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

Third International Symposium on the Ocean in a High-CO₂ World
24 September, 2012
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

\[ \text{CO}_2 \text{(aq)} + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \text{(aq)} \leftrightarrow \text{H}^+ \text{(aq)} + \text{HCO}_3^- \text{(aq)} \leftrightarrow 2\text{H}^+ \text{(aq)} + \text{CO}_3^{2-} \text{(aq)} \]
Inorganic carbon nutrients

$\text{HCO}_3^- = $ bicarbonate used by most aquatic plants/algae for photosynthesis

$\text{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 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

Ladies and gentlemen, fellow ecologists. It is appropriate that we recognize the role played by Robert MacArthur in the conceptual evolution of ecology, and I am truly moved by the opportunity to participate. It has not been an easy task to determine the tone and focus of my lecture. I am obviously not the person to evaluate MacArthur's many enduring contributions to an impressive variety of ecological subjects. That task is best left to historians of science and, in my opinion, the analysis should be made at some future date. Nor am I the one to enlighten you with novel mathematical treatments of important ecological processes—something Robert MacArthur excelled at. Rather, I plan to do the following. I will develop my own views on the importance of interspecific competition, a subject with which his name is inexorably linked. Although the topic has recently fallen on hard times (Simberloff 1982), I will ask whether such a strong indictment is reasonable for certain marine systems. To some extent, I will be relying heavily on observation. MacArthur continually urged ecologists to draw their inspiration from naturally occurring patterns and to use their naturalist's intuition. I have followed this advice in pursuing my interests in the occurrence and relative importance of interspecific competition between organisms resident on marine rocky shores. I will deal specifically and solely with the sessile moiety, both plant and animal, and the outcomes of their contests for a required and limiting resource, space.
Coralline red algae

Articulated forms

- Corallina
- Bossiella

Encrusting forms

- Lithothamnion phymatodeum
- P. whidbeyense
- Pseudolithophyllum muricatum
- Lithothamnion phymatodeum

Maerls and Rhodoliths

- Lithophyllum dentatum
- Phymatolithon calcareum

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

![Graph](image)

**Growth (Calcification, ct / min-tip-hr)**

- pH decreasing
- increasing growth caused by increasing [HCO$_3^-$]
- decreasing [CO$_3^{2-}$] becomes limiting

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

Pseufuliphyllum muricatum

Lithothamnion phymatodeum

Pseufuliphyllum whidbeyense

Lithophyllum impressum

Bossiella & Corallina sp.

Paine 1984
Position on the hierarchy

<table>
<thead>
<tr>
<th>PM</th>
<th>slow growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>med/fast growth</td>
</tr>
<tr>
<td>PW</td>
<td>fast growth</td>
</tr>
<tr>
<td>LI</td>
<td>med/slow growth</td>
</tr>
<tr>
<td>Art</td>
<td>fast growth, rapid colonizer</td>
</tr>
</tbody>
</table>

Fast lateral growth
= able to grow faster under low grazing pressure
Position on the hierarchy

<table>
<thead>
<tr>
<th>Thick, elevated edge</th>
<th>= delay overgrowth by another species</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>species A</th>
<th>species B</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>slow growth</td>
<td></td>
</tr>
<tr>
<td>LP</td>
<td>med/fast growth</td>
<td></td>
</tr>
<tr>
<td>PW</td>
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</tr>
<tr>
<td>LI</td>
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<td></td>
</tr>
<tr>
<td>Art</td>
<td>fast growth rapid colonizer</td>
<td></td>
</tr>
</tbody>
</table>

It is harder for species B to win in Scenario 2 because it must travel farther to achieve overgrowth.
Growth strategy trade-offs

