Physiological changes in crustose coralline algae alter competitive interactions in response to acidification

Sophie J. McCoy, Robert T. Paine, Catherine A. Pfister, and J.Timothy Wootton

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THE UNIVERSITY OF CHICAGO

Environment affects species distributions

- effects on physical resources

  & physiological needs of organisms

- mediation of species interactions

> community composition

macro scale

tropical intertidal

temperate intertidal

Environment affects species zonation

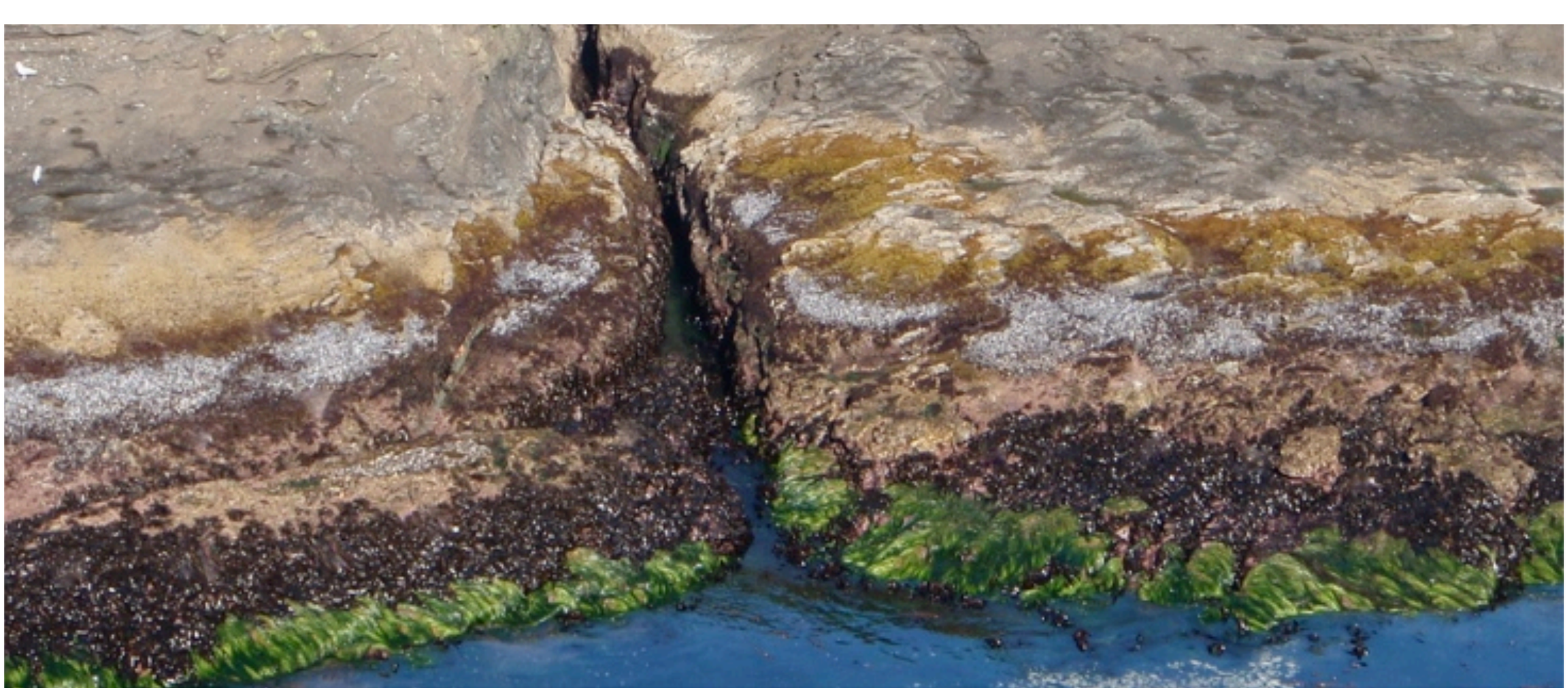
- effects on physical resources

  & physiological needs of organisms

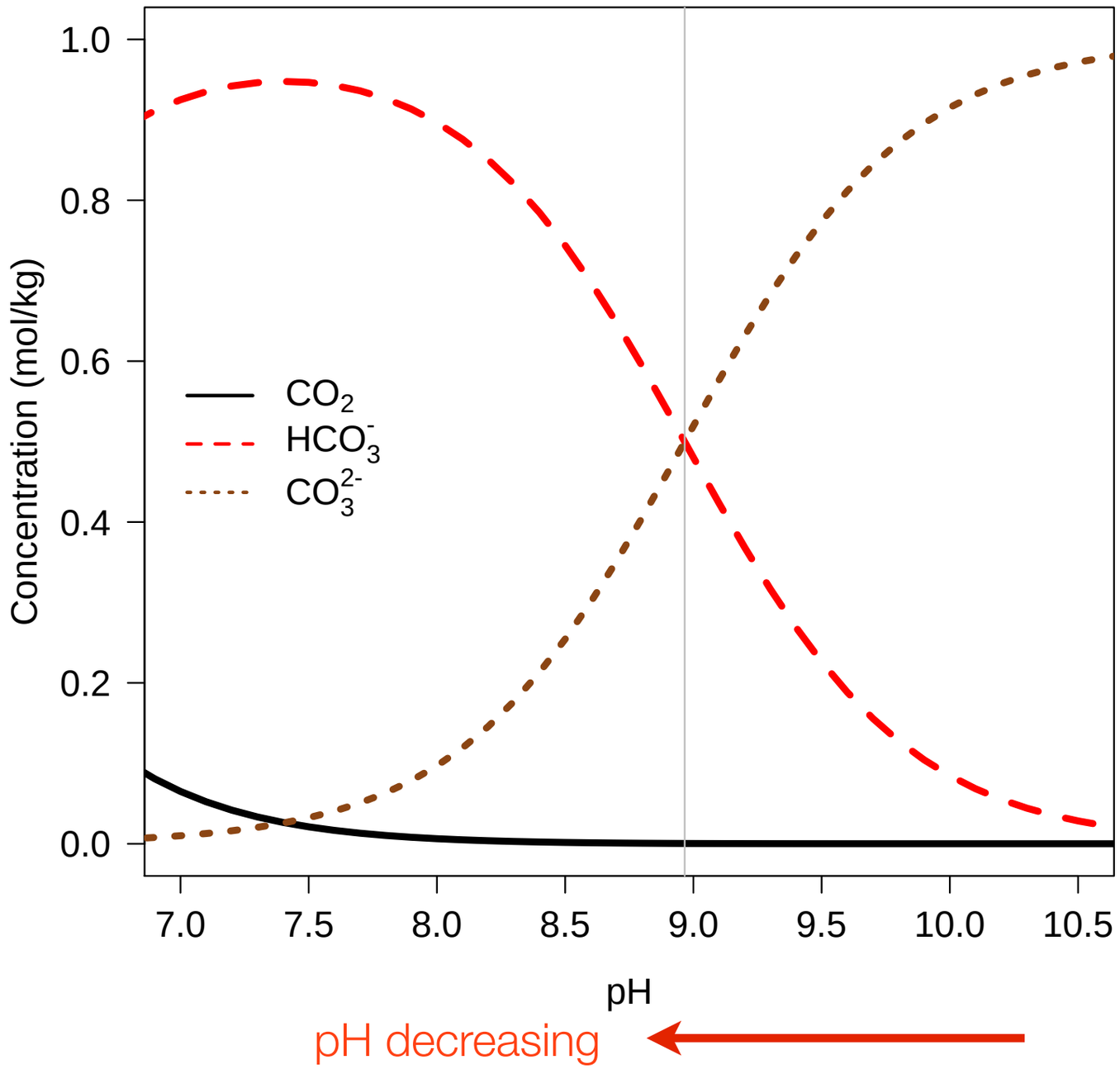
- mediation of species interactions

> community composition

local scale

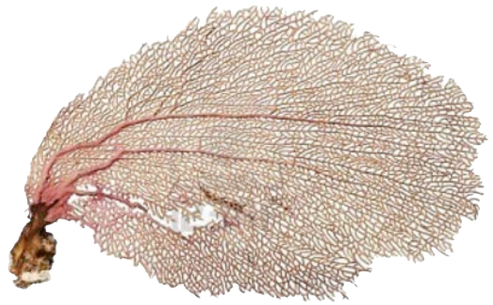


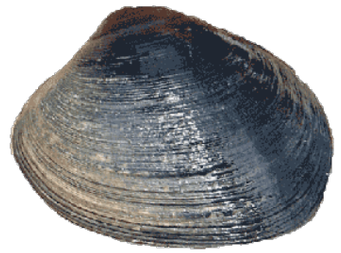
Ocean acidification as major environmental change



$CO_{2\,(aq)} + H_2O \leftrightarrow H_2CO_{3\,(aq)} \leftrightarrow H^+_{(aq)} + HCO_3^-{}_{(aq)} \leftrightarrow 2H^+_{(aq)} + CO_3^{2-}{}_{(aq)}$

