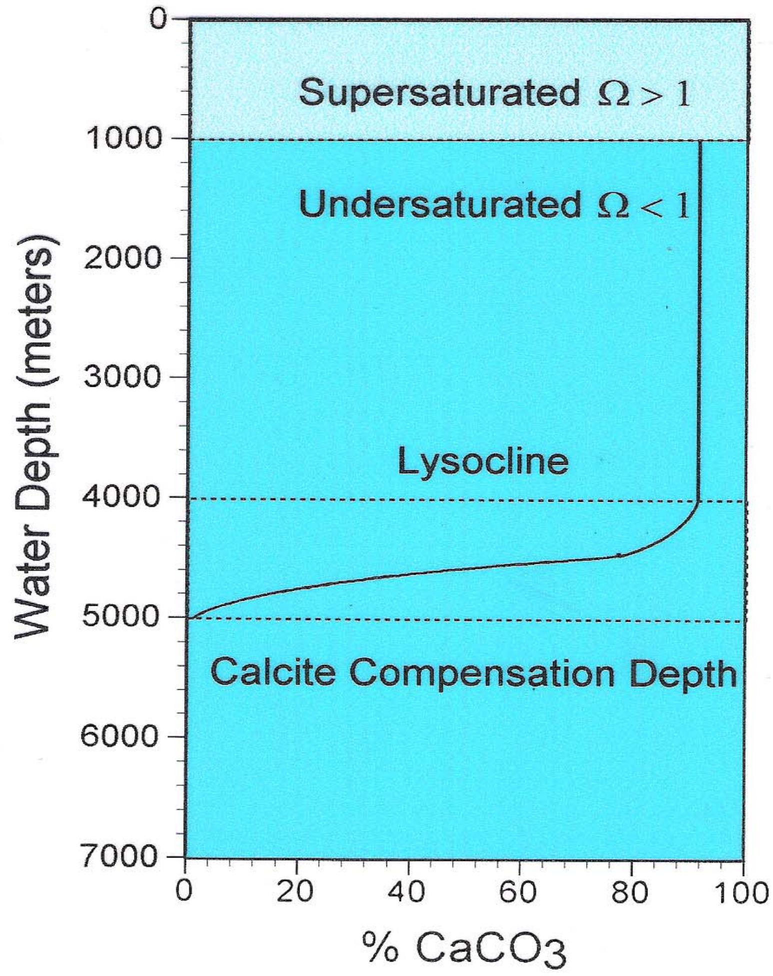
# Death by Dissolution:

# The fate of carbonate-bearing organisms in nearshore marine environments in a high $CO_2$ world.

Ocean Carbon & Biogeochemistry

Mark A. Green



Supersaturated Ω > 1
Undersaturated Ω < 1
Lysocline
Calcite Compensation Depth
Water Depth (meters)
0
1000
2000
3000
4000
5000
6000
7000
0
20
40
60
80
100
% CaCO3

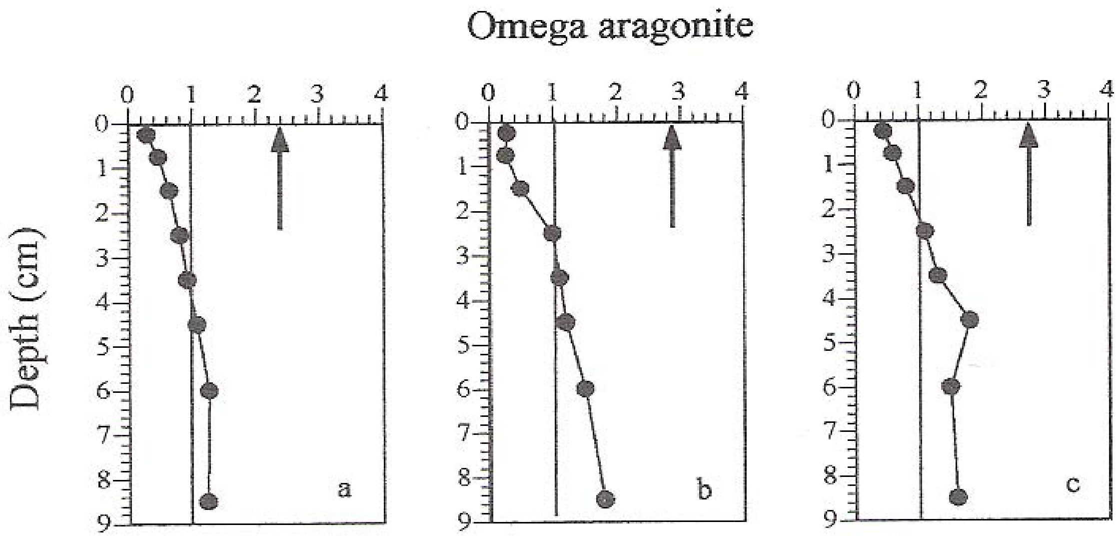



Fig. 5. Sediment saturation state in three coastal estuaries located along the northeastern United States coast. Sediments shown here were recovered during late spring/early summer in (a) Casco Bay estuary, (b) Barnstable harbor, and (c) Long Island sound and all show marked undersaturation from the sediment–water interface to depths of 2–3 cm. Maximum undersaturation occurs adjacent to the SWI in each case with $\Omega_{aragonite}$ values ranging from ~0.2 to 0.4. Overlying water saturation states are shown by the dark arrow and are supersaturated in each case.

