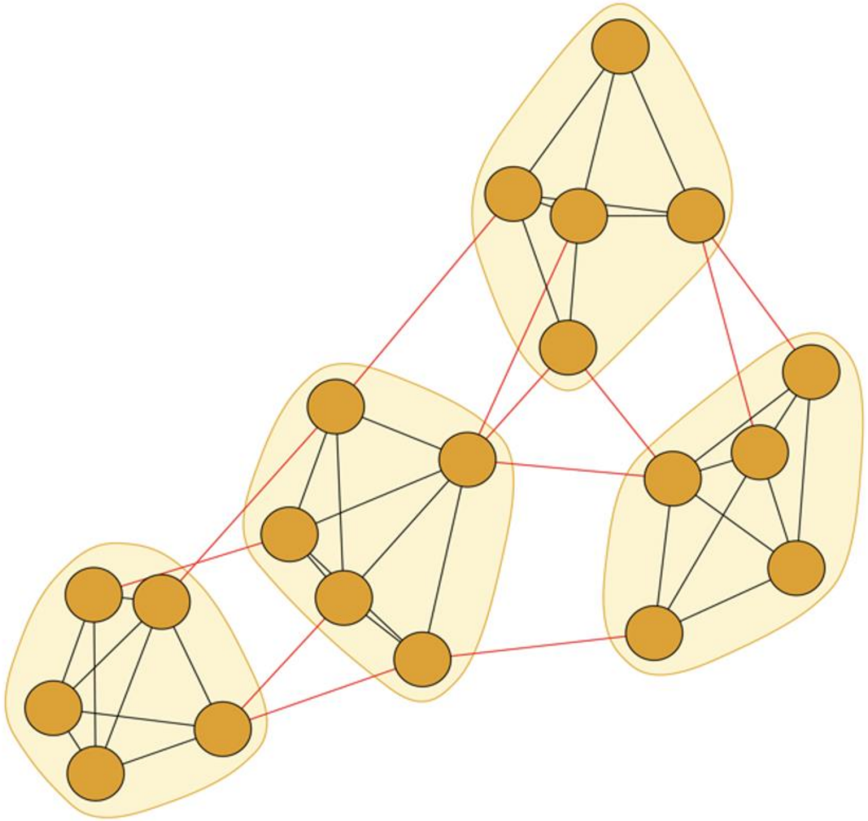




(Yoon et al. 2015, Gonzalez et al. 2017)

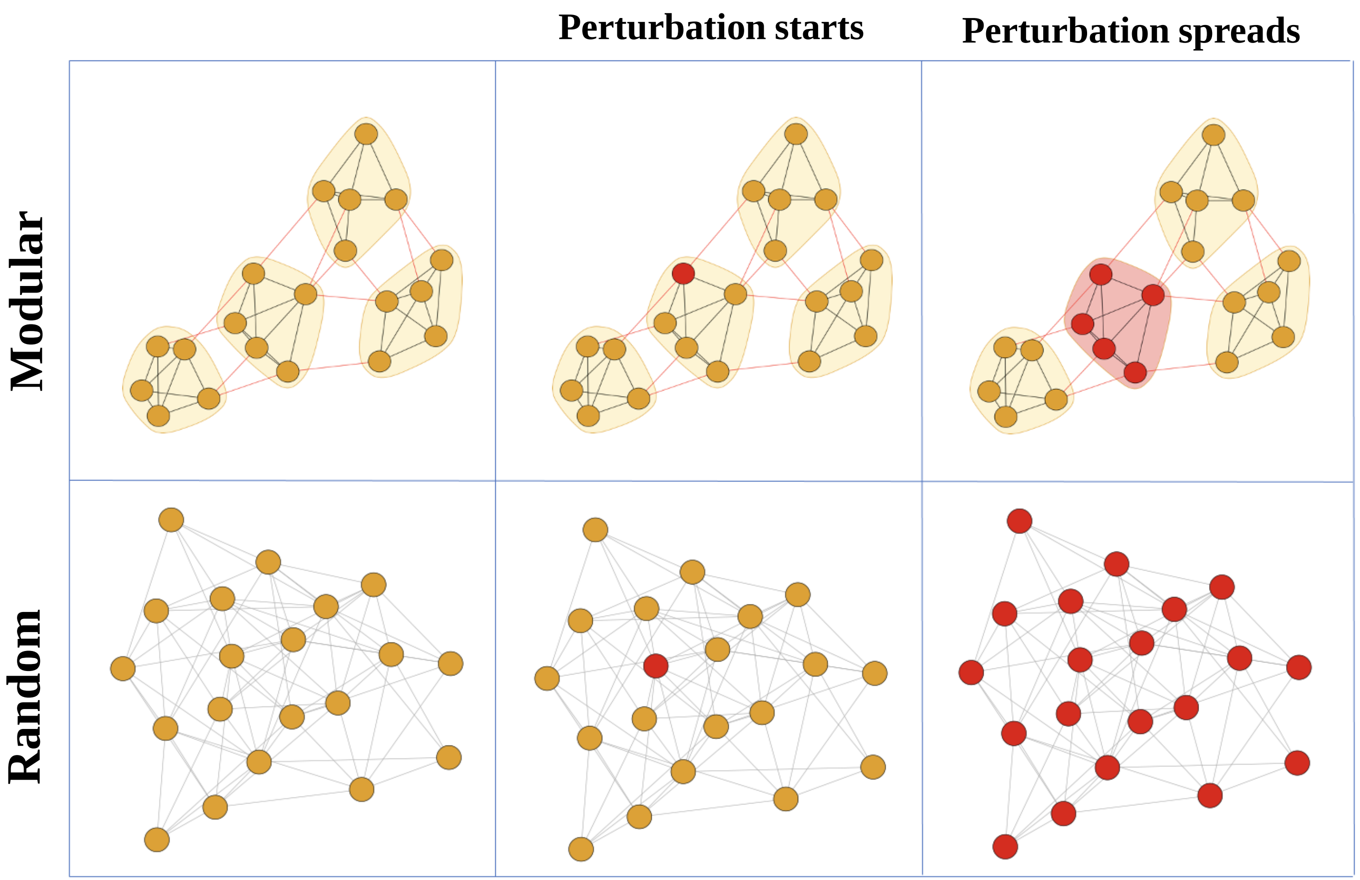
Modularity

Describes the tendency of nodes to cluster into modules



(Newman 2004, 2006, Newman and Girvan 2004)