Inorganic carbon nutrients

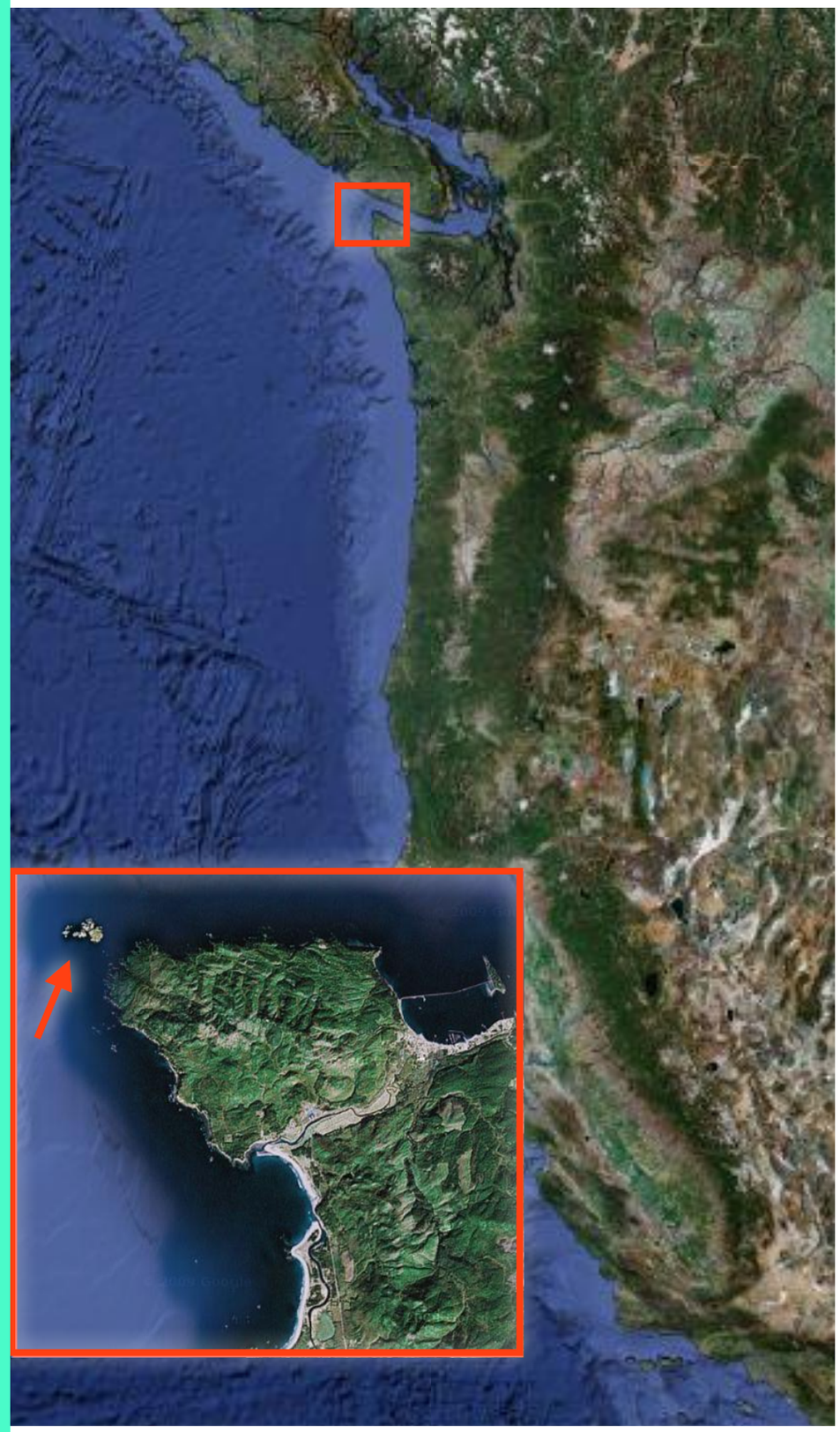


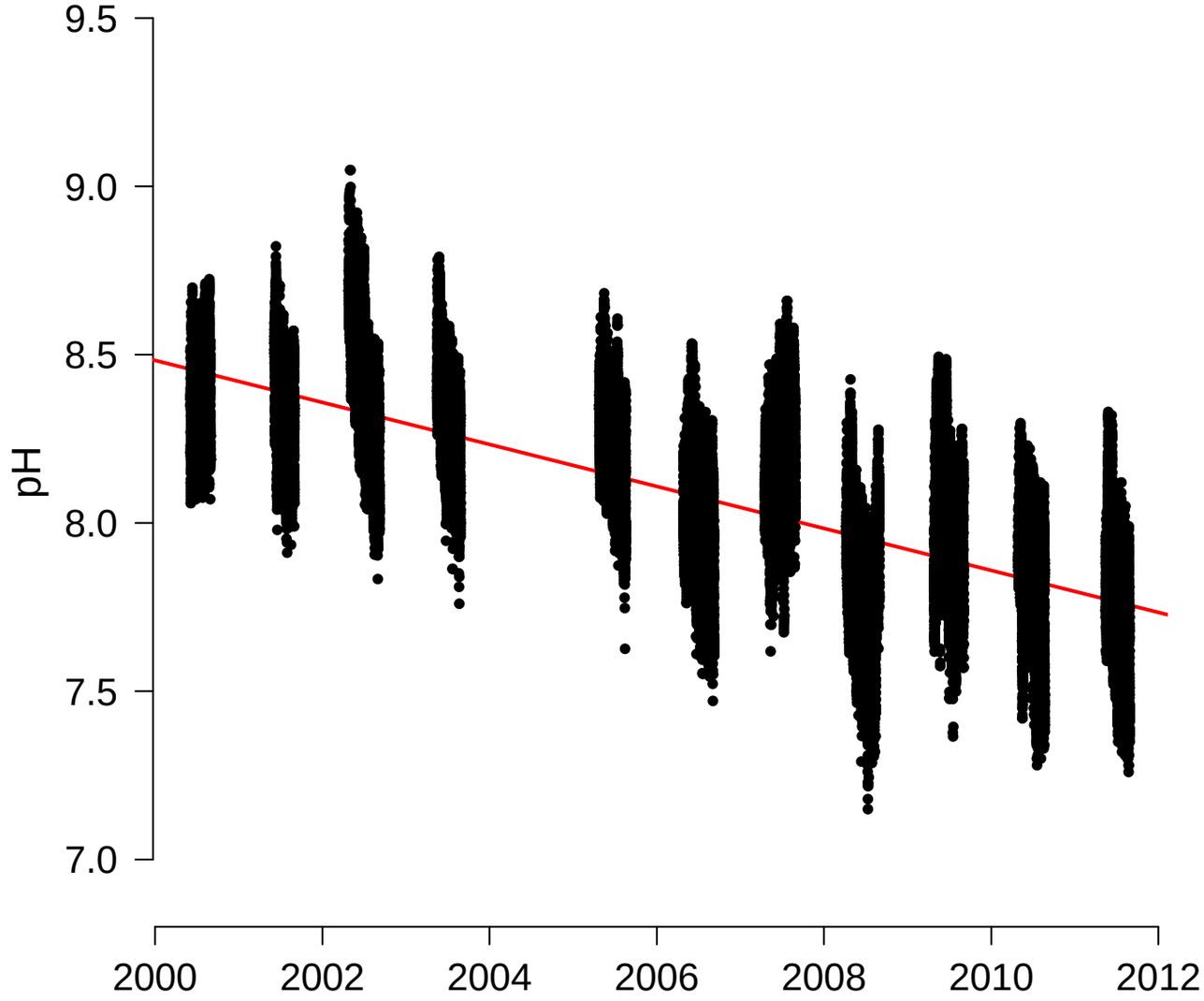


HCO_3^- = bicarbonate
used by most aquatic plants/algae for photosynthesis

CO_3^{2-} = carbonate
used to make skeletons and shells of many marine organisms (e.g., bivalves, corals, sponges)

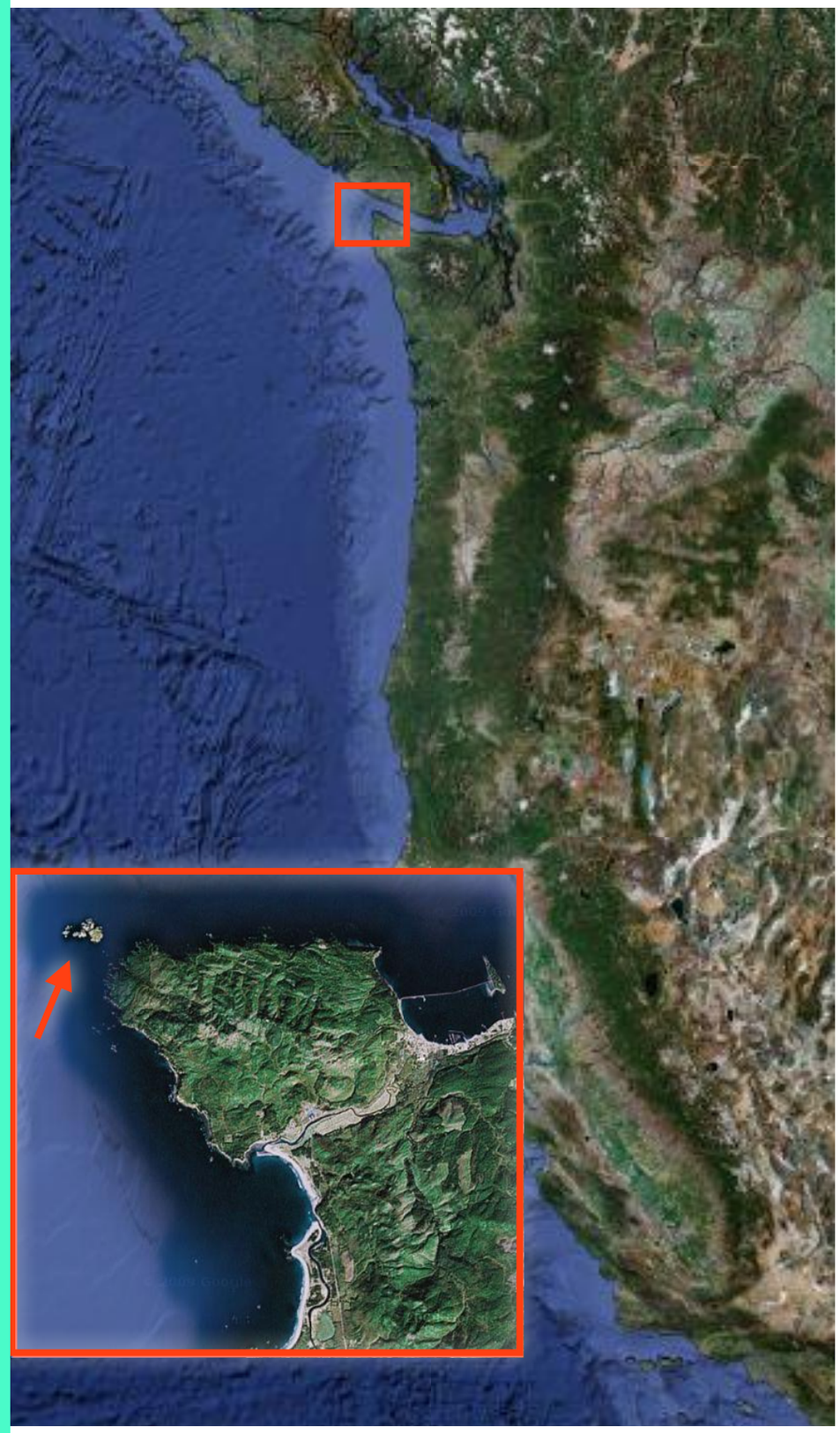
Context for change at Tatoosh Island, WA





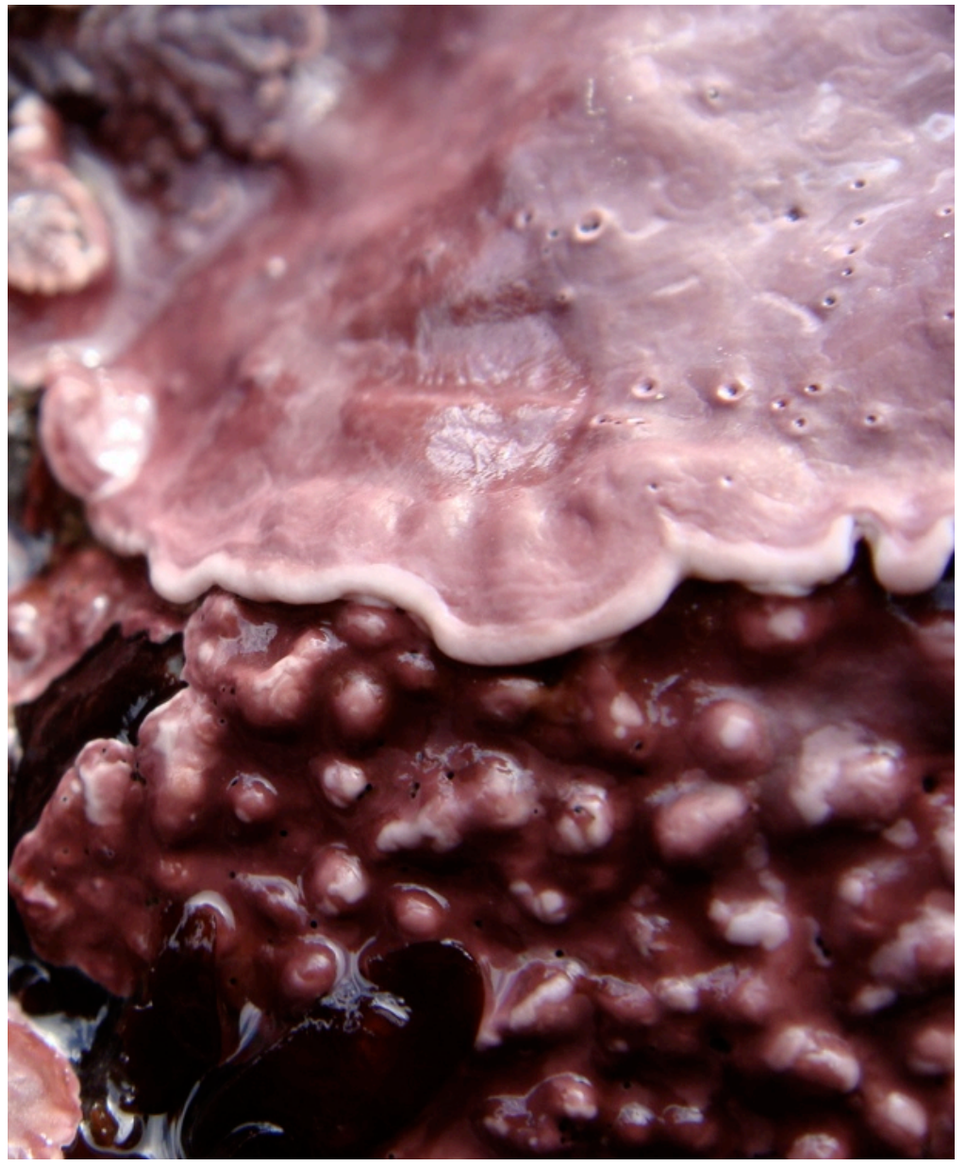
Wootton et al. 2008; Wootton et al. *in prep*

Ecological baseline at Tatoosh Island



Species dynamics, interactions, and natural history are well-studied

Ecological baseline at Tatoosh Island

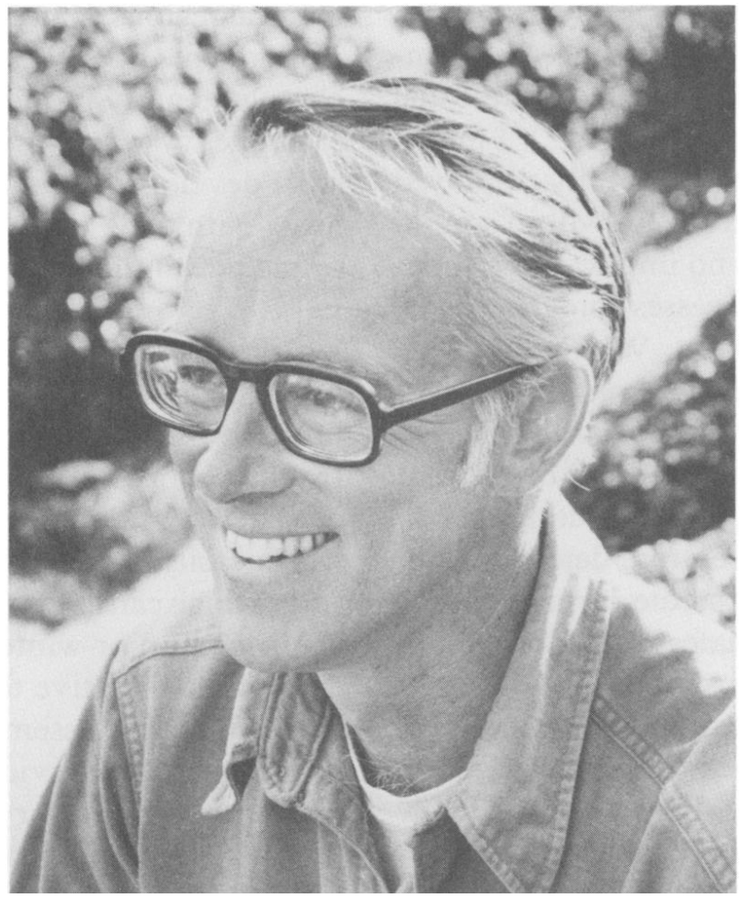


ECOLOGICAL DETERMINISM IN THE COMPETITION FOR SPACE

The Robert H. MacArthur Award Lecture
Presented on 9 August 1983
Grand Forks, North Dakota

by

R. T. PAINE
Department of Zoology, University of Washington, Seattle, Washington 98195 USA



Paine 1984

Coralline red algae

Articulated forms

Corallina

Bossiella

Maerls and Rhodoliths

Phymatolithon calcareum

Lithophyllum dentatum

Encrusting forms

Pseudolithophyllum muricatum

P. whidbeyense

Lithothamnion phymatodeum

HCO_3^- = bicarbonate
used by most aquatic plants/algae for photosynthesis

CO_3^{2-} = carbonate
used to make skeletons and shells of many marine organisms (e.g., bivalves, corals, sponges)