Green et al. 2004, *Limnol. Oceanogr.*

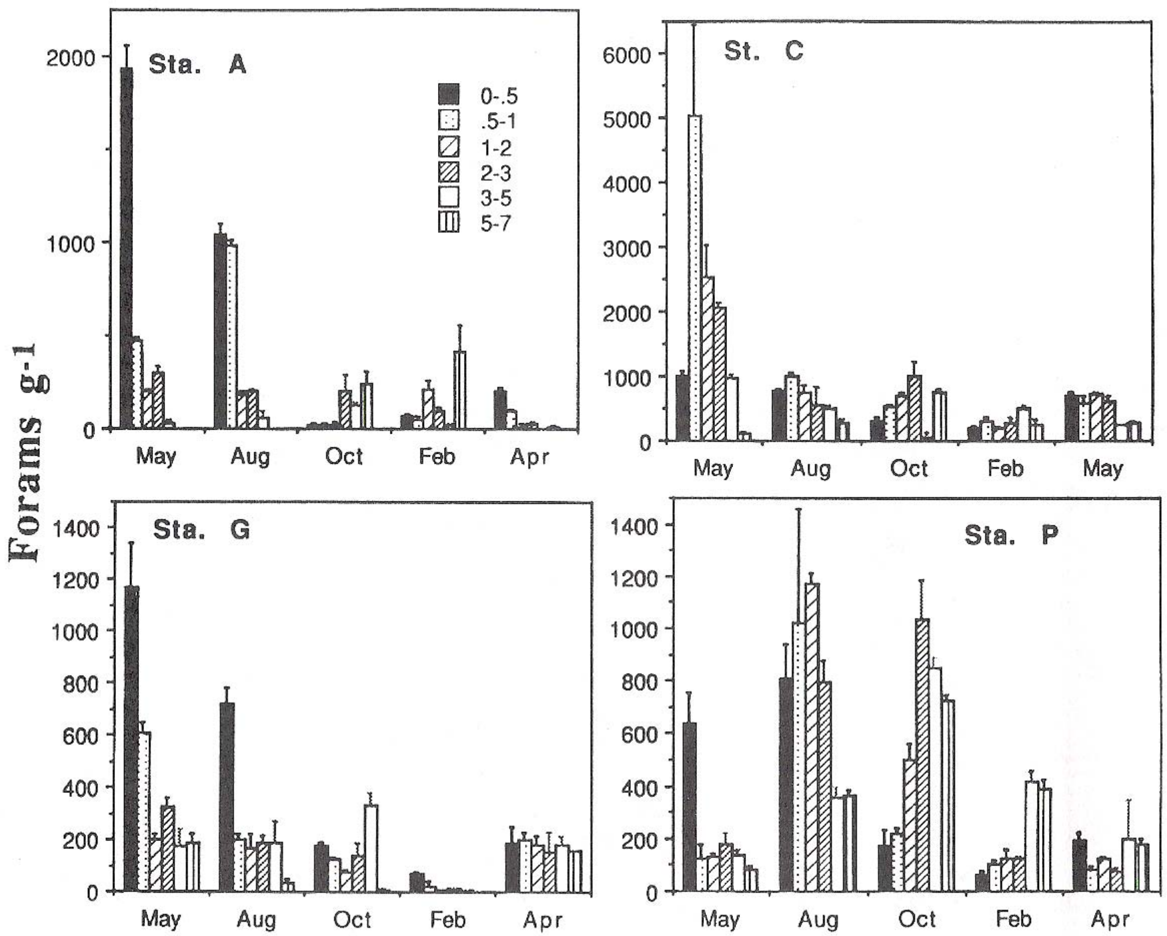
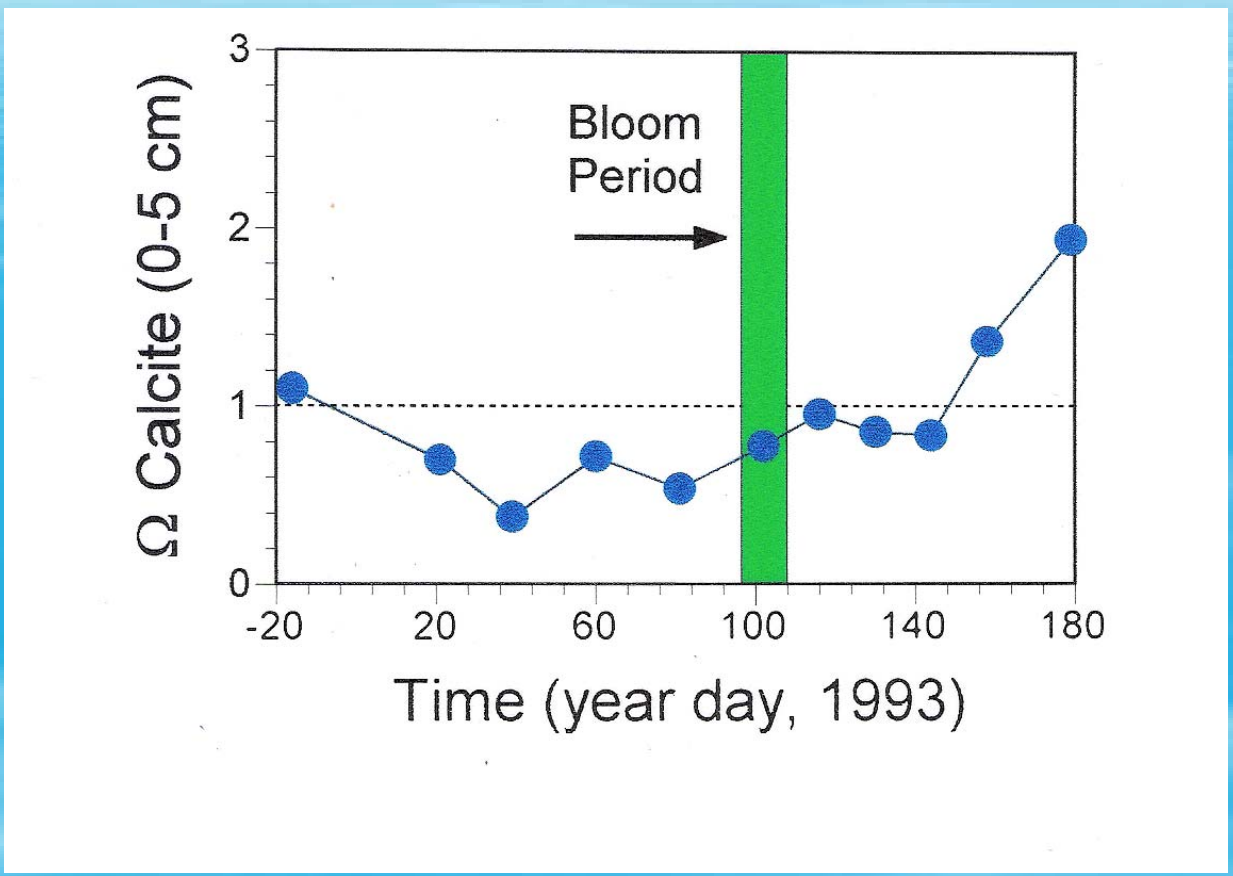
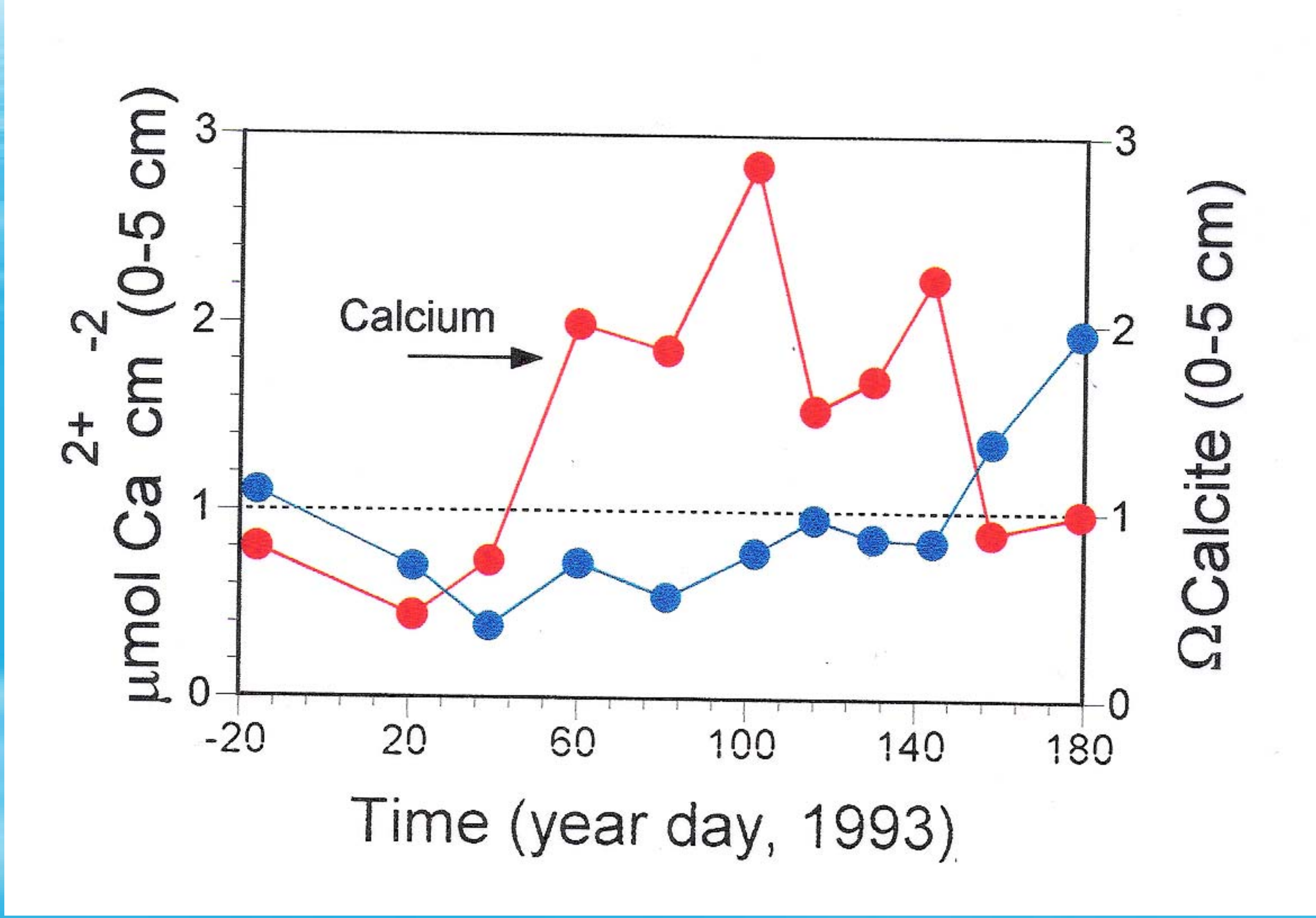