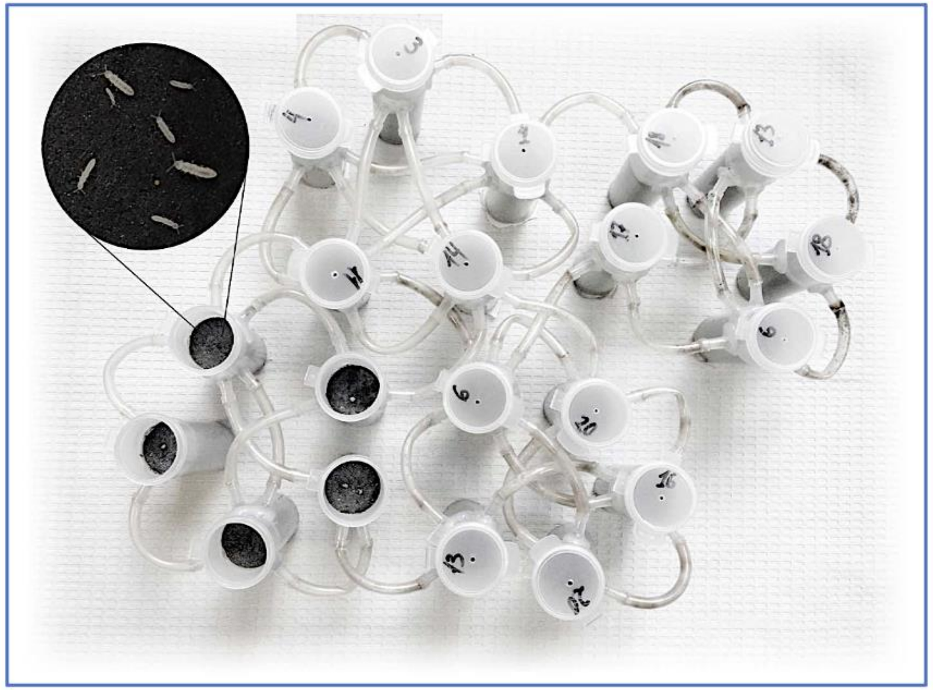
Modularity limits perturbation spread



ECOLOGICAL NETWORKS

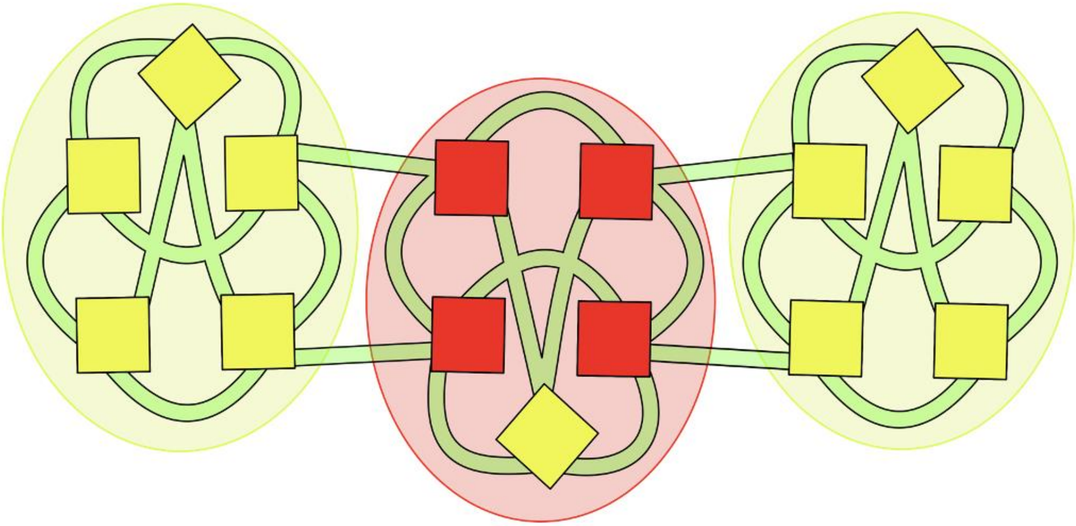
Effects of network modularity on the spread of perturbation impact in experimental metapopulations

Luis J. Gilarranz,[1,2] Bronwyn Rayfield,[3] Gustavo Liñán-Cembrano,[4] Jordi Bascompte,[1,2] Andrew Gonzalez[3]*



(Gilarranz et al. 2017, Kolchinsky et al. 2015, Alcalde Cuesta et al. 2016, Grilli et al. 2016)

Test of modularity



- Model system: rocky intertidal macroalgal assemblages dominated by *Ericaria amentacea*

- Can modular structure in spatial networks constraint the spread of algal turfs?

Cleared nodes → 0% *E. amentacea*

Uncleared nodes → 100% *E. amentacea*

Links → 50% *E. amentacea*

Modular networks consisting of:

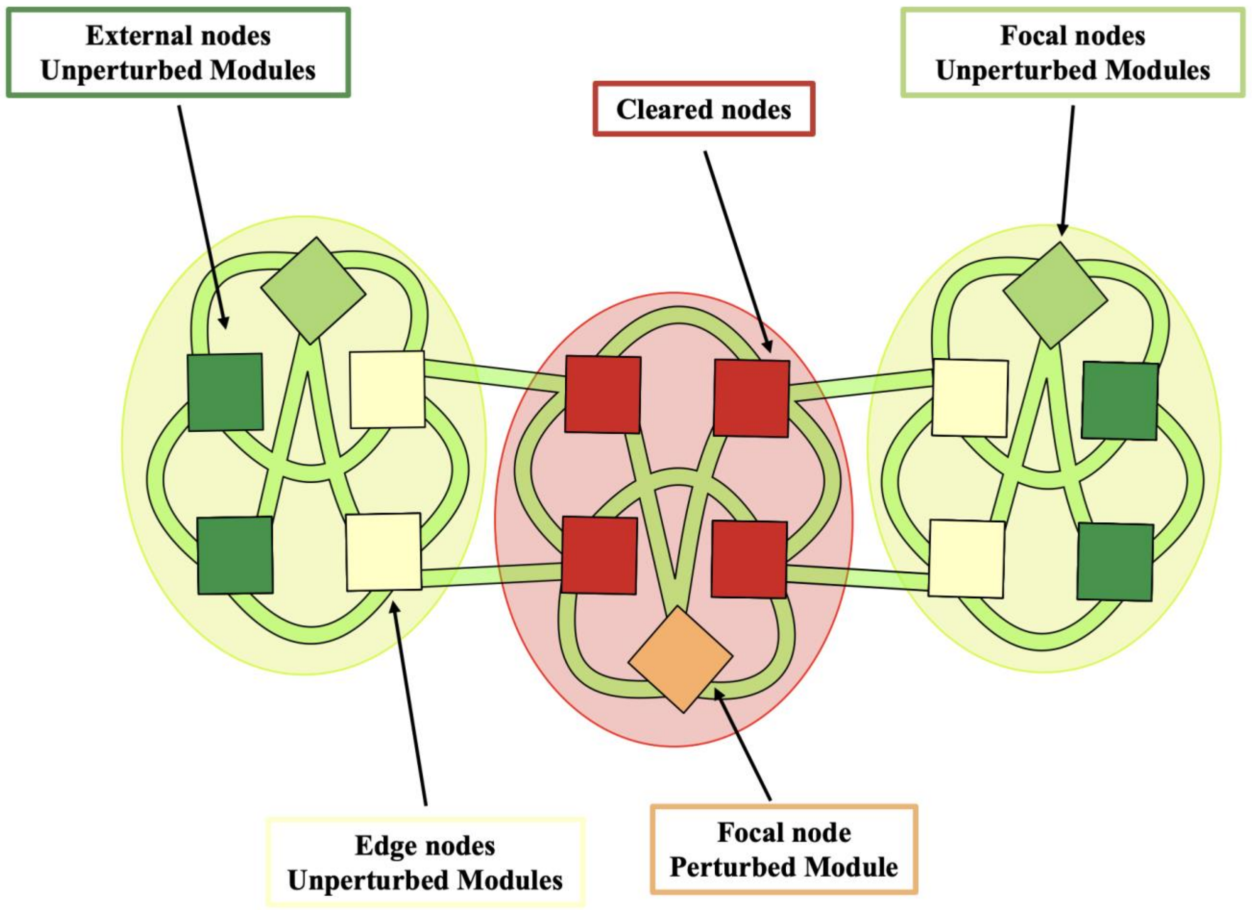
- **1 perturbed module**
- **2 unperturbed modules**