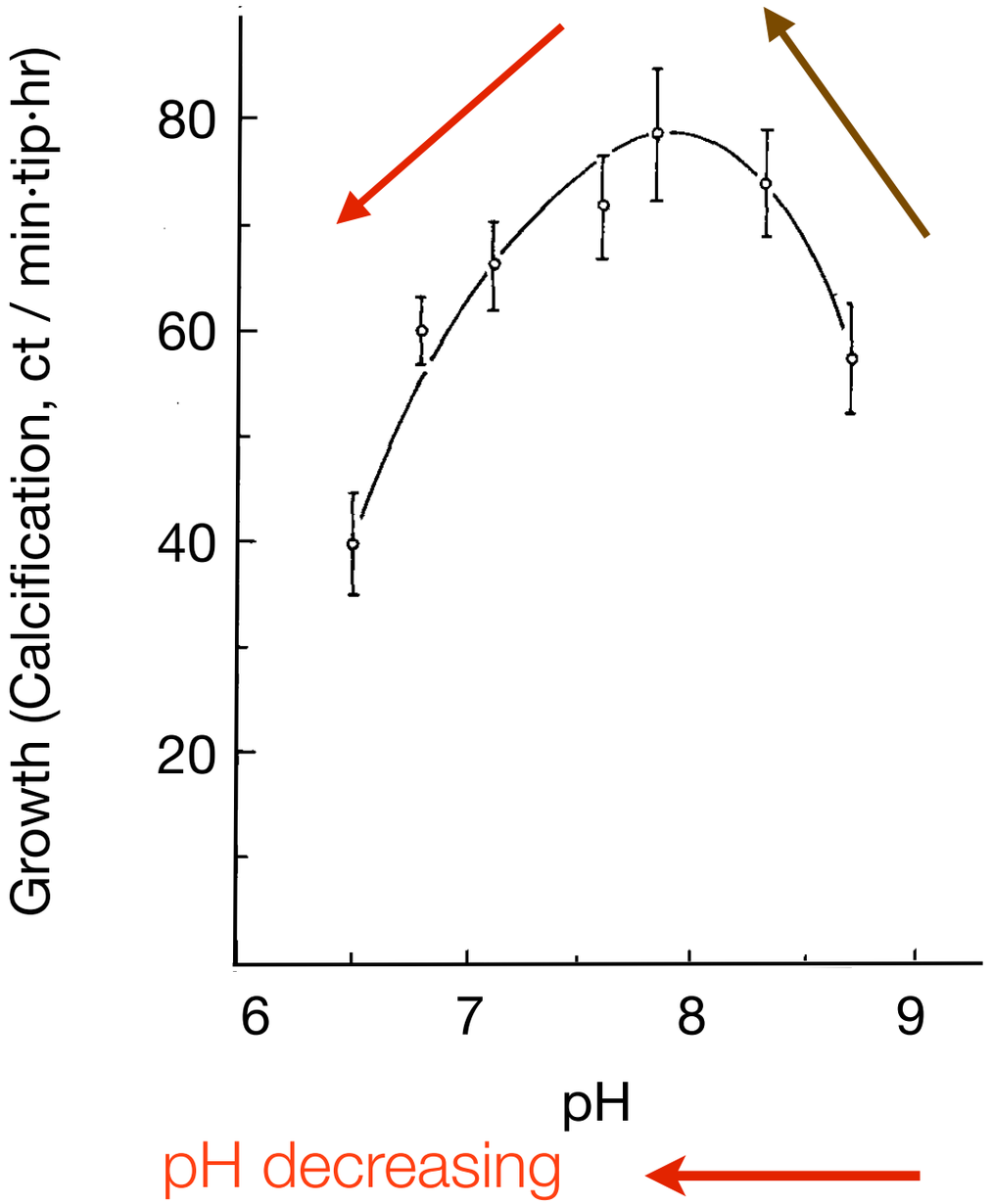
Coralline red algae (Rhodophyta, Corallinales)

- use bicarbonate (HCO_3^-) for photosynthesis
- use carbonate (CO_3^{2-}) to make skeleton

Bossiella orbigniana

decreasing $[CO_3^{2-}]$ becomes limiting

increased growth caused by increasing $[HCO_3^-]$



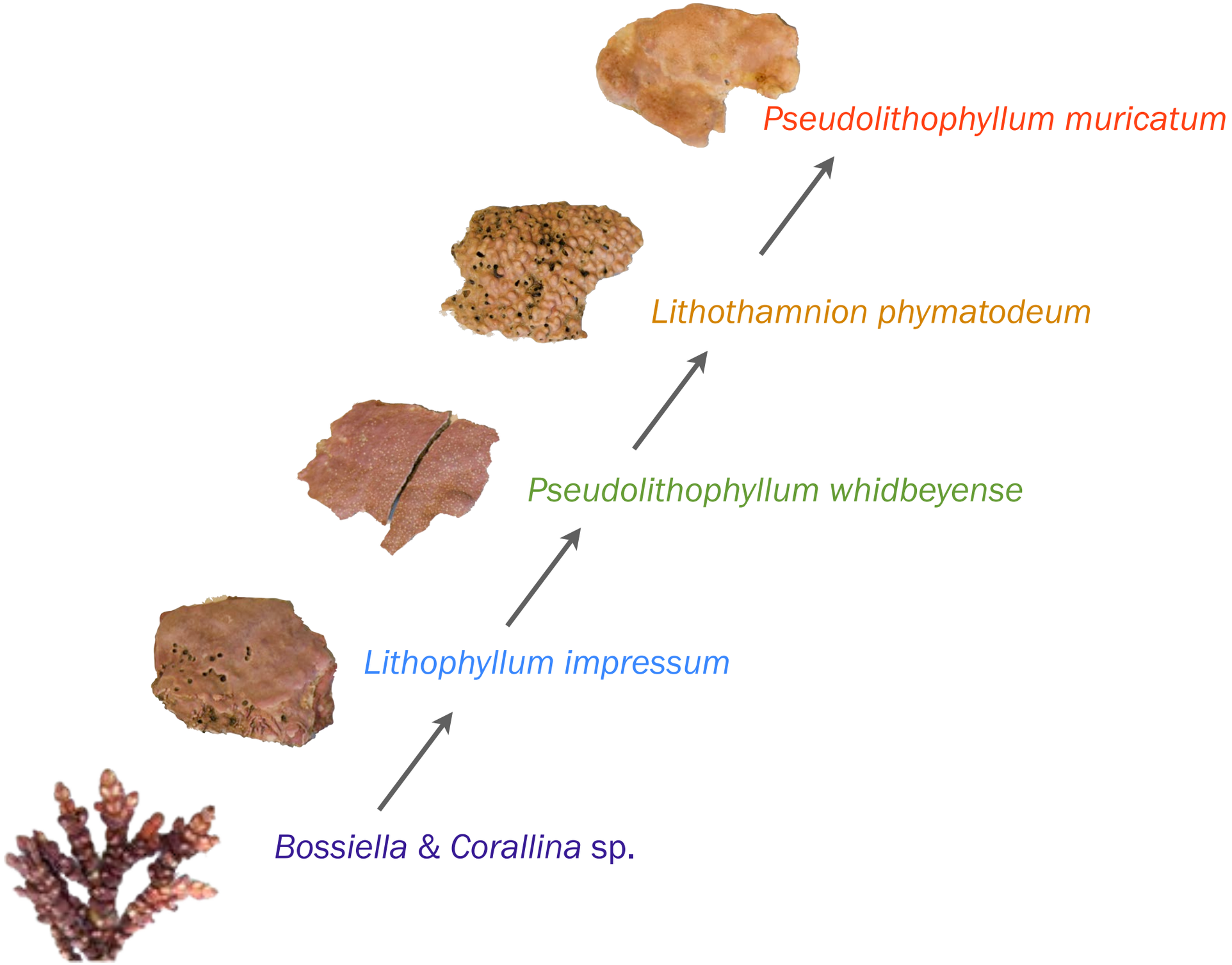
Smith and Roth 1979

Do we observe ecological responses within or among coralline algae to ocean acidification at Tatoosh Island?

Use **observed community response** to identify important physiological responses that mediate **ecological processes**

Interactions - Herbivore-mediated competitive hierarchy

grazers
absent

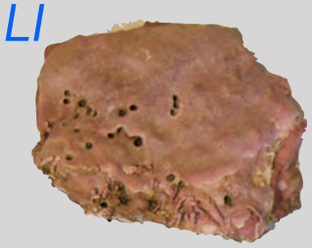
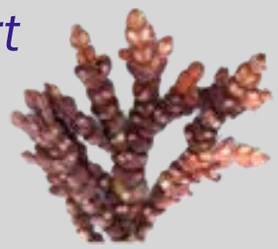


Paine 1984

Position on the hierarchy

Fast lateral growth

= able to grow faster under low grazing pressure

PM 	slow growth
LP 	med/fast growth
PW 	fast growth
LI 	med/slow growth
Art 	fast growth rapid colonizer

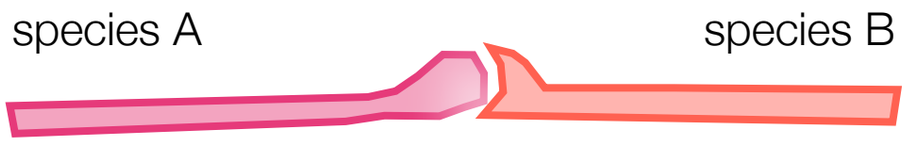
Position on the hierarchy

Thick, elevated edge

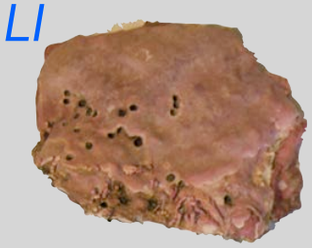
= delay overgrowth by another species

Scenario 1

Scenario 2



It is harder for species B to win in Scenario 2 because it must travel farther to achieve overgrowth

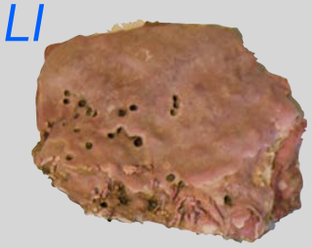
PM 	slow growth
LP 	med/fast growth
PW 	fast growth
LI 	med/slow growth
Art 	fast growth rapid colonizer

Growth strategy trade-offs

Fast lateral growth and thick edge

Overall thickness

= better equipped to resist grazing damage

PM 	very thick thallus elevated edge	slow growth
LP 	med thallus thin edge protuberances	med/fast growth
PW 	thin thallus thin edge	fast growth
LI 	med/thick thallus med edge	med/slow growth
Art 	very thin thallus articulated segments	fast growth rapid colonizer

Grazers

crusts must be thickly calcified to withstand heavy grazing

Katharina tunicata

Tonicella lokii

Lottia spp.