Fig. 4. As Fig. 2, but of the total foraminiferan assemblage.

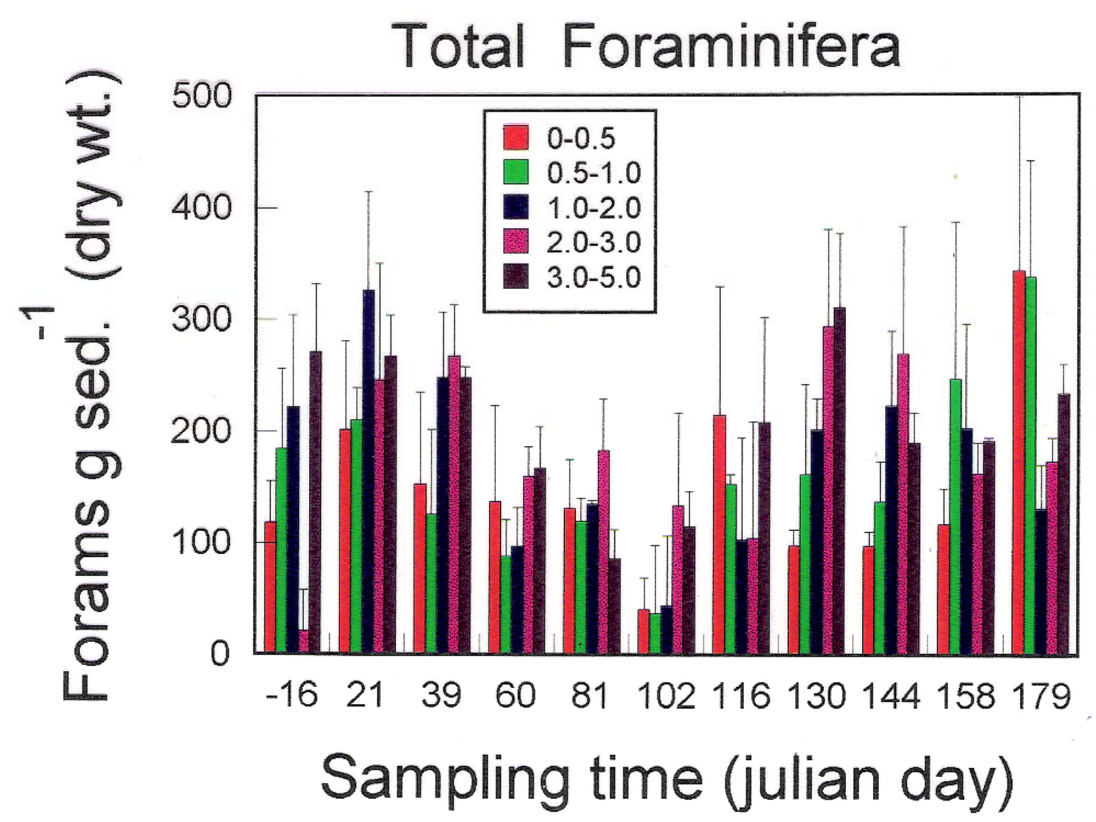
Green et al., 1993, *Limnol. Oceanogr.*

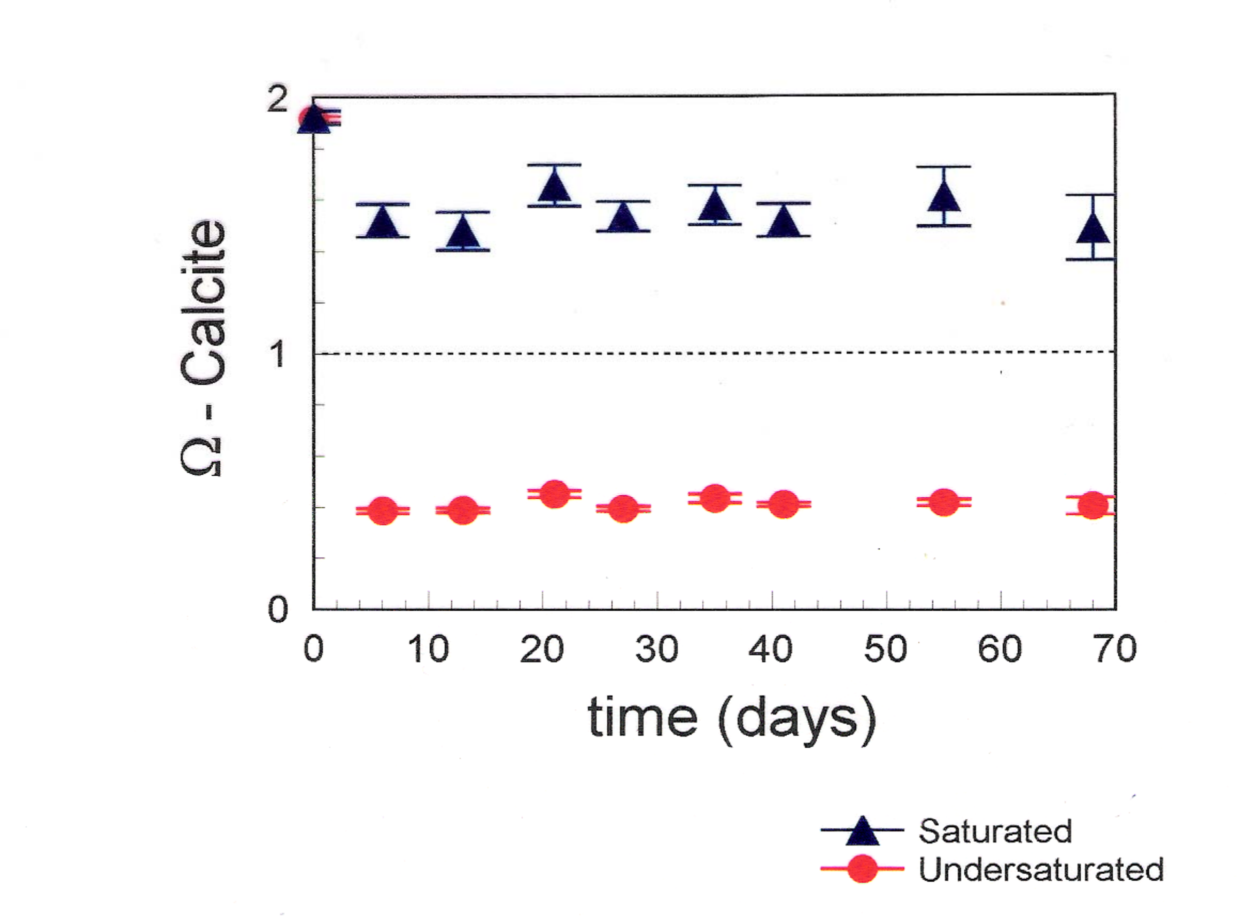



Green et al., J. Mar. Res., 59:769-794, 2001