Hypotheses

H1. The **Focal node inside the Perturbed Module** was subject to a higher pressure from algal turfs than:

- **Edge nodes in Unperturbed Modules**
- **Focal nodes in Unperturbed Modules**

H2. The buffering effect of modularity on turf propagation was expected to increase with the distance from the Cleared nodes



Metacommunity model

Algal turf dynamics

$$\frac{dT_k}{dt} = f(T_k) + p(T_k)$$

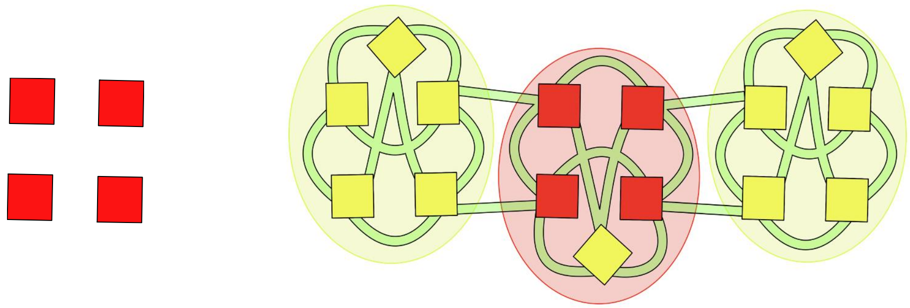
Local dynamics — **Vegetative propagation**