Strongylocentrotus purpuratus

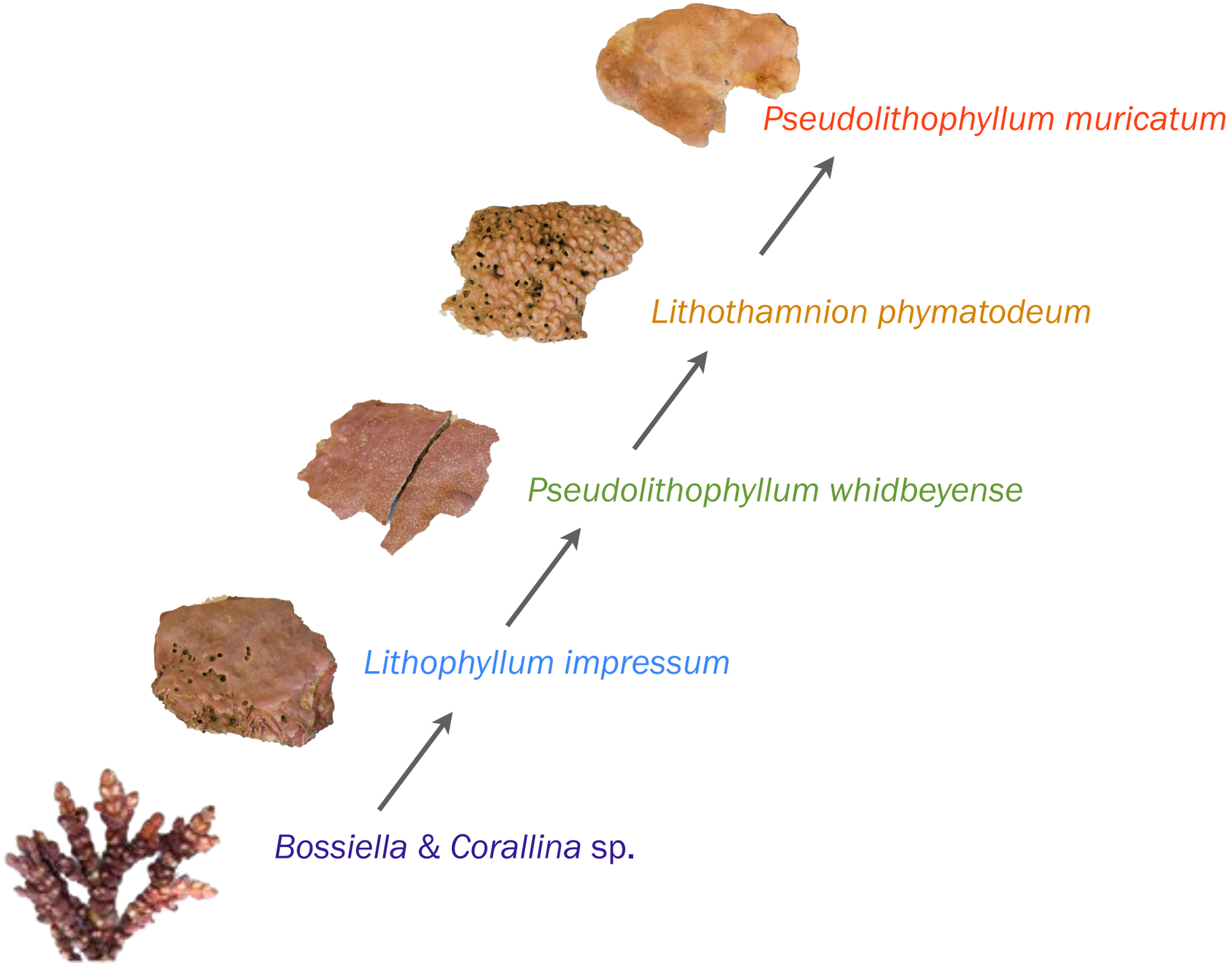
Acmea mitra

Mopalia ciliata

Johnson and Mann 1986; Paine 1984; Steneck and Paine 1986; Steneck, Hacker and Dethier 1991