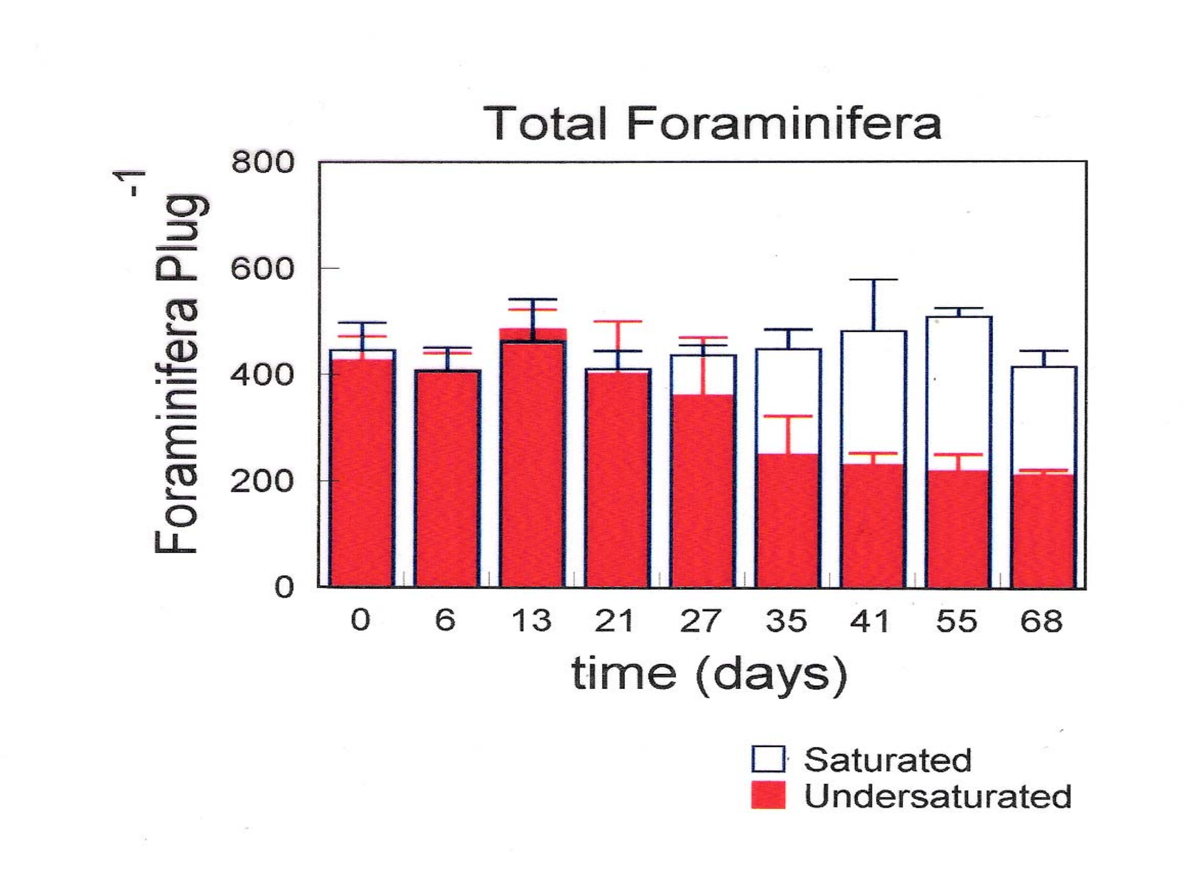



Green et al., 1998, *Jour. Mar. Res.*

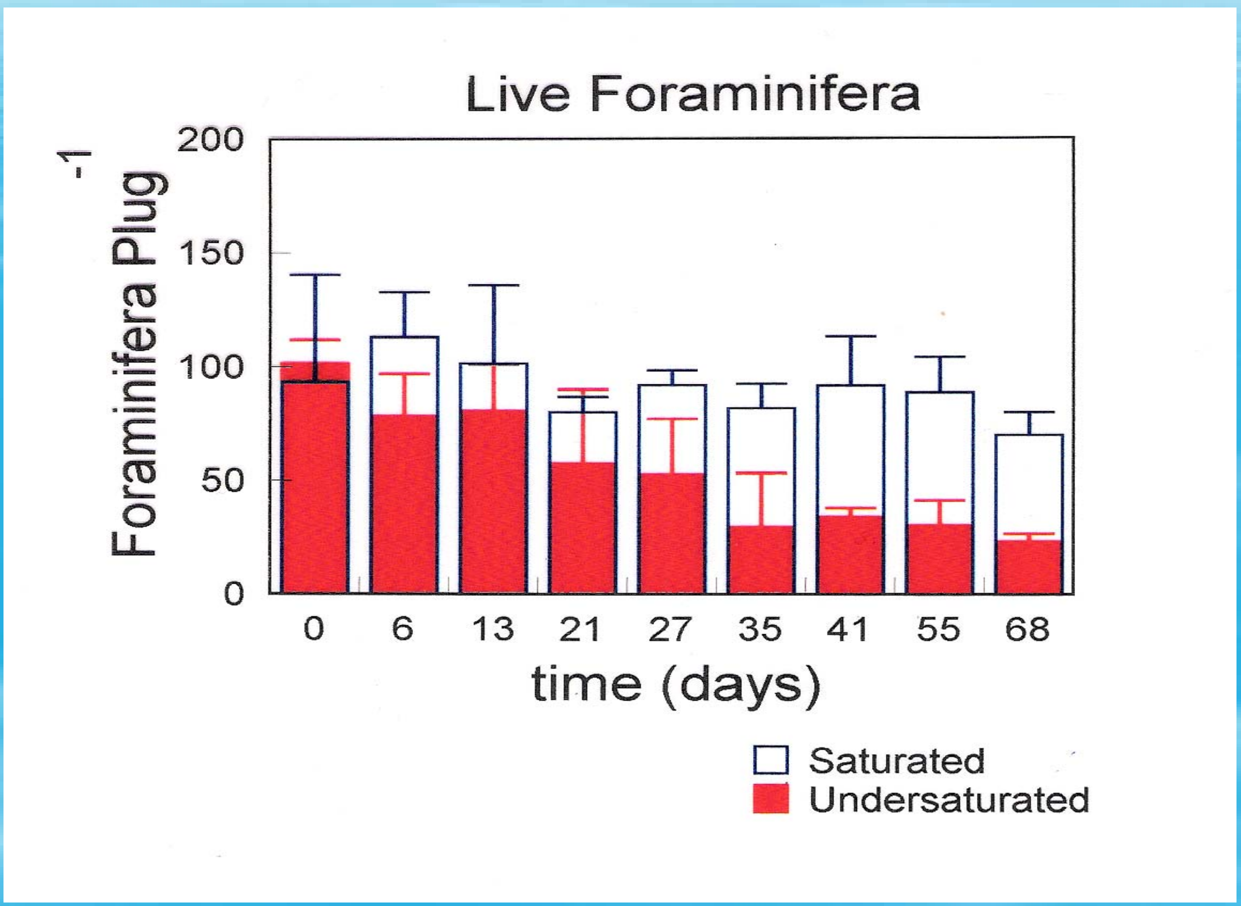

Total Foraminifera
Forams g sed.$^{-1}$ (dry wt.)
500
400
300
200
100
0
0-0.5
0.5-1.0
1.0-2.0
2.0-3.0
3.0-5.0
-16 21 39 60 81 102 116 130 144 158 179