E. amentacea dynamics

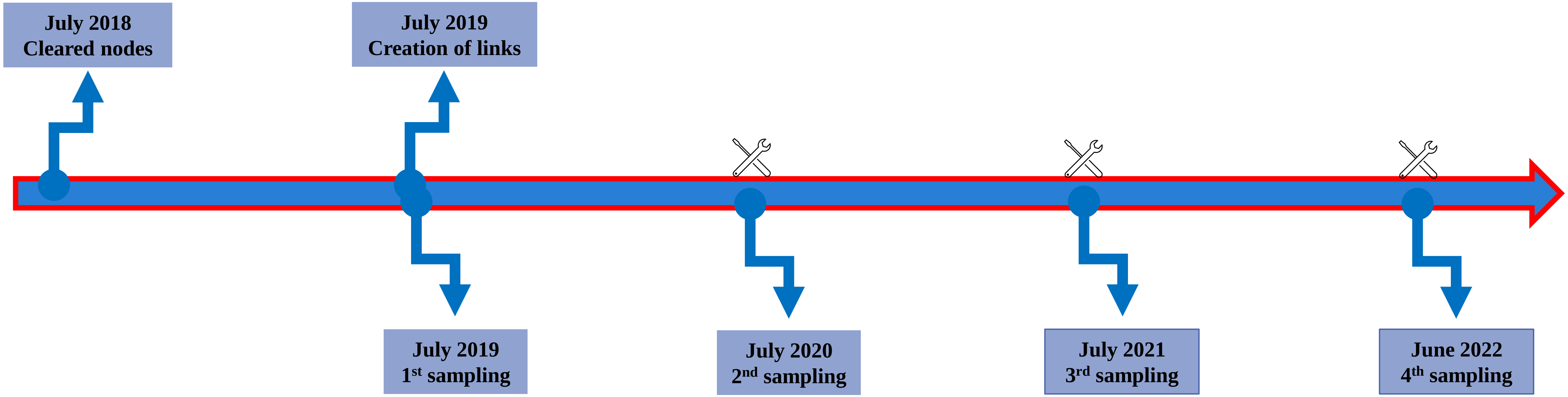
$$\frac{dC_k}{dt} = f(C_k)$$

Local dynamics	=	Growth term	+	Settlement of propagules	+	Competition term

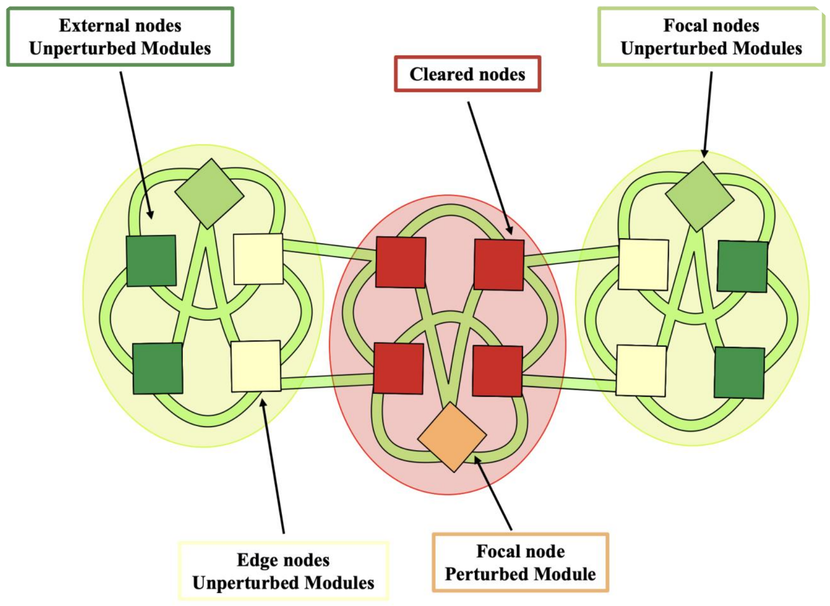
Experimental design & sampling

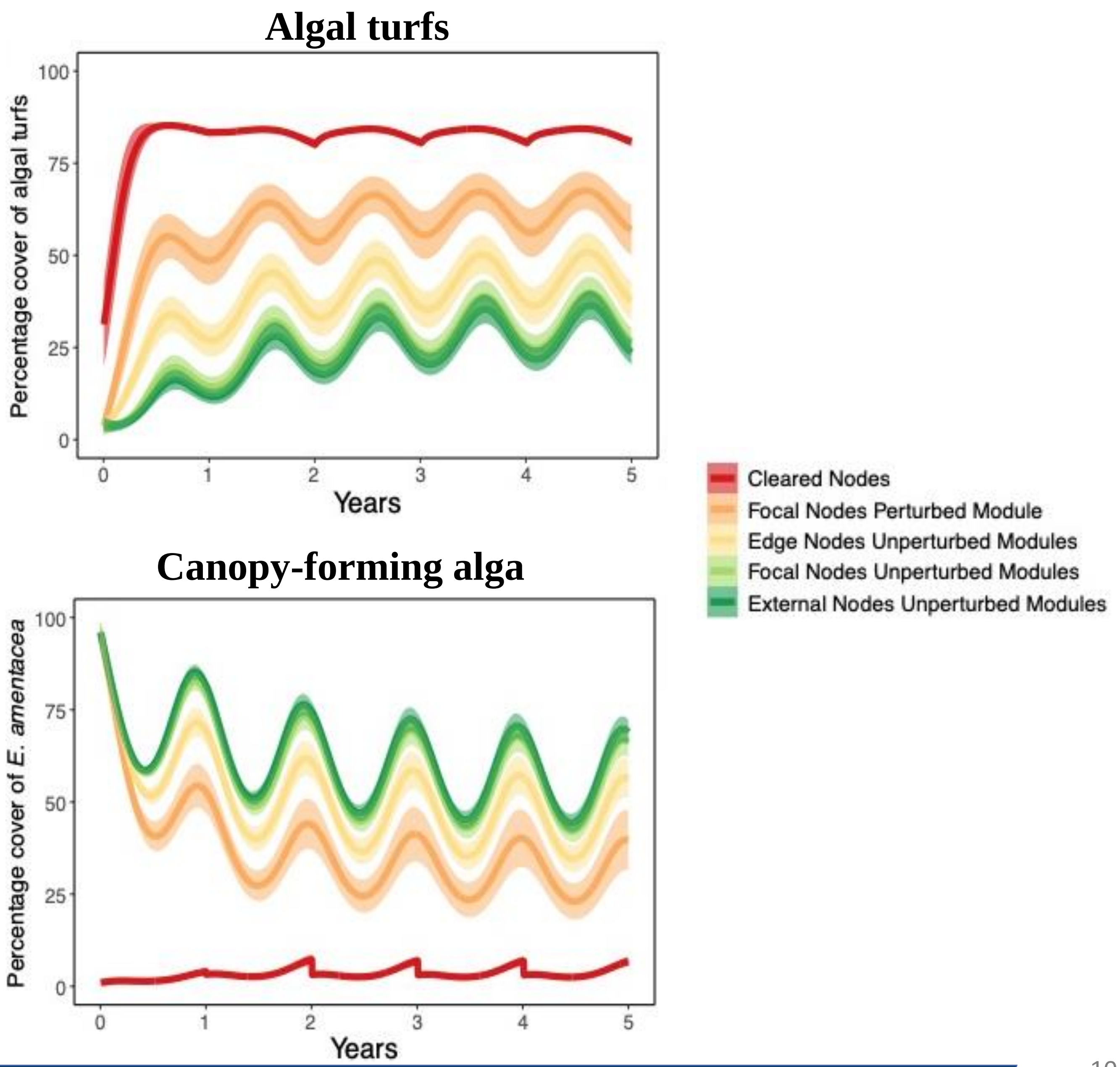


- Cleared nodes → 0% *E. amentacea* (30 cm x 30 cm)
- Uncleared nodes → 100% *E. amentacea* (30 cm x 30 cm)
- Links → 50% *E. amentacea* (120 cm x 20 cm)