Fast lateral growth and thick edge

Overall thickness
= better equipped to resist grazing damage

<table>
<thead>
<tr>
<th>PM</th>
<th>very thick thallus elevated edge</th>
<th>slow growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>med thallus thin edge protuberances</td>
<td>med/fast growth</td>
</tr>
<tr>
<td>PW</td>
<td>thin thallus thin edge</td>
<td>fast growth</td>
</tr>
<tr>
<td>LI</td>
<td>med/thick thallus med edge</td>
<td>med/slow growth</td>
</tr>
<tr>
<td>Art</td>
<td>very thin thallus articulated segments</td>
<td>fast growth rapid colonizer</td>
</tr>
</tbody>
</table>
Grazers

crusts must be thickly calcified to withstand heavy grazing

Johnson and Mann 1986; Paine 1984; Steneck and Paine 1986; Steneck, Hacker and Dethier 1991
Interactions - Herbivore-mediated competitive hierarchy

grazers absent

Pseudolithophyllum muricatum
Lithothamnion phymatodeum
Pseudolithophyllum whidbeyense
Lithophyllum impressum
Bossiella & Corallina sp.

Paine 1984
Interactions - Herbivore-mediated competitive hierarchy

low grazer abundance

P. muricatum

L. phymatodeum

P. whidbeyense

L. impressum

Bossiella & Corallina sp.

Paine 1984
Interactions - Herbivore-mediated competitive hierarchy

high grazer abundance

P. muricatum

L. phymatodeum  L. impressum

P. whidbeyense

Bossiella & Corallina sp.

Paine 1984
Overgrowth interactions experimental setup

Hedophyllum Cove 2010-2013

• grazers present  x 3
• grazers removed  x 3
  › 12 replicates / plot

12 July 2010

27 Aug 2011
Results from competitive bouts

Competitive ability index
- ranges from 0-1

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

<table>
<thead>
<tr>
<th>Losers (Overgrown)</th>
<th>PM</th>
<th>LP</th>
<th>PW</th>
<th>LI</th>
<th>Art</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>21</td>
<td>14</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>LP</td>
<td>6</td>
<td>12</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>PW</td>
<td>19</td>
<td>30</td>
<td>33</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>LI</td>
<td>5</td>
<td>24</td>
<td>26</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Art</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

2010-2012 grazers removed

CAI = \frac{\# \text{ wins}}{\# \text{ wins} + \# \text{ losses}}
Altered competitive interactions

![Graph showing altered competitive interactions with grazers for PM, LP, PW, LI, and Art between 1981-97 and 2012. The graph uses archival data (red circles) and modern data (black diamonds).](image-url)
Altered competitive interactions

with grazers

no grazers

PM

LP

PW

LI

Art

1981-97  2012

1981-97  2012

archival data

modern data

McCoy et al. in prep
Altered competitive interactions

Competitive Index

0 1 2 3 4 5 6


with grazers  no grazers

PM  LP  PW  LI  Art

archival data  modern data

McCoy et al. in prep
What mechanisms might be responsible for these observed changes in species interactions?
Effect of morphology?

- **PM**: very thick thallus, elevated edge
- **LP**: med thallus, thin edge protuberances
- **PW**: thin thallus, thin edge
- **LI**: med/thick thallus, med edge
- **Art**: very thin basal thallus, articulated segments

Graphs showing data with and without grazers for the years 1981-97 and 2012.

- **Archival data** (red circles)
- **Modern data** (diamonds)

McCoy et al. *in prep*
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 $\text{CO}_3^{2-}$ 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*
Thickness at growing edge in *P. muricatum*

McCoy *in prep*
Thickness at growing edge in *P. muricatum*

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
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Phycological Society of America
Grazer abundance

Abundance Katharina Tunicata / m²

- Site 1 - Hedophyllum Cove
- Site 2 - Simon's Landing
Altered competitive interactions - 2 sites

PM

LP

PW

LI

Art

with grazers

no grazers

1.0

0.8

0.6

-0.5

0

5

10

1981-97

2012

1981-97

2012

archival data

modern data

modern data, Simon’s Landing

McCoy et al. in prep
δ¹³C at Tatoosh Island
context for pH trend

- 663-1008 AD: 0.36‰ decline
- 1960-1990: 0.53‰ decline
- 1999-2009: -0.071‰ / year

closer look at 1999-2009

Pfister et al. 2011
SST at Tatoosh Island

SST (°C)