Sampling time (julian day)




Green et al., 1998, *Limnol. Oceanogr.*




Green et al., 1998, *Limnol. Oceanogr.*




Green et al., 1998, *Limnol. Oceanogr.*

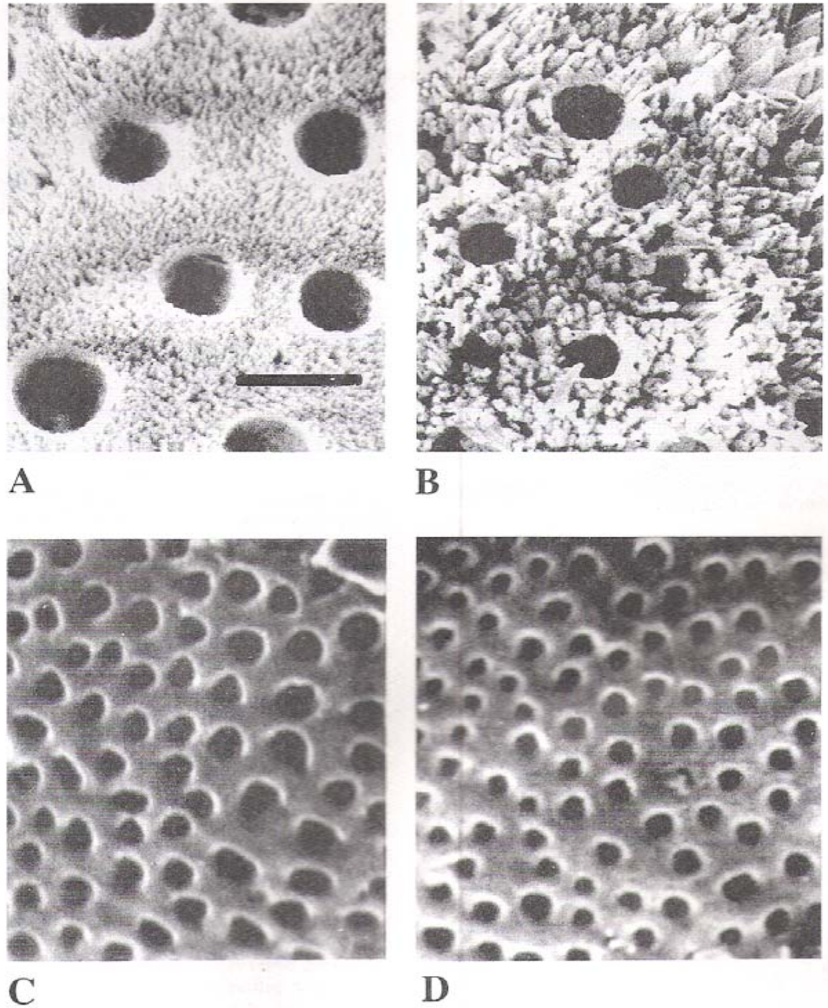
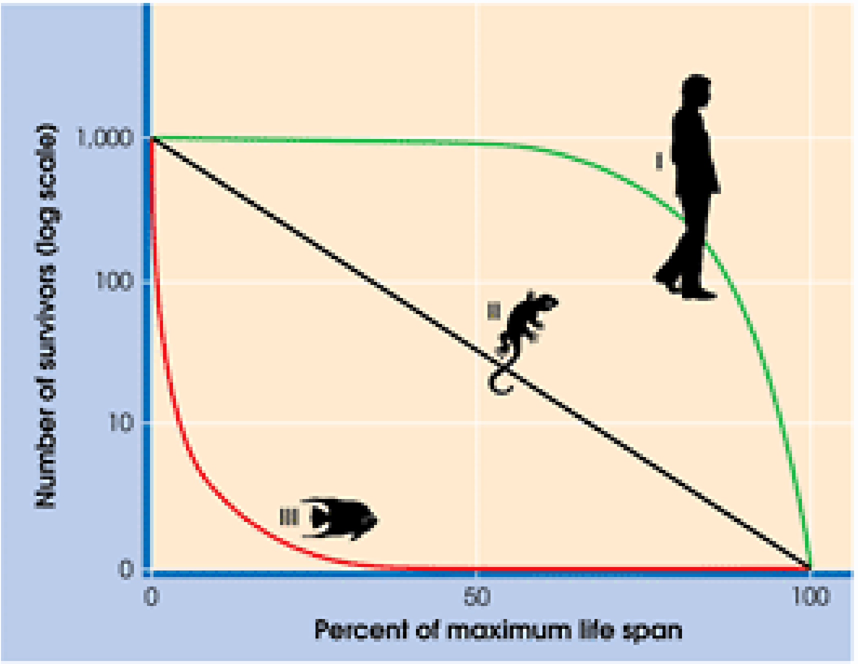