Model simulations



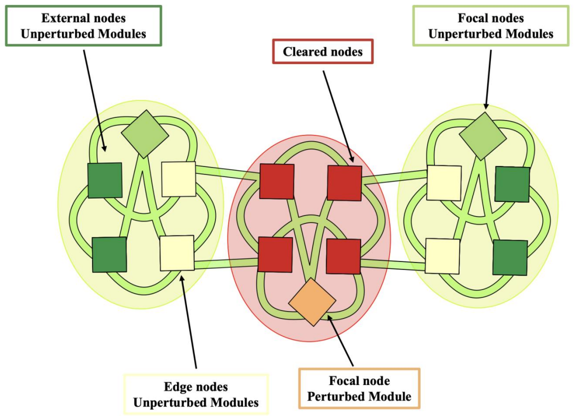


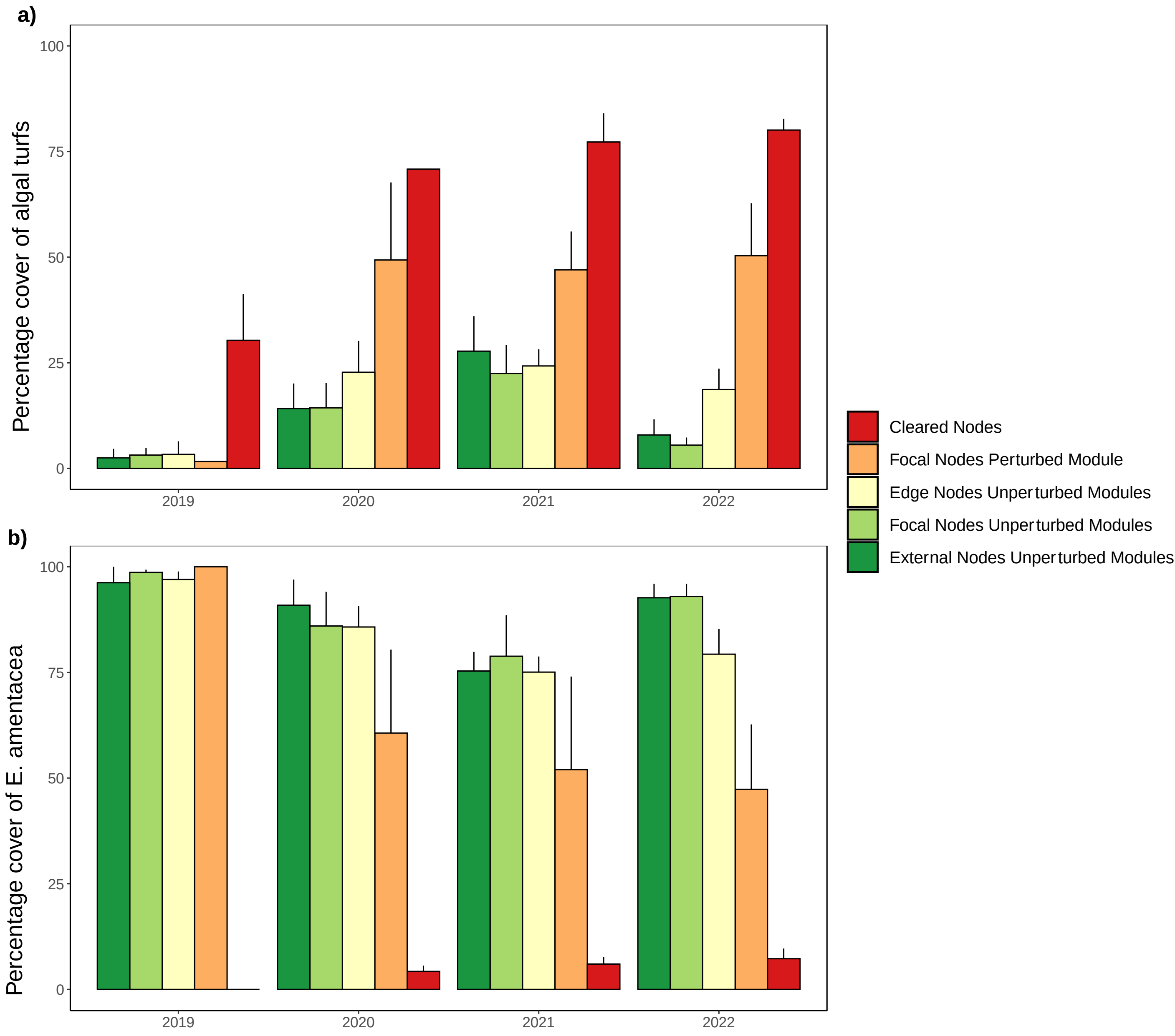
Experimental results

- Algal turfs successfully colonized cleared nodes

- F-P nodes displayed a larger cover of algal turfs than all the other nodes in the unperturbed modules

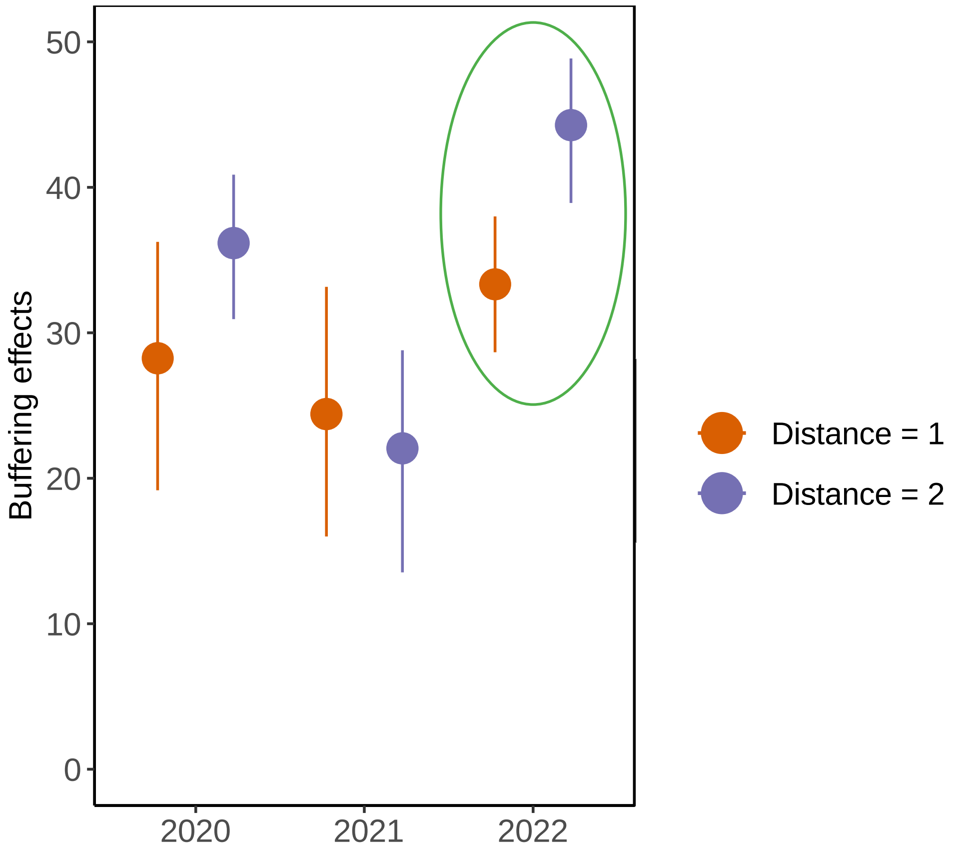
- The increase of algal turfs within uncleared nodes was associated with an opposite trend in the abundance of *E. amentacea*





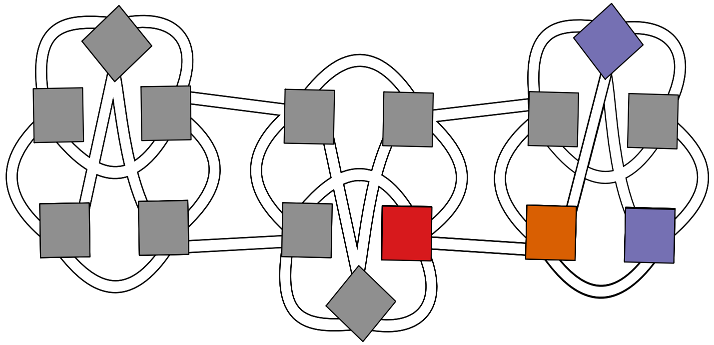
Buffering effect

Difference between algal turf increase in the F-P node and in nodes outside the perturbed module



- The spread of algal turfs was significantly buffered throughout the whole experiment at both distances

- Significant difference in buffering effects was observed between topological distances in 2022



Concluding remarks

- Experimental results partially supported the second hypothesis (that the buffering effect would increase with distance from cleared nodes)
- Model simulations and experimental results showed that modularity limited the spread of algal turfs within the perturbed module (H1)
- The buffering effect of modularity can operate under real, but variable environmental conditions
- Network-based approaches can be used to predict disturbance spread within ecological spatial networks and to guide the identification of priority areas for conservation