Interactions - Herbivore-mediated competitive hierarchy

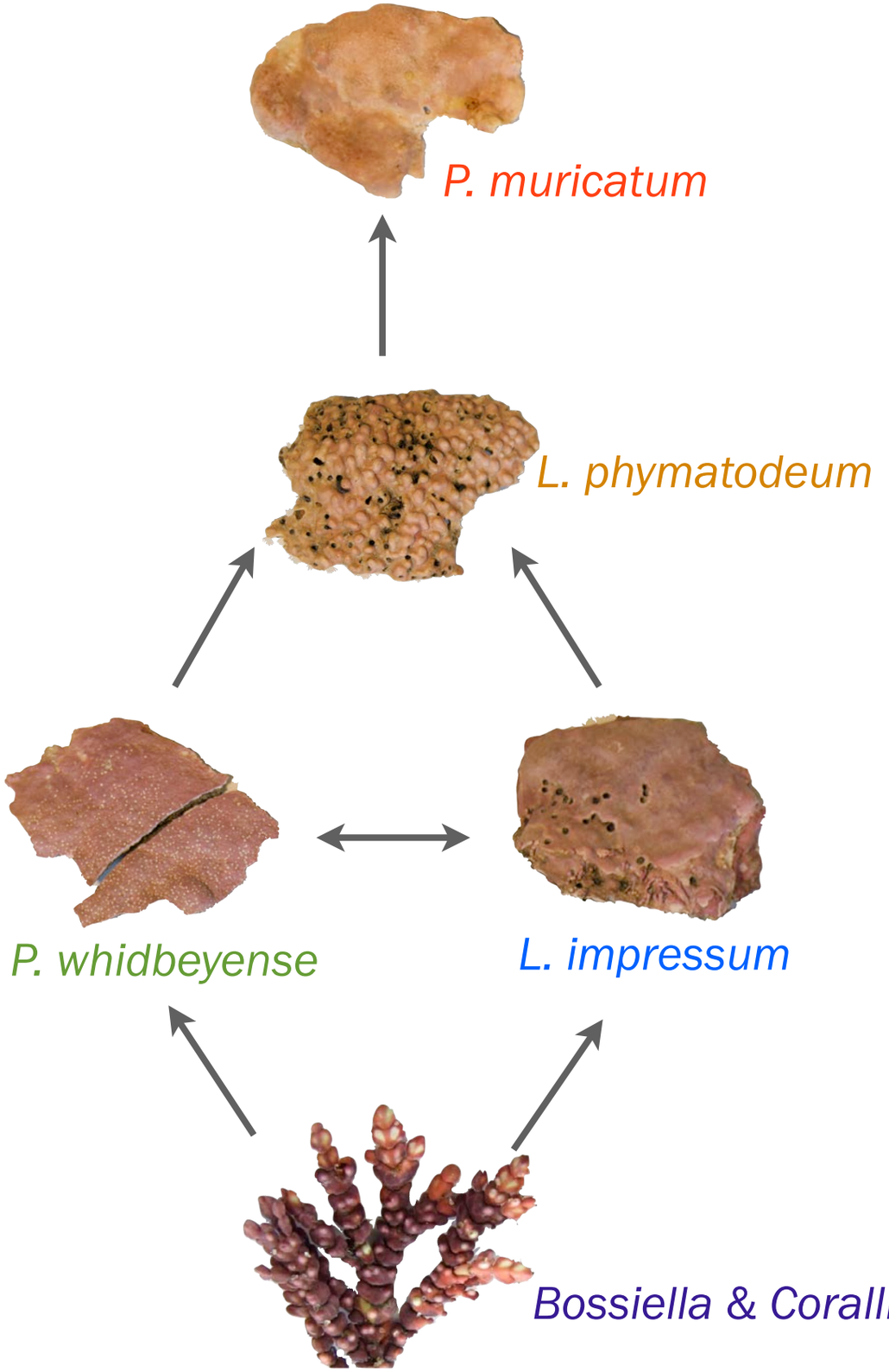
grazers
absent



Paine 1984

Interactions - Herbivore-mediated competitive hierarchy

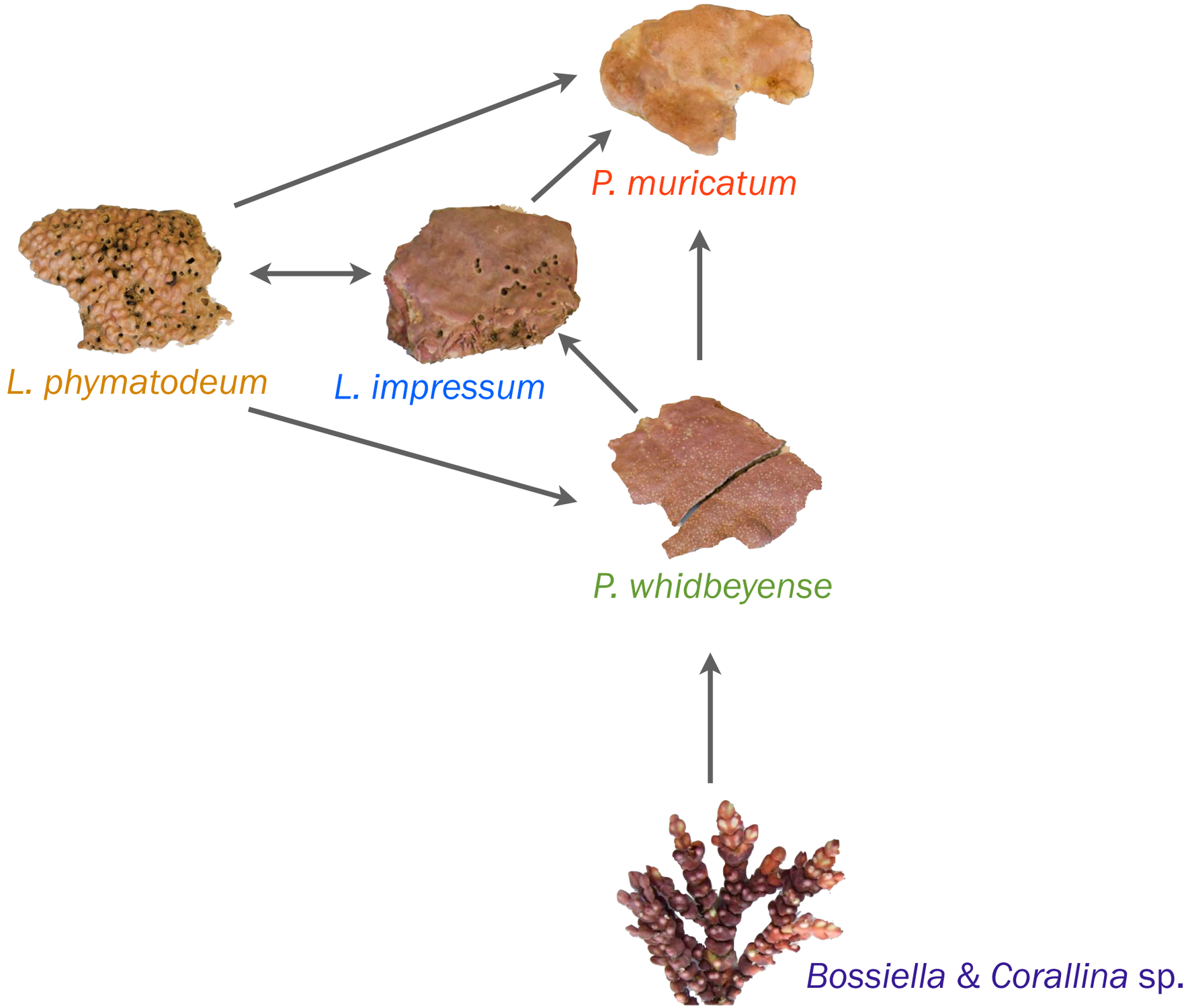
low grazer
abundance



Paine 1984

Interactions - Herbivore-mediated competitive hierarchy

high grazer abundance

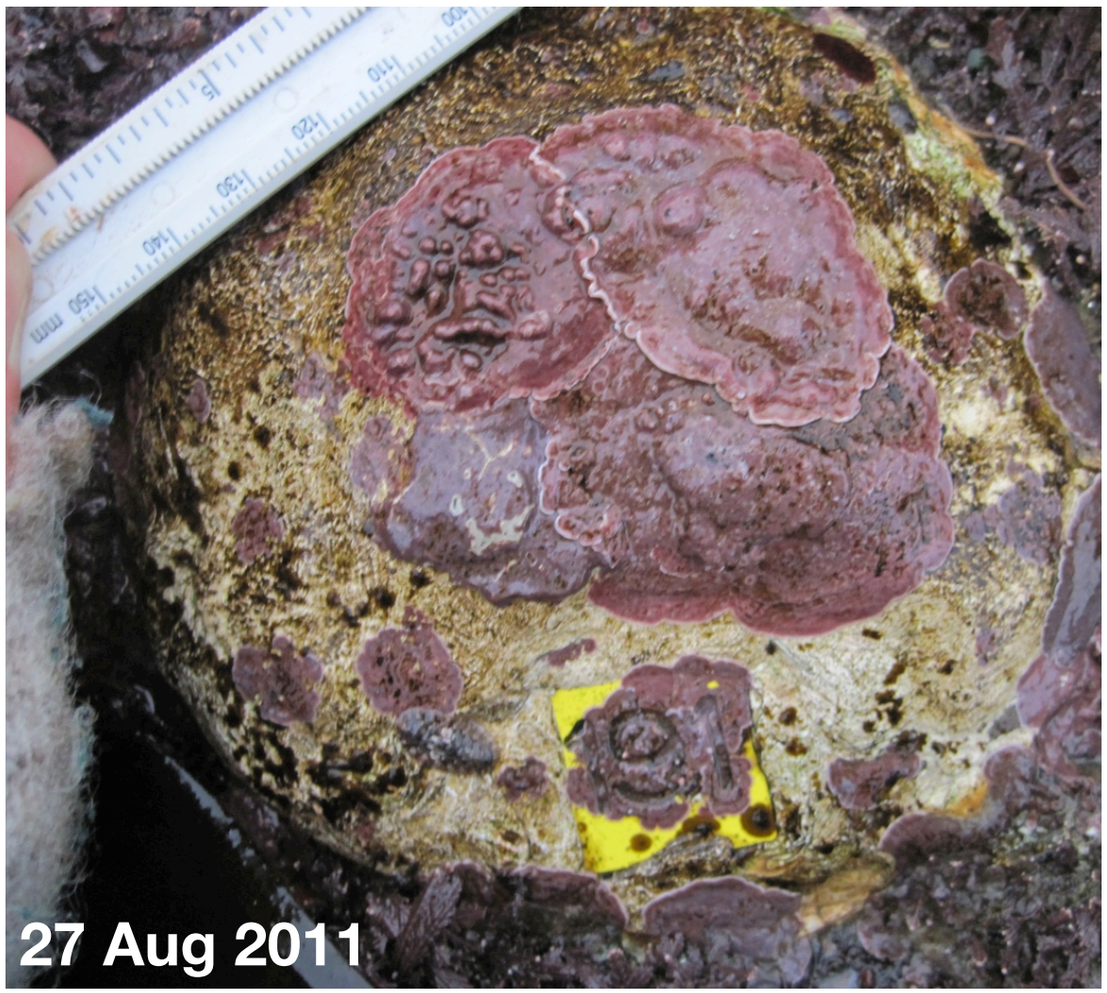


Paine 1984

Overgrowth interactions experimental setup

Hedophyllum Cove 2010-2013

- grazers present x 3
- grazers removed x 3
  - 12 replicates / plot



Results from competitive bouts

2010-2012
grazers removed

Competitive ability index
- ranges from 0-1

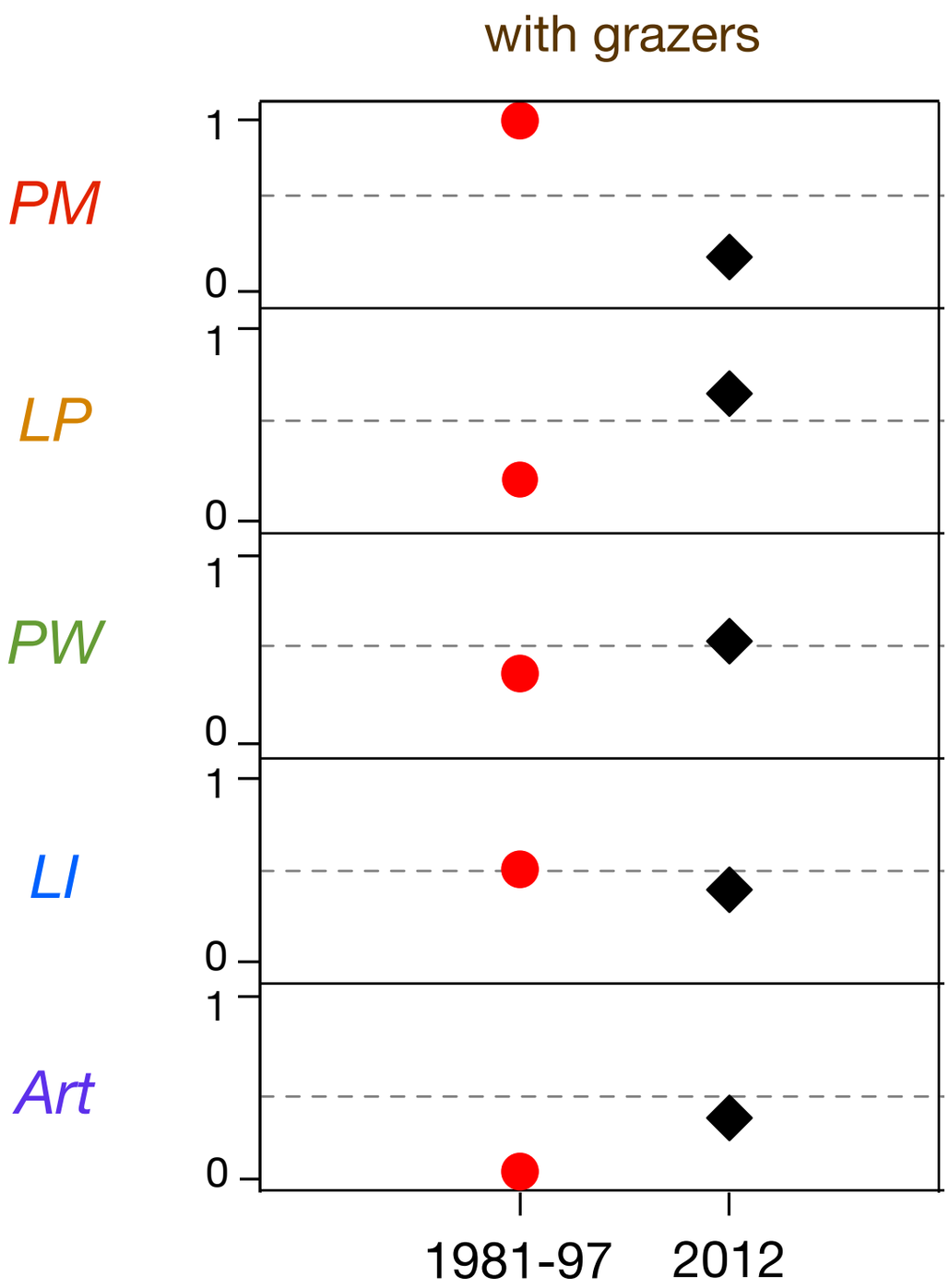
$$CAI = \frac{\#\ wins}{\#\ wins + \#\ losses}$$

Winners

Losers (Overgrown)	PM	LP	PW	LI	Art
PM		21	14	1	1
LP	6		12	10	1
PW	19	30		33	10
LI	5	24	26		0
Art	1	7	2	5	