Fig. 9. Scanning electron microscopy photographs of foraminifera recovered on day 13 and day 27 from experimental (A, B) and control (C, D) sediment plugs (magnification = 5,000×; scale bar = 4 $\mu$m).

Green et al., 1998, *Limnol. Oceanogr.*

# Survivorship in Populations



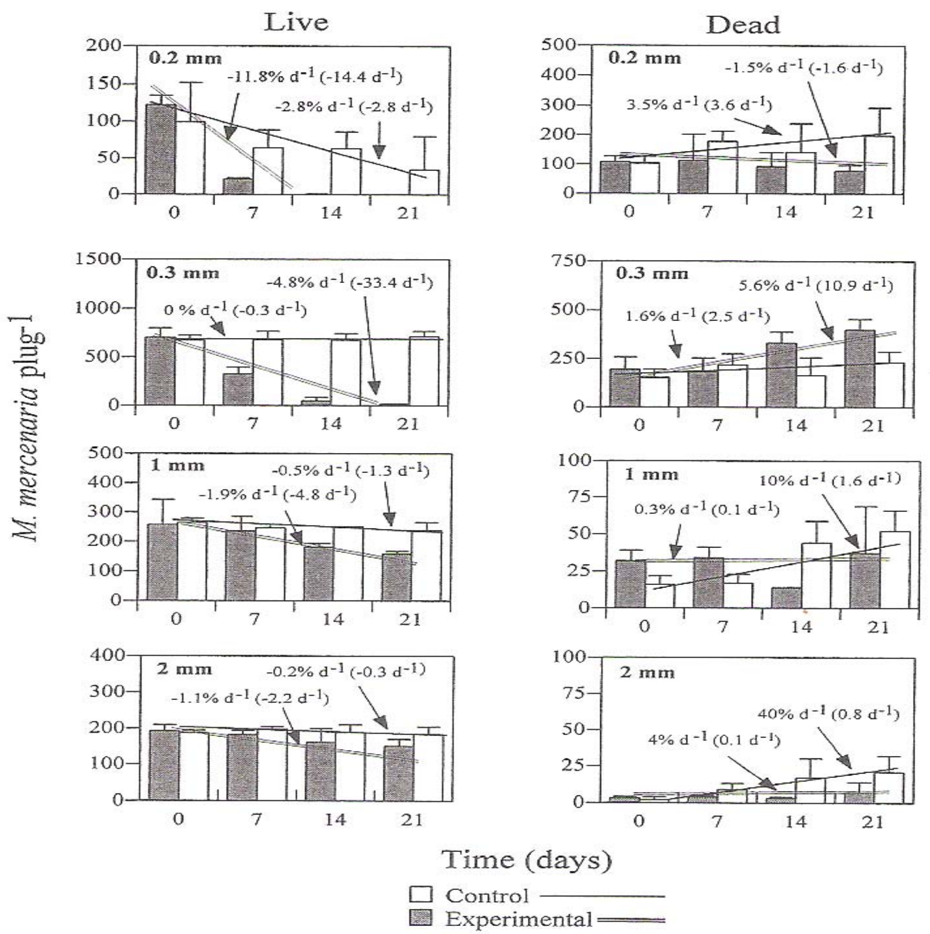
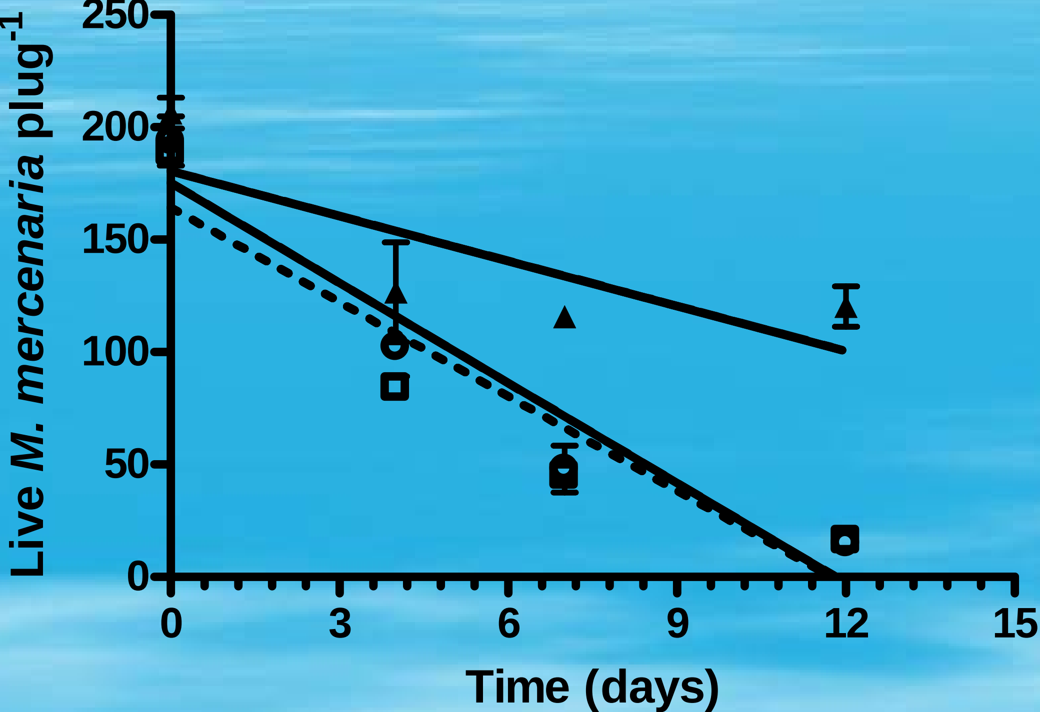



Fig. 3. Mean densities (±SD) of live (left column) and dead (right column) *M. mercenaria* in the 0.2-, 0.3-, 1.0-, and 2.0-mm size classes in experimental-undersaturated and control-saturated treatments. Mortality rates and accumulation of dead bivalves are shown as % $d^{-1}$ for both treatments. Also shown (in parentheses) are the absolute changes in both live and dead bivalve numbers as a function of time.