Thank you

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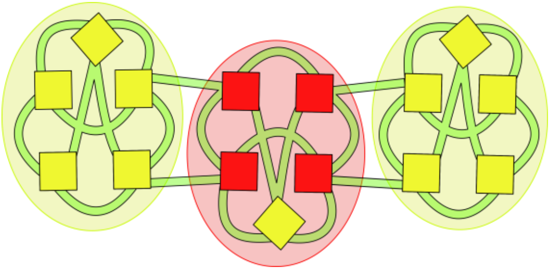
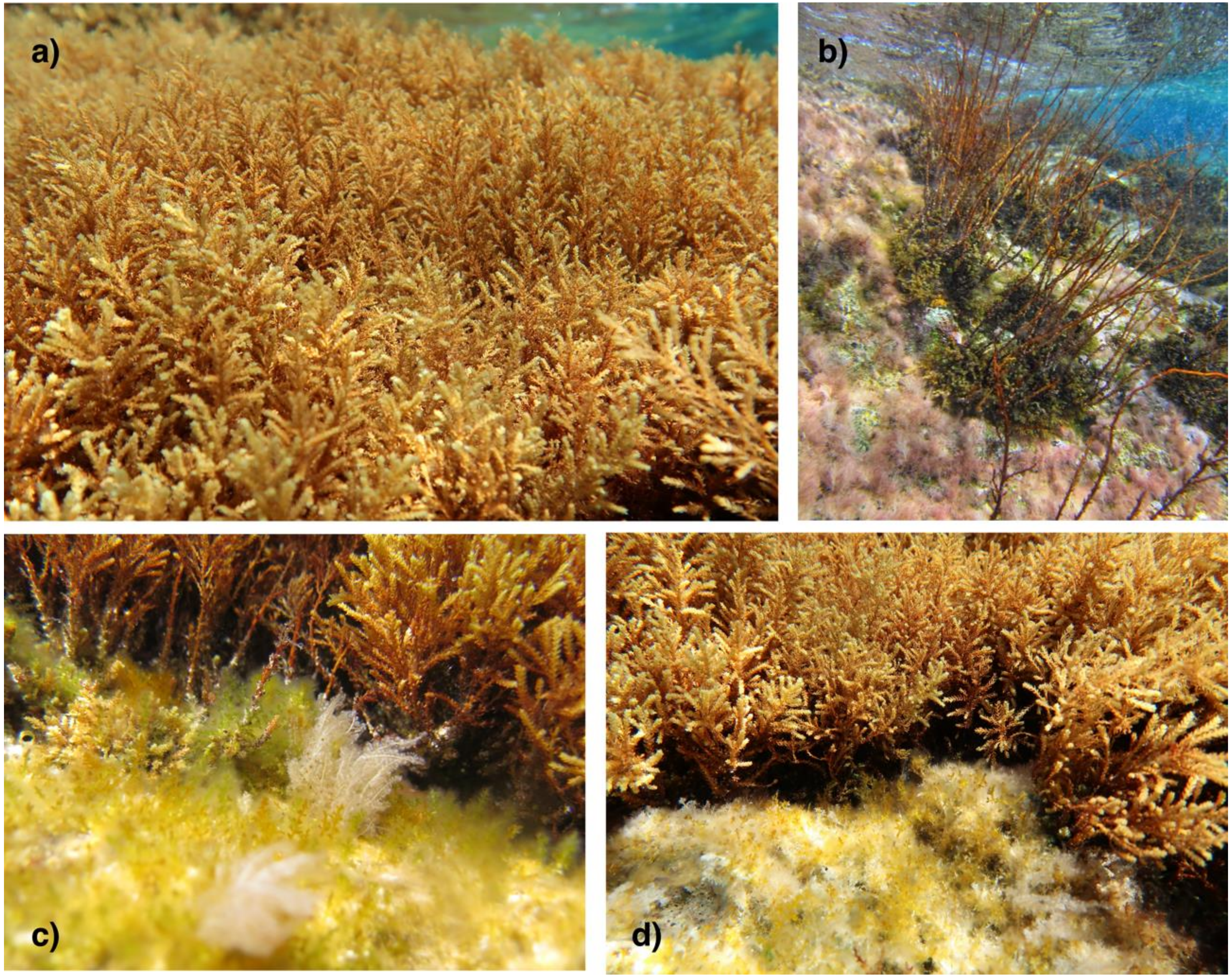
Metacommunity model





Metacommunity model

Algal turf dynamics

$$\frac{dT_k}{dt} = f(T_k) + p(T_k)$$

Local dynamics

$$f(T_k) = r_T T_k \left(1 - \frac{T_k}{K_T}\right) + w_T - a_T T_k C_k$$

Growth term

Competition term

Settlement of propagules from the water column

Vegetative propagation

$$p(T_k) = \sum_l m \cdot (T_l - T_k)$$

Rate of vegetative propagation

Metacommunity model

E. amentacea dynamics

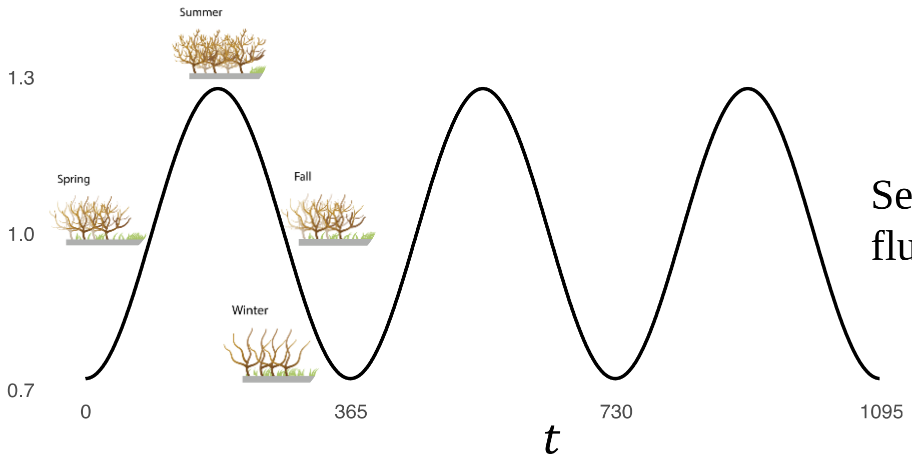
$$f(C_k) = \frac{dC_k}{dt} = r_C C_k \sigma_t \left(1 - \frac{C_k}{K_C \sigma_t}\right) + \eta_t w_C - a_C C_k T_k$$