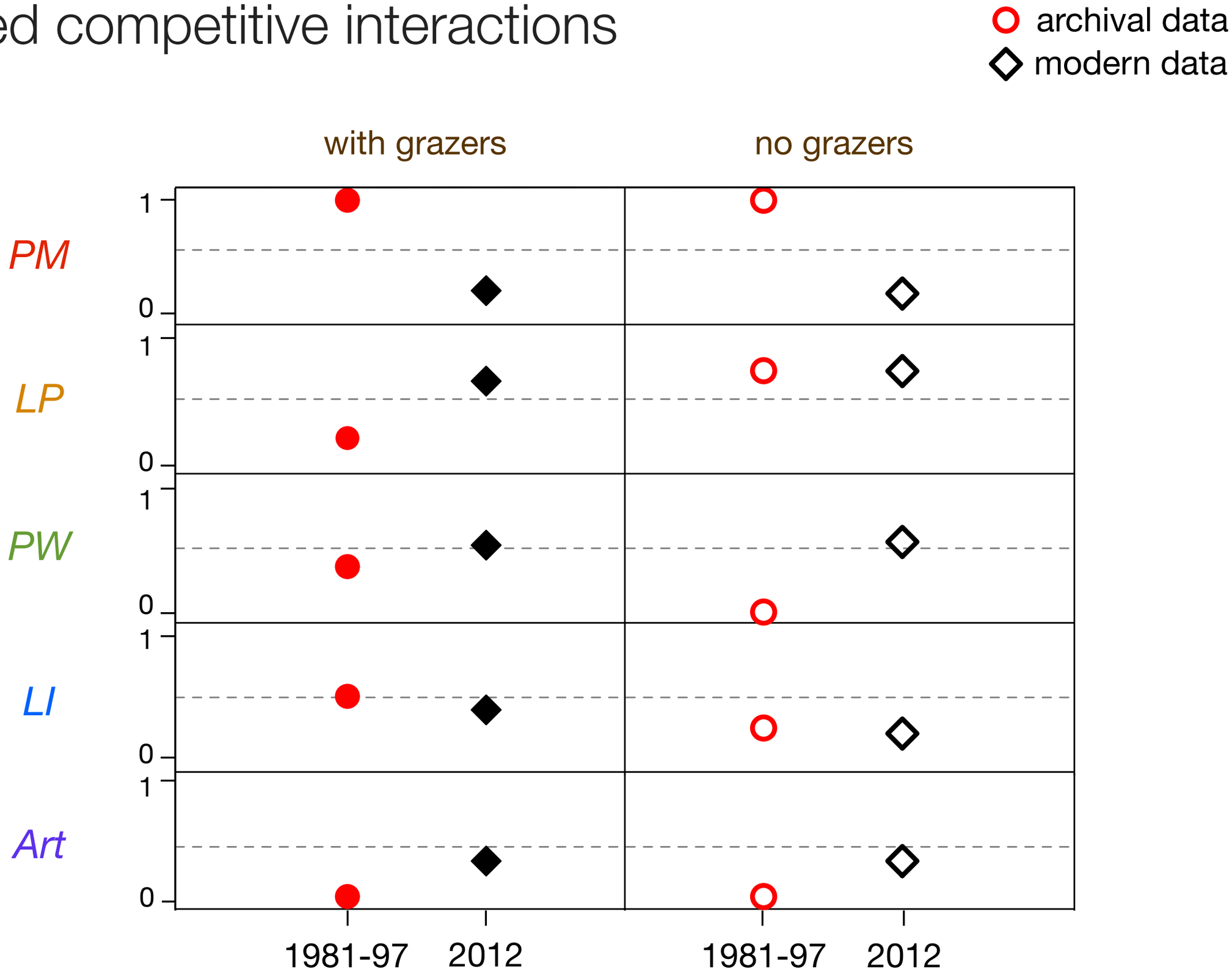
Altered competitive interactions

archival data
modern data



McCoy et al. *in prep*

Altered competitive interactions



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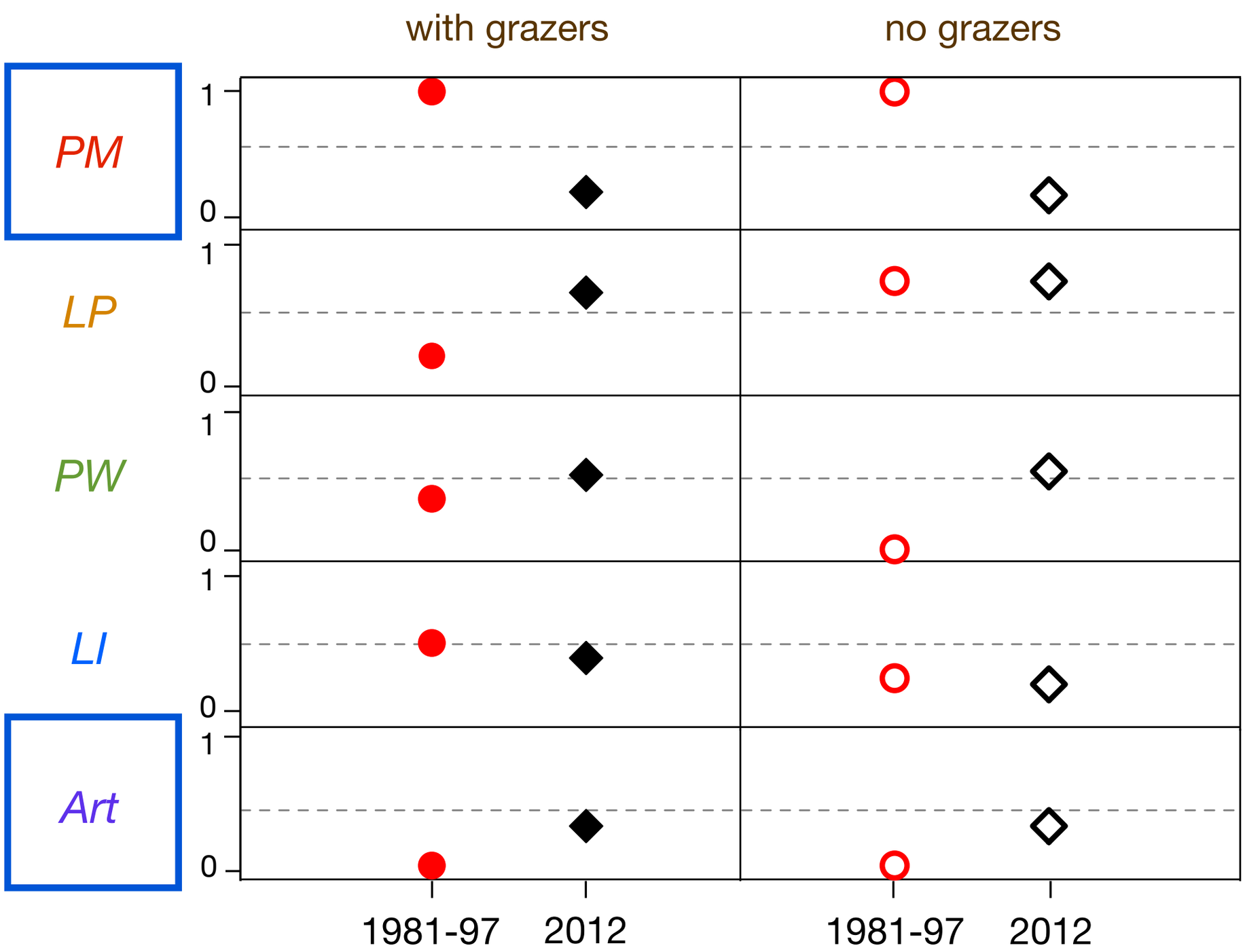
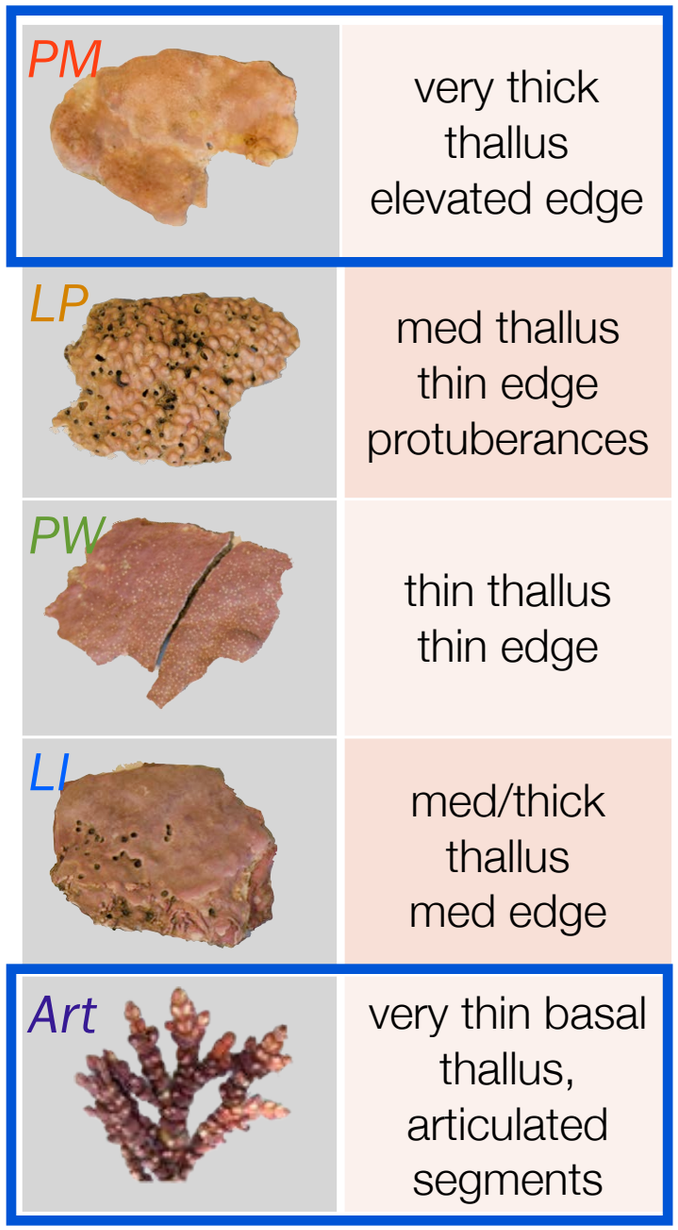
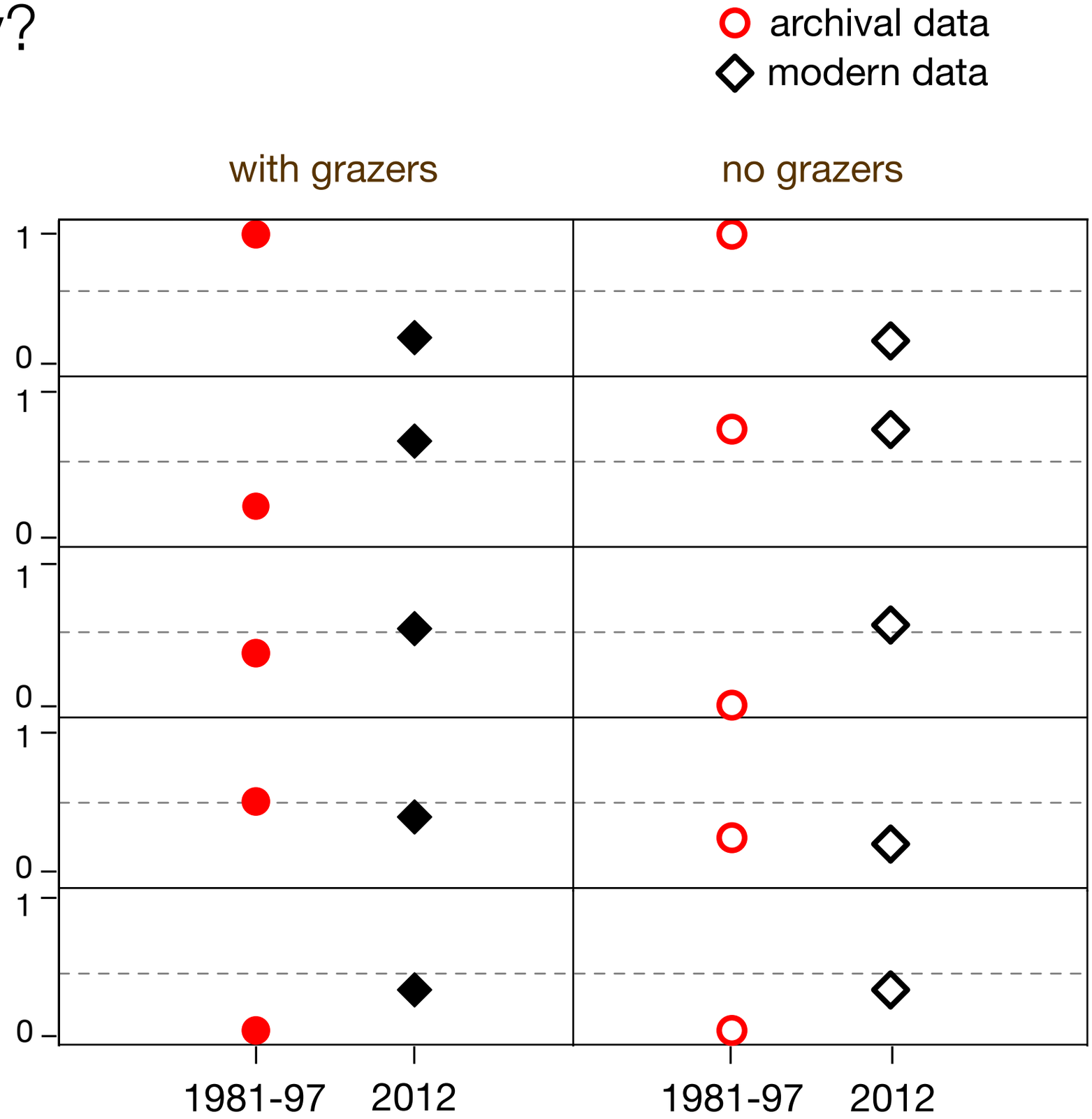


McCoy et al. *in prep*

What mechanisms might be responsible for these observed changes in species interactions?

Effect of morphology?





McCoy et al. *in prep*

Effect of morphology?

Reduced competitive ability is associated with traits requiring more calcified tissue:

1) thicker algal crust 2) thick, elevated growing edge

Ocean acidification reduces CO_3^{2-} available for calcification.

Effect of morphology?

Reduced competitive ability is associated with traits requiring more calcified tissue:

1) thicker algal crust 2) thick, elevated growing edge

Ocean acidification reduces CO_3^{2-} available for calcification.

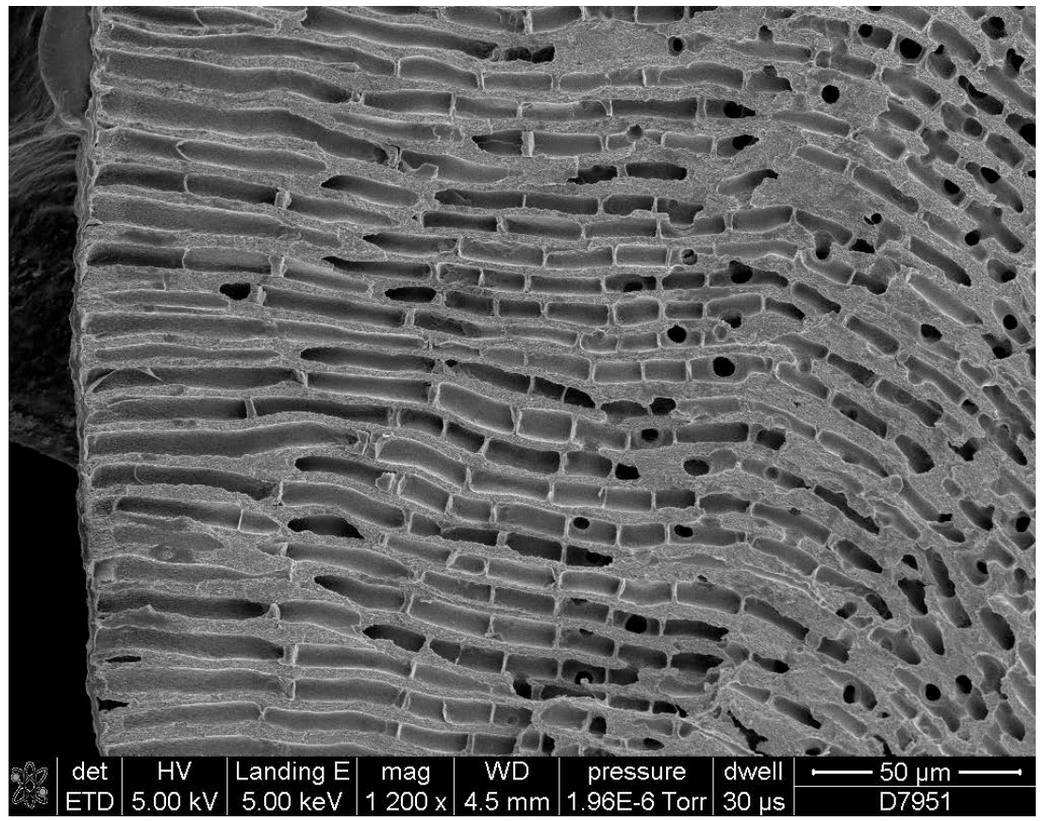
Thus, in *P. muricatum* we might expect:

1) decreased calcified tissue density 2) decreased edge thickness

Testing hypotheses in *P. muricatum*

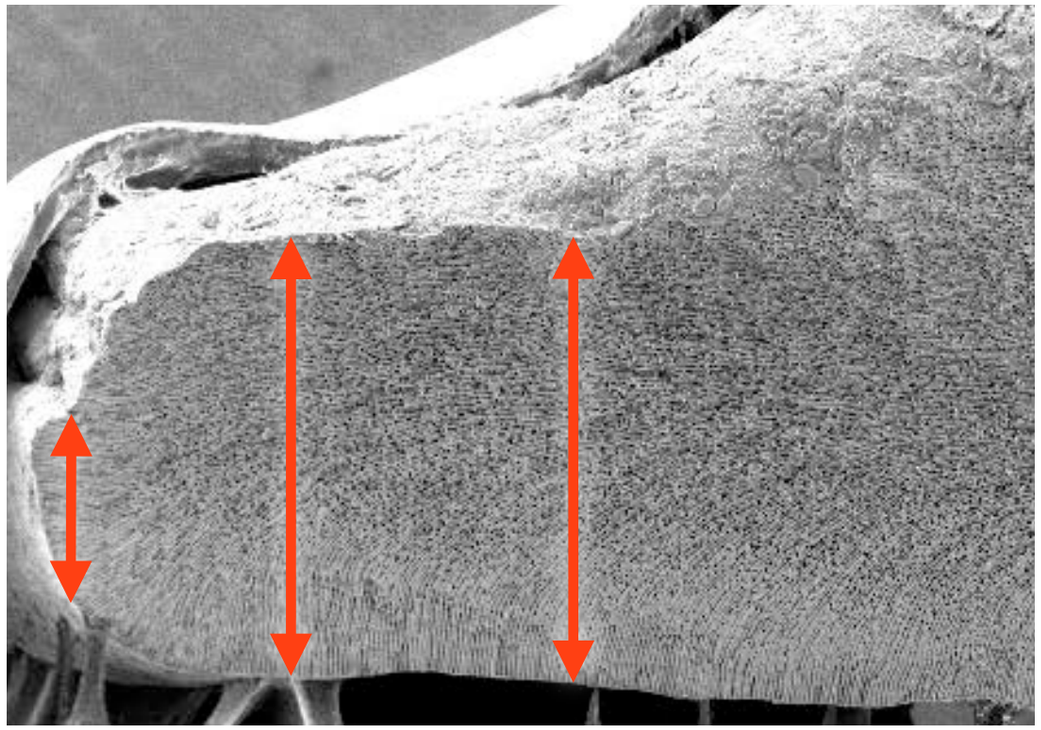
SEM imaging

1) % calcified tissue (by area)