Green et al., 2004, *Limnol. Oceanogr.*

# 0.2 mm live *M. mercenaria*



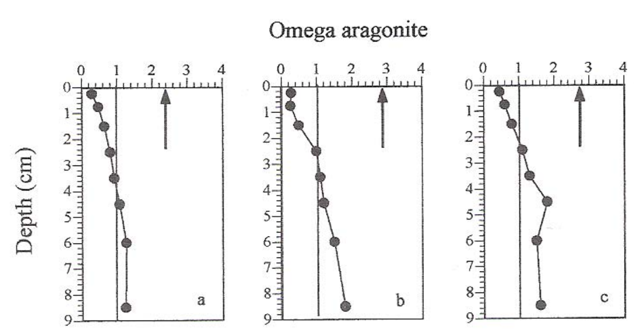
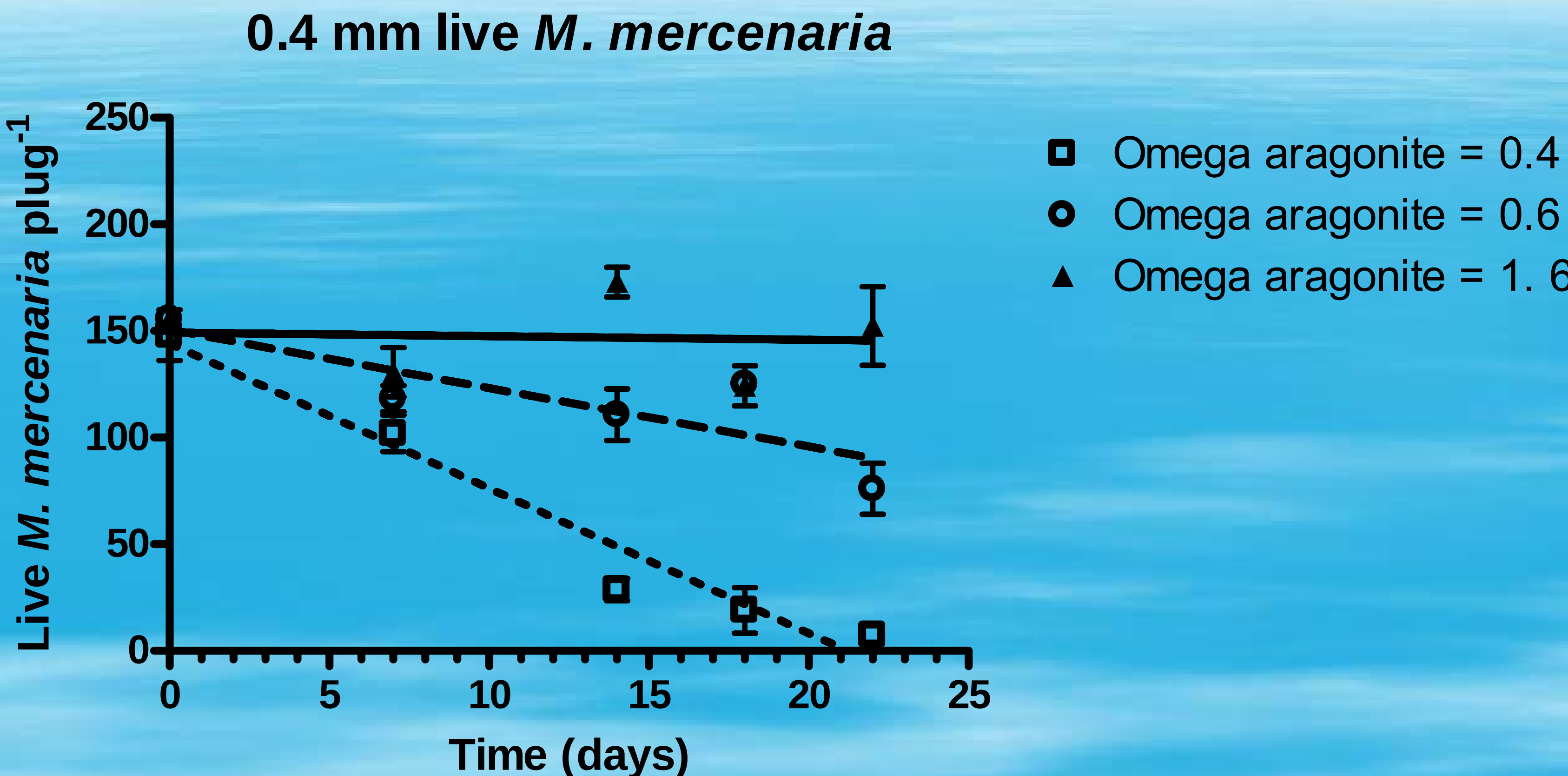
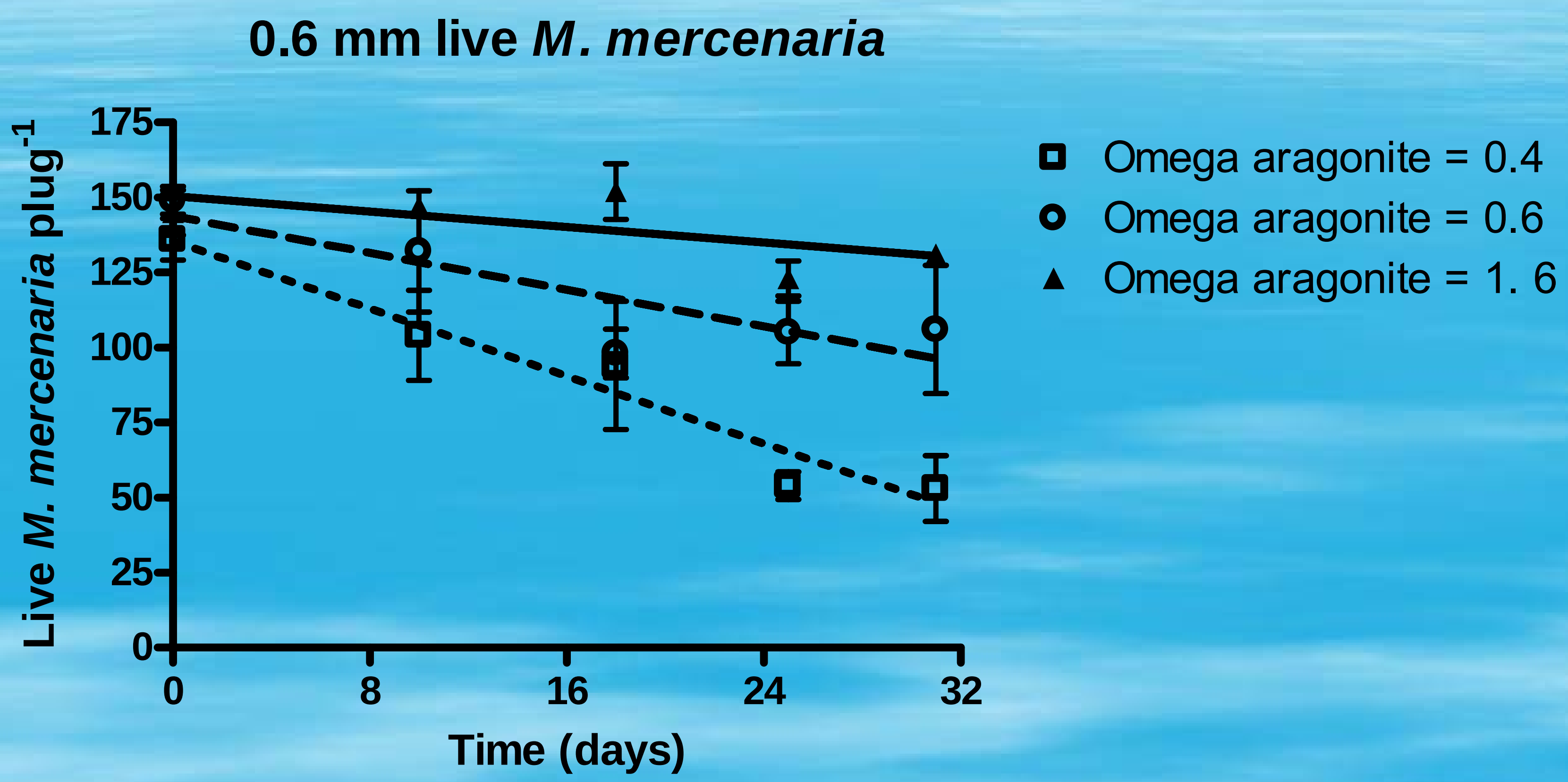