Growth term

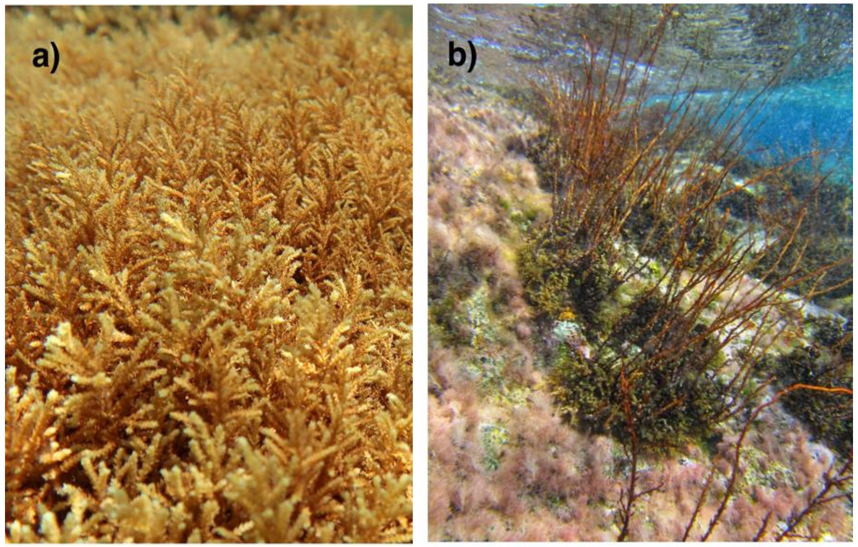
Competition term

Release of zygotes from adults during summer

$$\sigma_t = 1 - \alpha \cos\left(\frac{2\pi t}{365}\right)$$



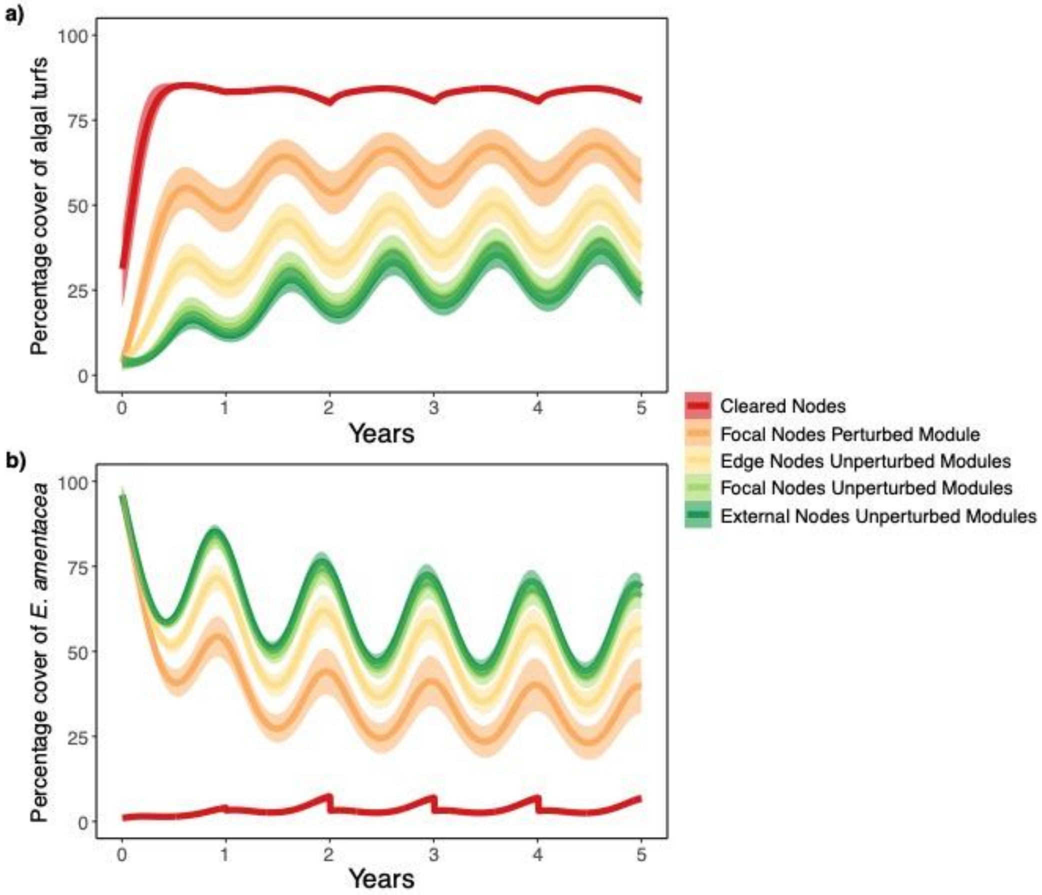
Seasonal fluctuations

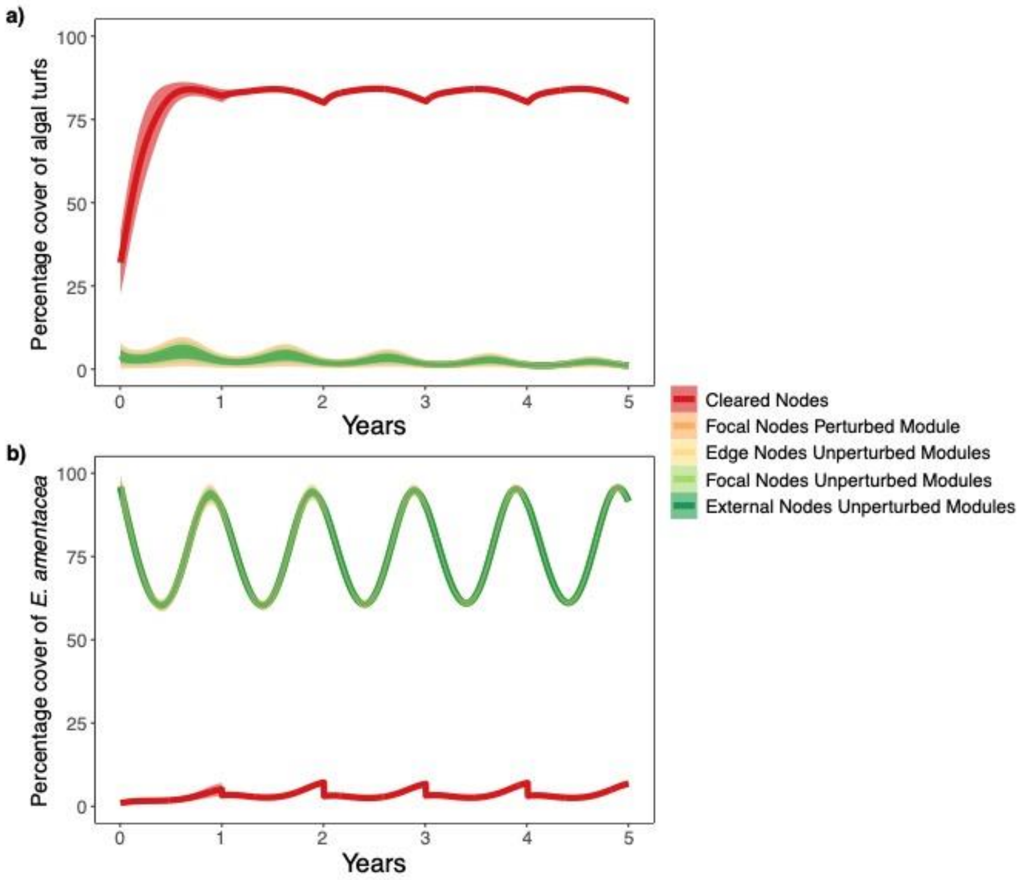


Model simulations

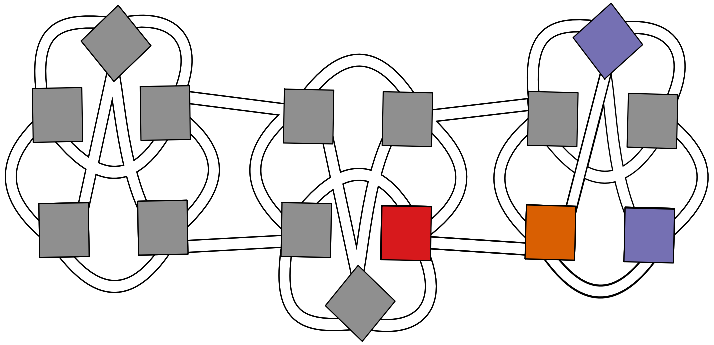
Model

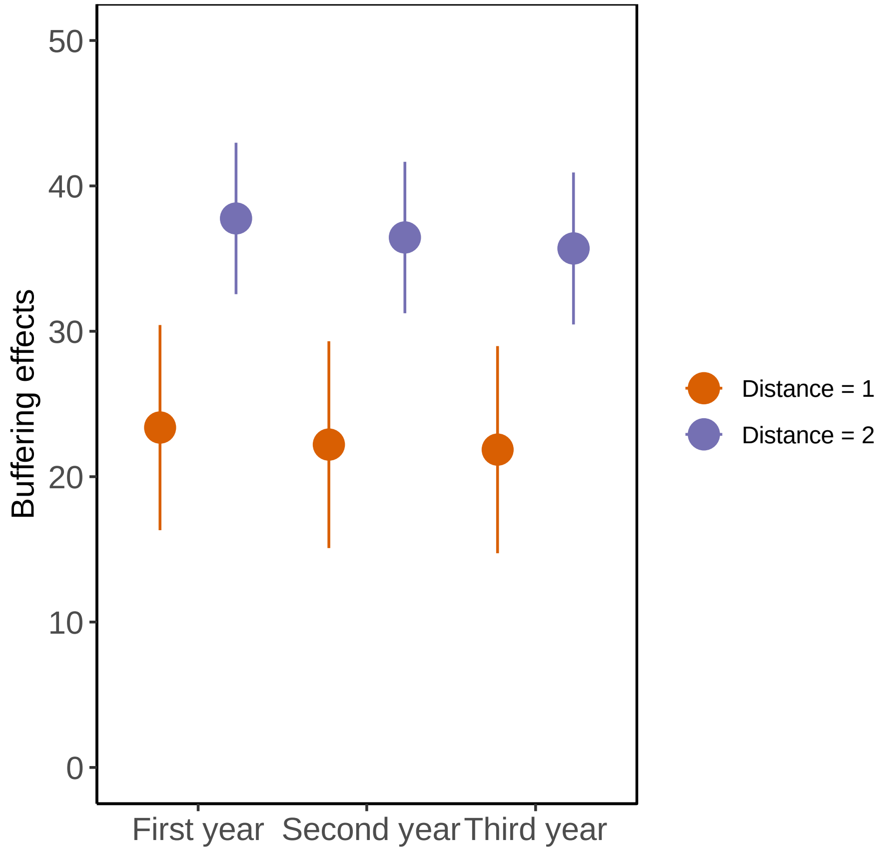
Null model





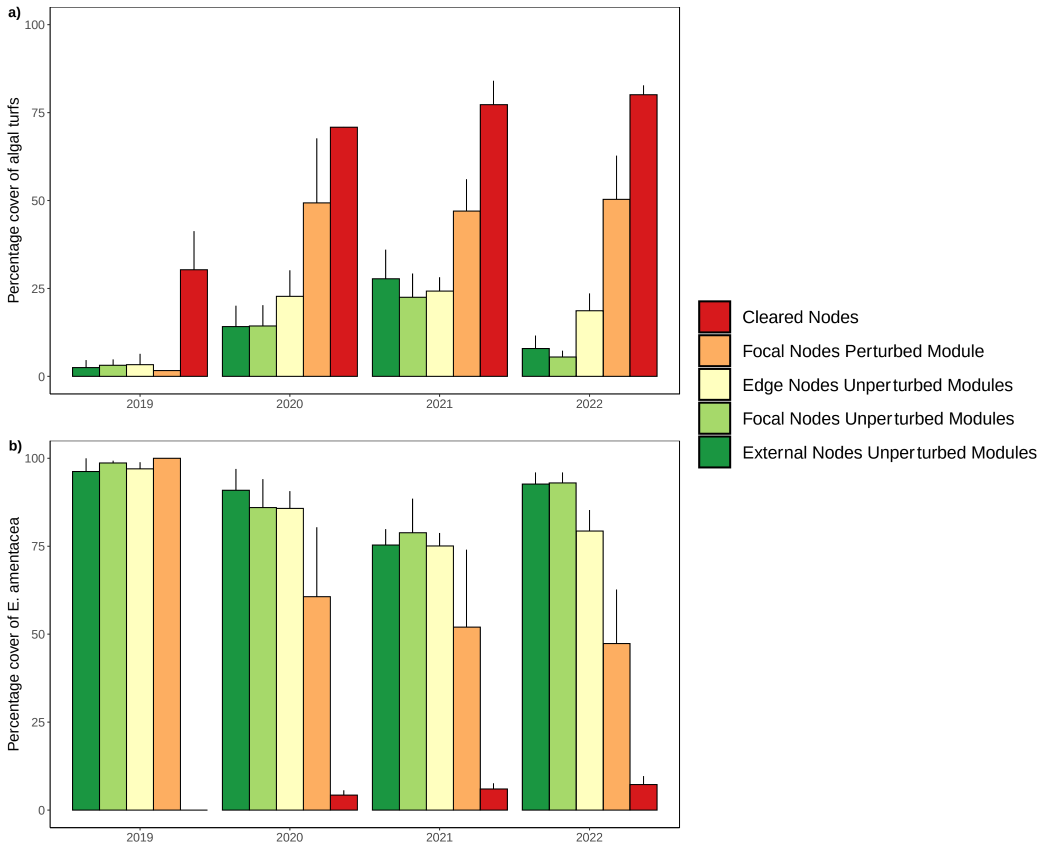
Model simulations





Buffering effect: difference between algal turfs increase in the F-P node and in nodes outside the perturbed module

Experimental results



Results of Linear Mixed Effect Models (LMEM) of algal turf abundance using focal nodes in the perturbed modules (F-P) as reference (Intercept).

Fixed effects	Mean at the last year		Temporal trend	
	Coefficient (SE)		Coefficient (SE)	