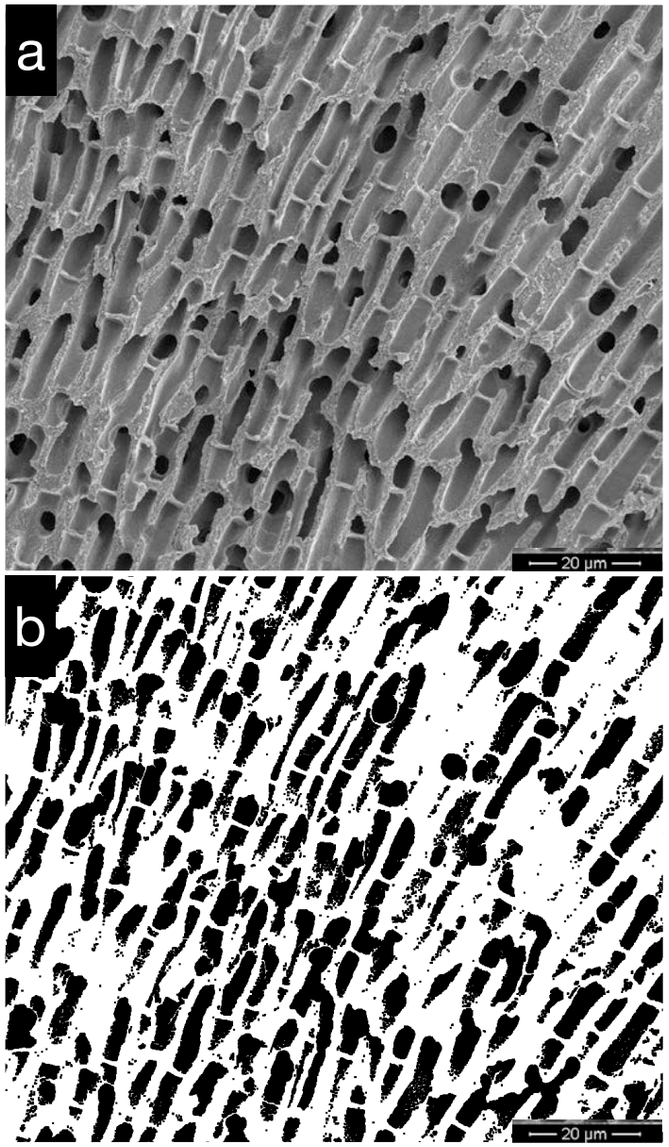


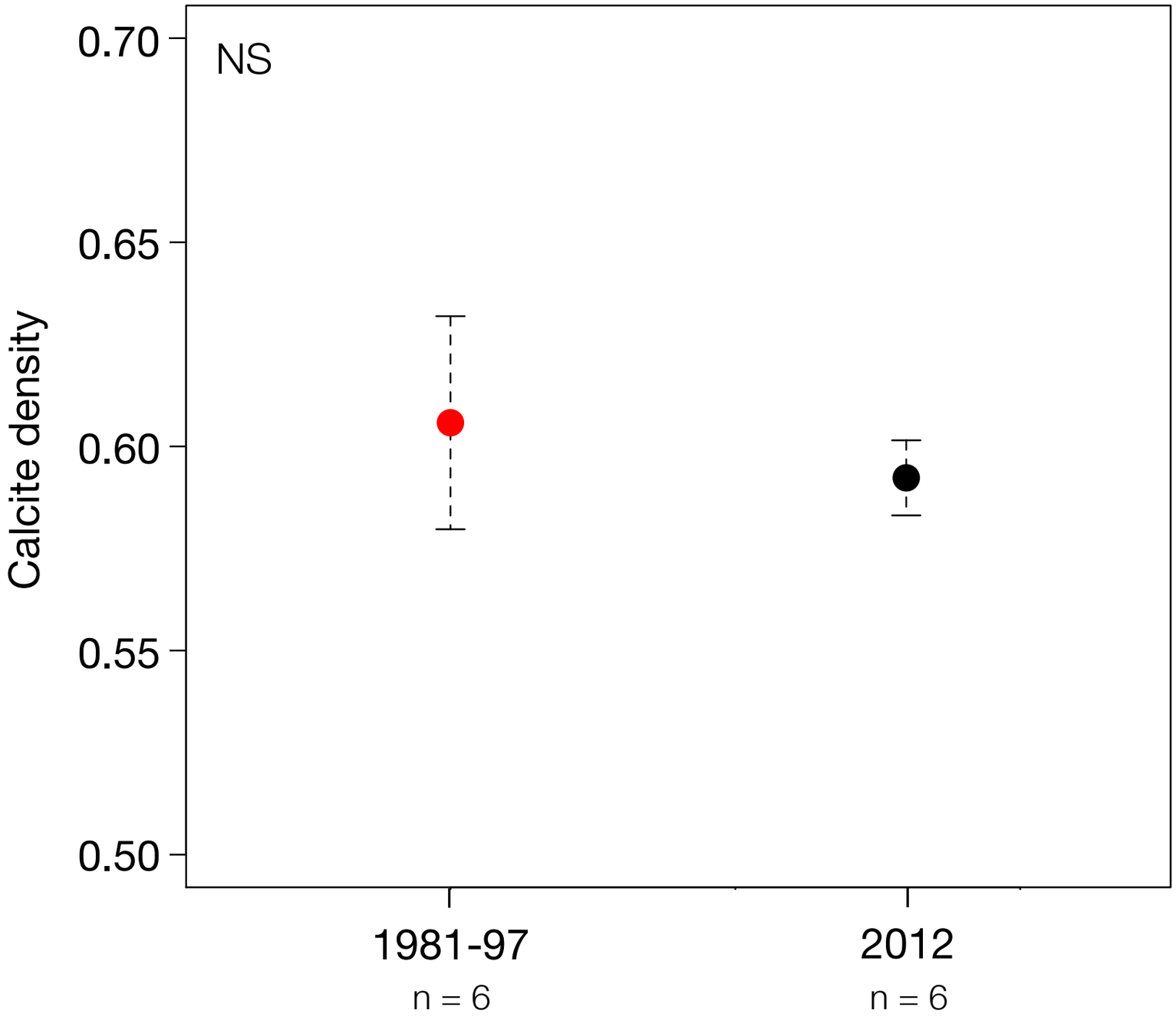
2) thickness at growing edge

growing edge of crust



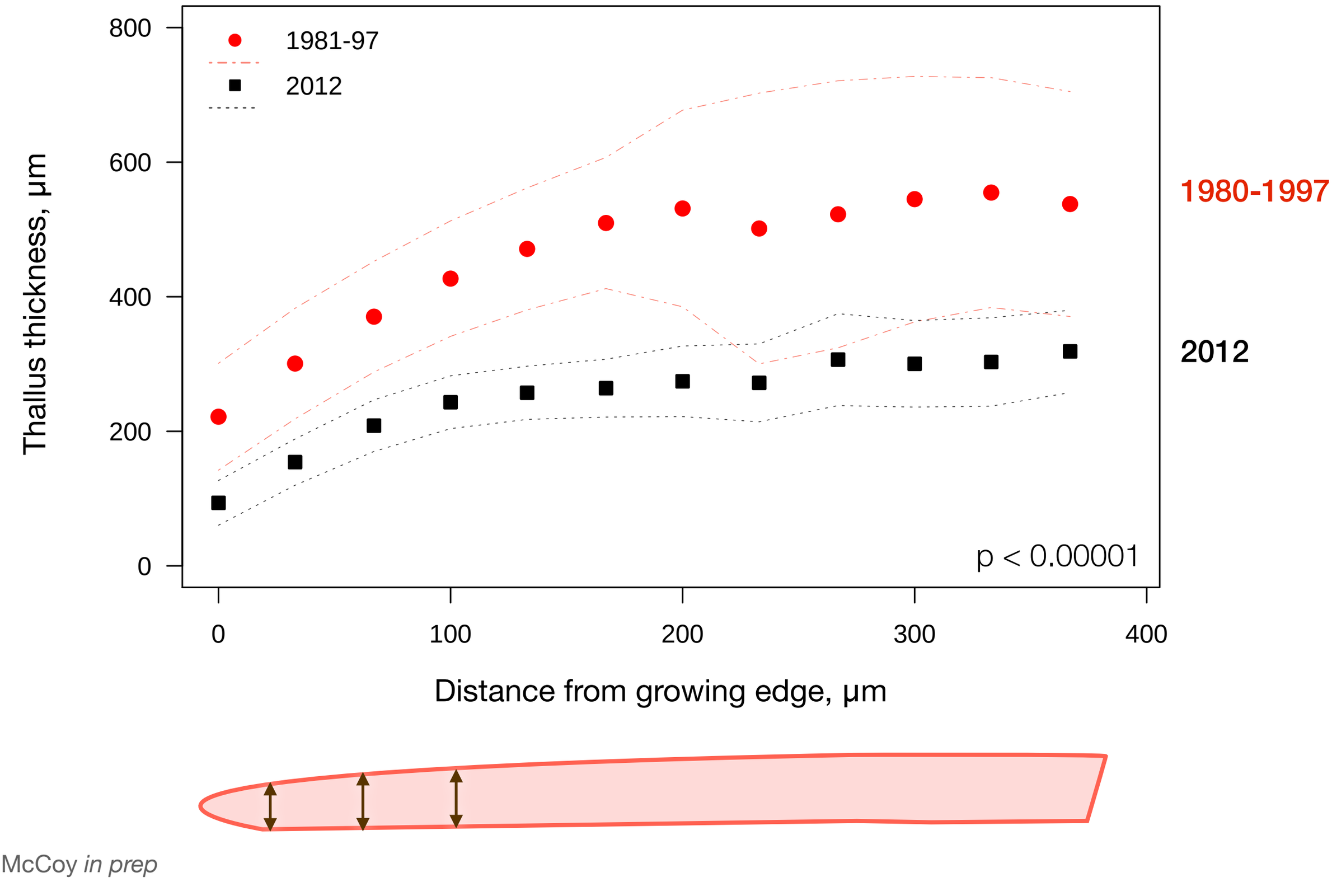
% calcified tissue in *P. muricatum*





McCoy *in prep*

Thickness at growing edge in *P. muricatum*



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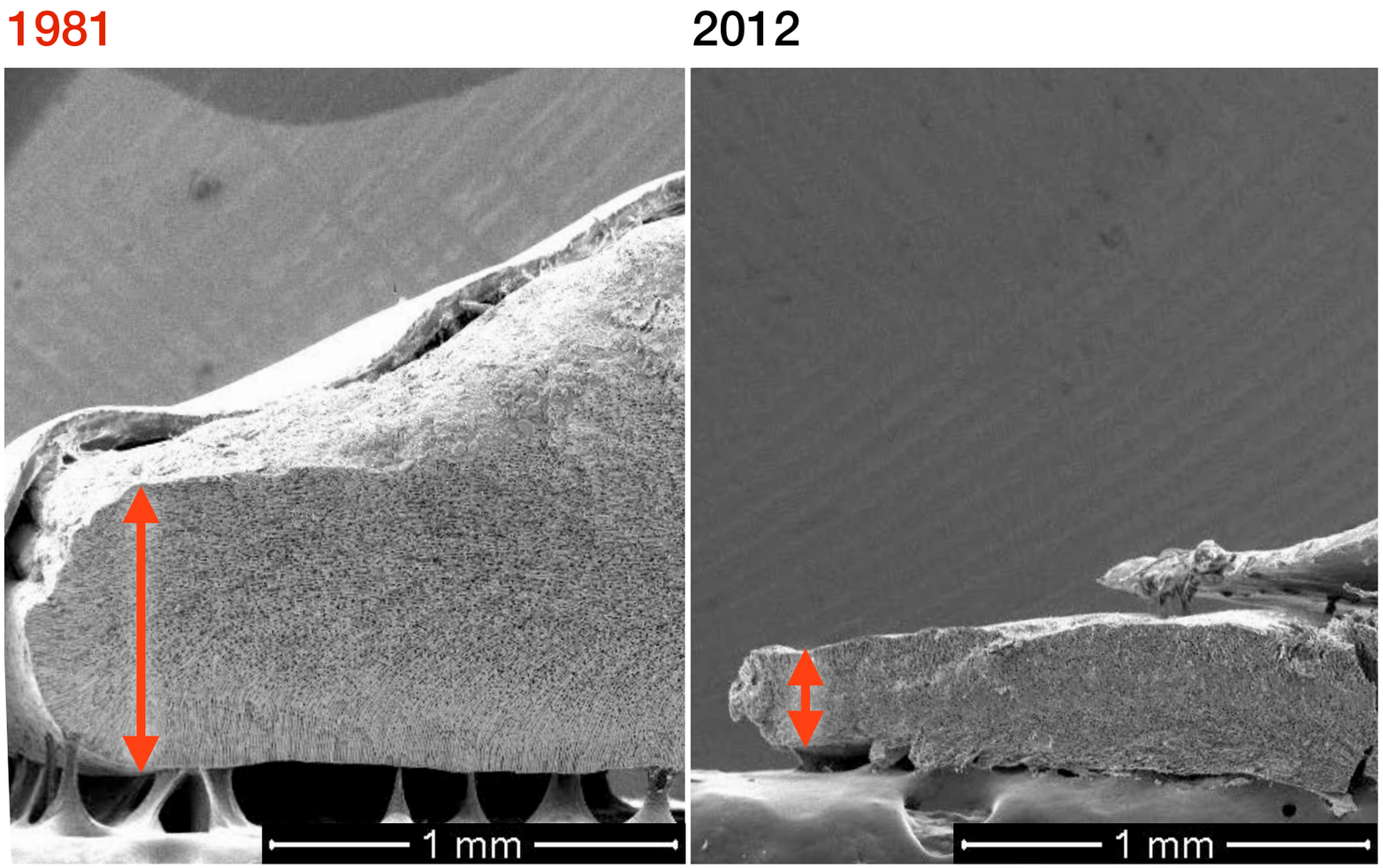

McCoy *in prep*

Conclusions

Competitive interactions show response to OA in the field when compared to historical baselines.

- Former competitive dominant now wins < 50% competitive bouts
- **Physiological response** to OA has direct effect on species interactions in nature

Implications for intertidal biodiversity

- Coralline algae important to the recruitment of seagrasses and many invertebrates
- Overgrowth boundaries provide substrate irregularity for attachment

Acknowledgements

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Phycological Society of America

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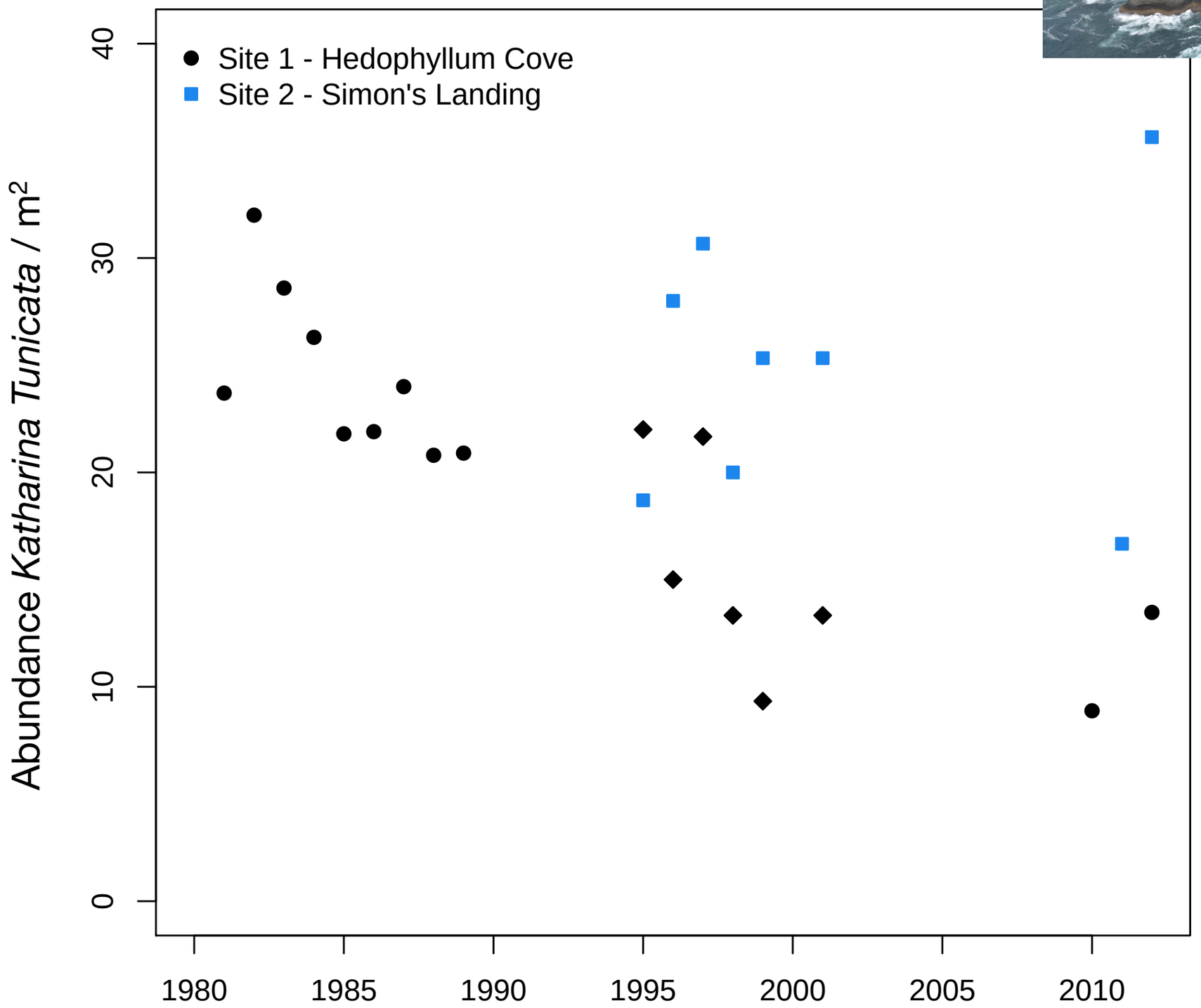
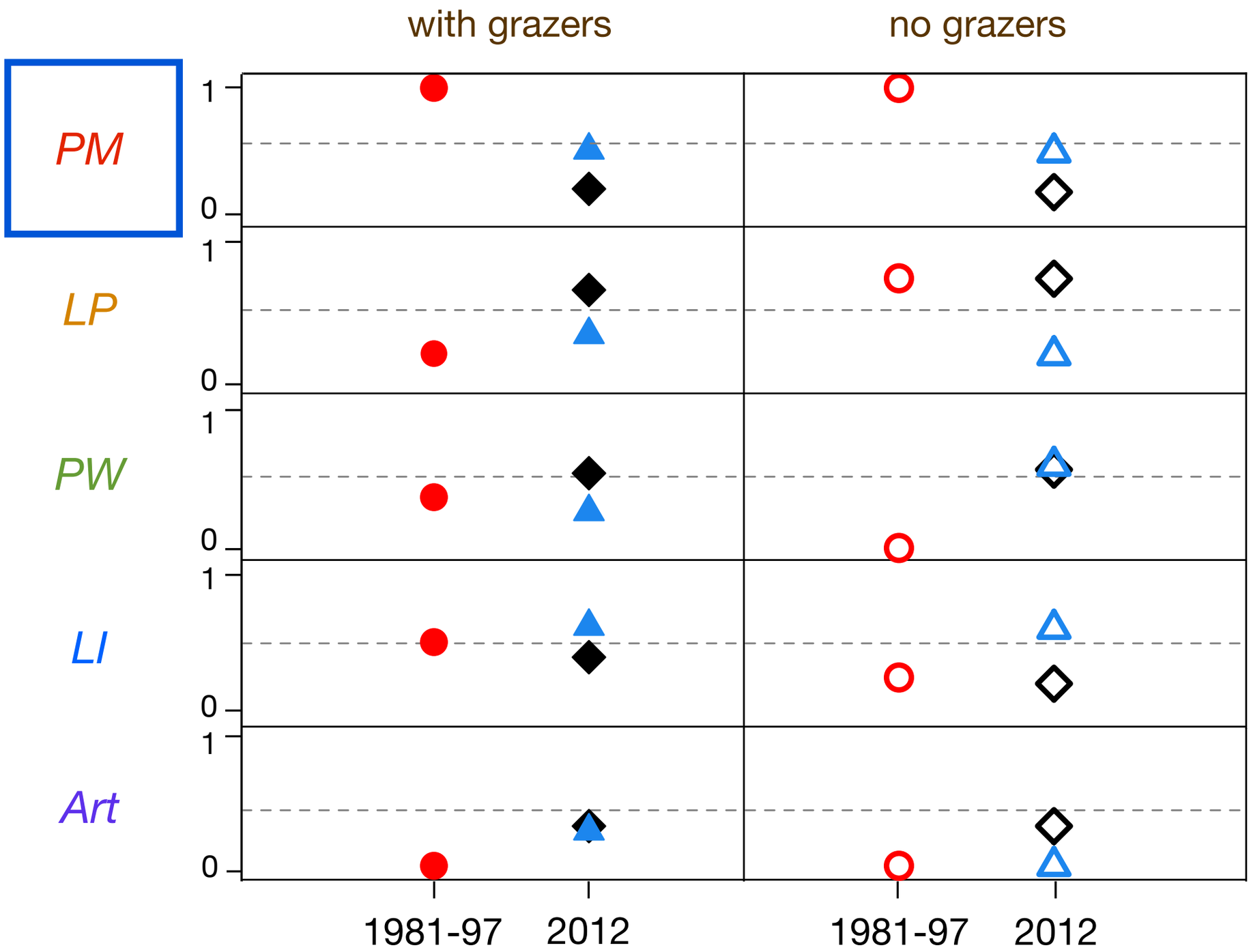
Grazer abundance



Altered competitive interactions - *2 sites*

archival data
modern data
modern data, Simon's Landing

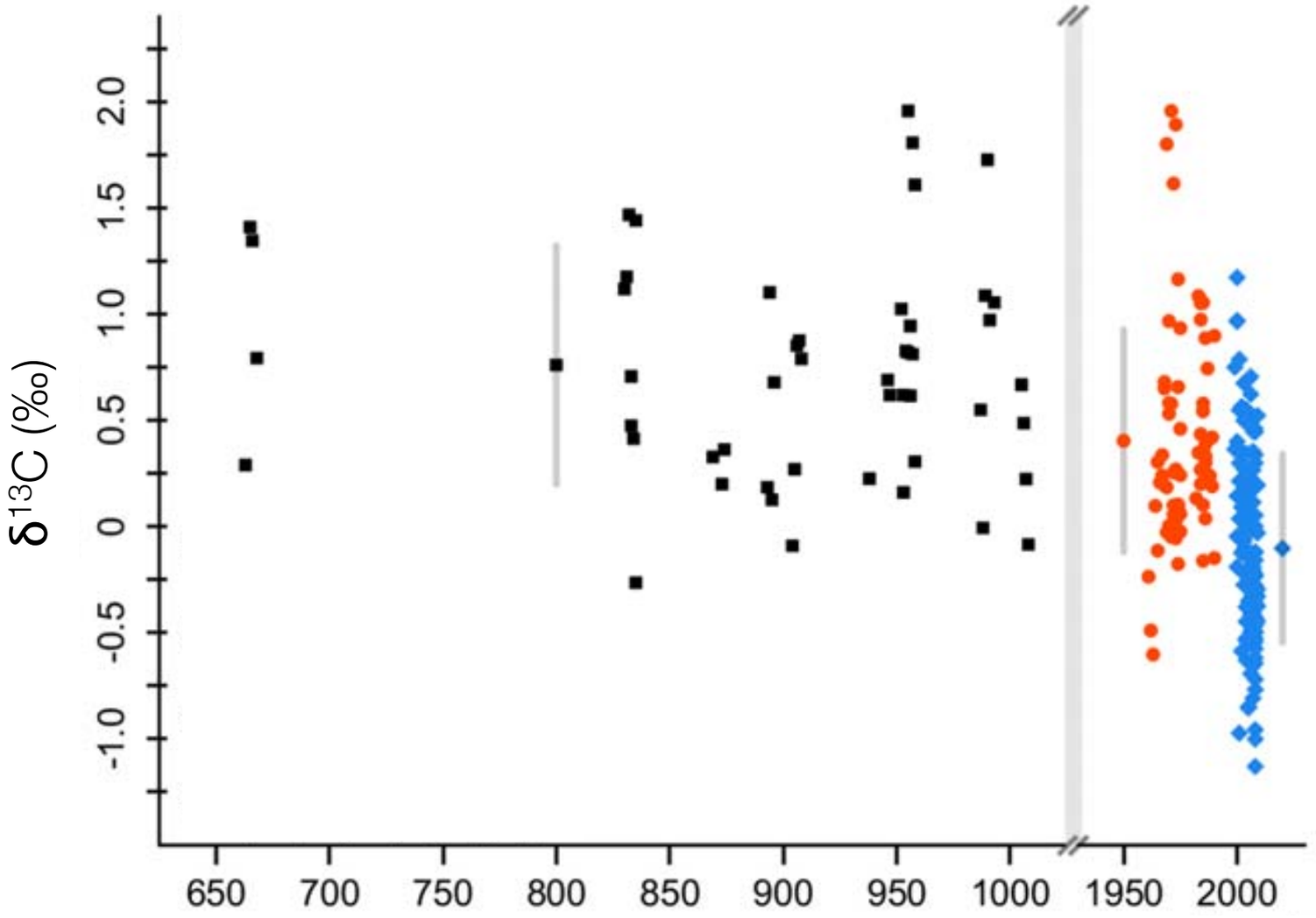


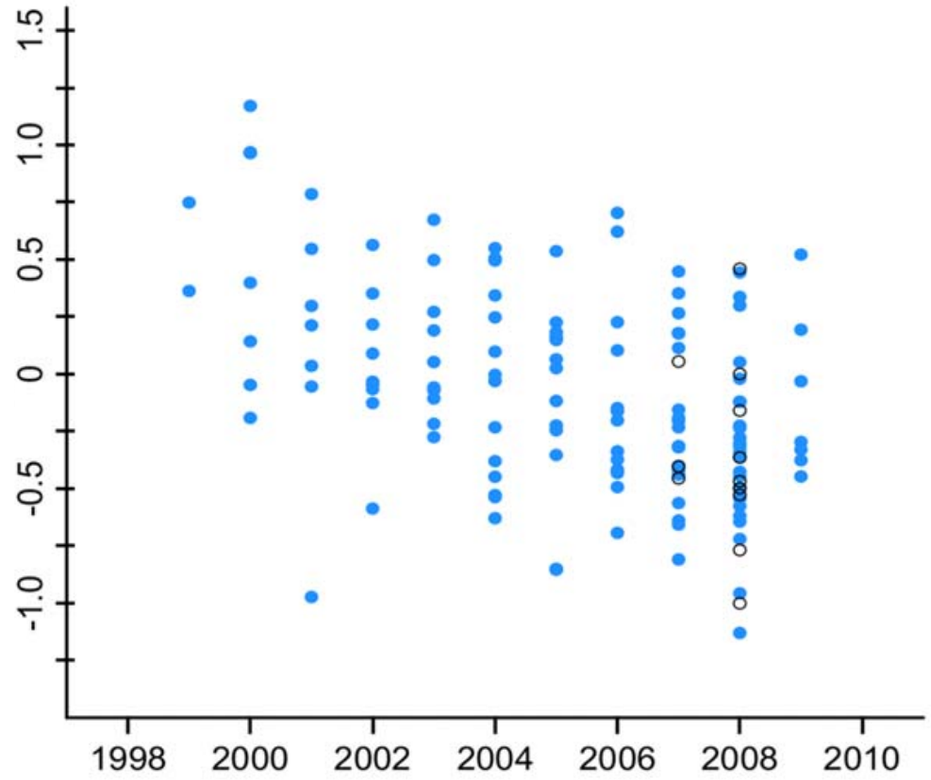
McCoy et al. *in prep*

$\delta^{13}C$ at Tatoosh Island

context for pH trend

- 663-1008 AD
- 1960-1990 — 0.36‰ decline
- 1999-2009 — 0.53‰ decline





closer look at 1999-2009

-0.071‰ / year

Pfister *et al.* 2011

SST at Tatoosh Island