(Intercept)	γ_{FP}	58.63 (7.58) ***	$\gamma_{FP\ x\ Year}$	14.36 (3.75) ***
F-U	γ_{FU}	-44.98 (8.72) ***	$\gamma_{FU\ x\ Year}$	-12.85 (4.37) **
E-U	γ_{EU}	-34.25 (7.96) ***	$\gamma_{EU\ x\ Year}$	-9.61 (3.99) *
Ext-U	γ_{ExtU}	-41.07 (7.96) ***	$\gamma_{ExtU\ x\ Year}$	-11.38 (3.99) **

Results of Linear Mixed Effect Models (LMEM) of *E. amentacea* abundance using focal nodes in the perturbed modules (F-P) as reference (Intercept).

Fixed effects	Mean at the last year		Temporal trend	
	Coefficient (SE)		Coefficient (SE)	
(Intercept)	γ_{FP}	40.00 (8.74) ***	$\gamma_{FP\ x\ Year}$	-16.66 (4.18) ***
F-U	γ_{FU}	45.50 (10.64) ***	$\gamma_{FU\ x\ Year}$	14.25 (5.12) **
E-U	γ_{EU}	34.74 (9.71) ***	$\gamma_{EU\ x\ Year}$	10.30 (4.67) *
Ext-U	γ_{ExtU}	44.84 (9.71) ***	$\gamma_{ExtU\ x\ Year}$	14.03 (4.67) **

Buffering effect

Difference between algal turfs increase in the F-P node and in nodes outside the perturbed module