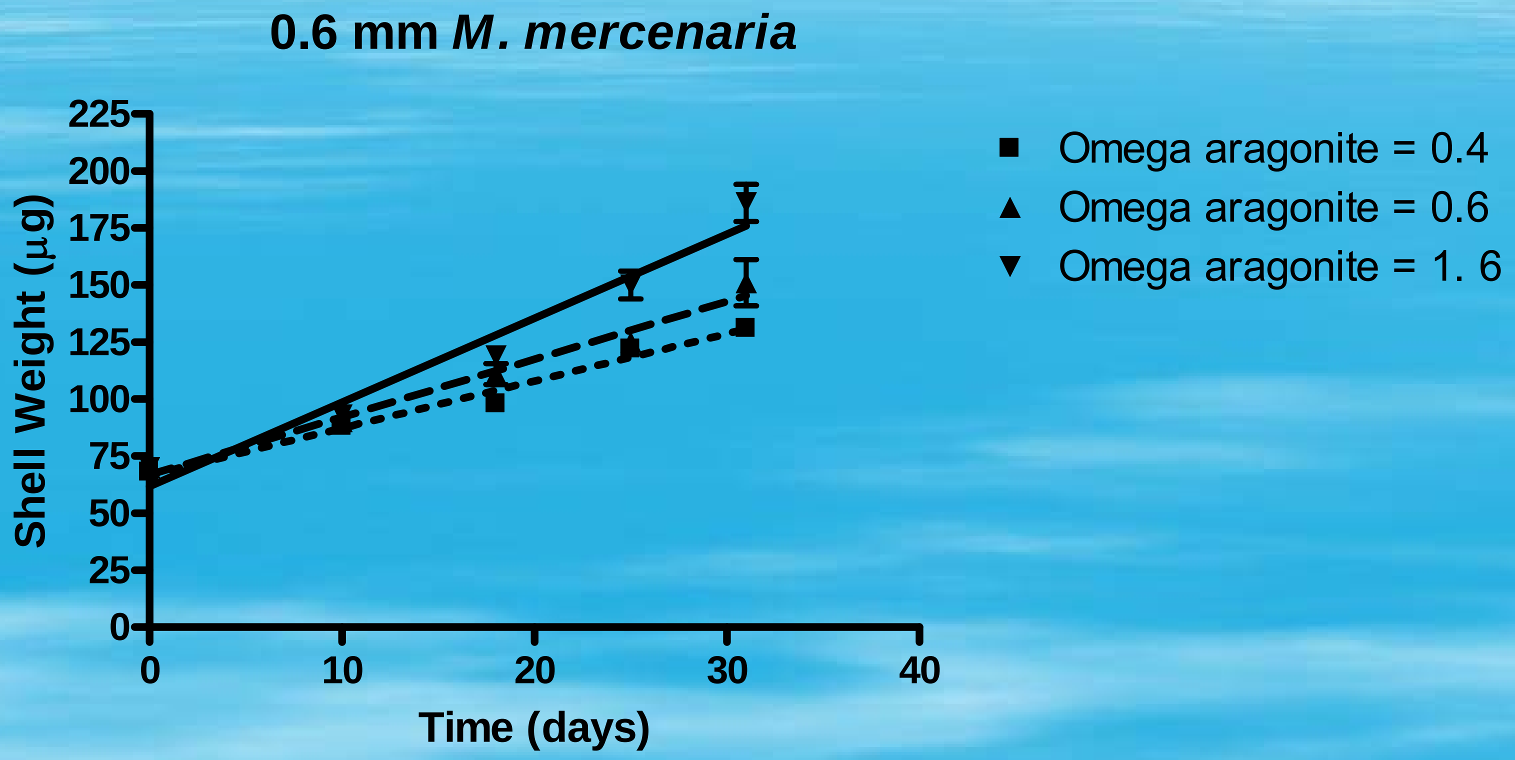

Fig. 5. Sediment saturation state in three coastal estuaries located along the northeastern United States coast. Sediments shown here were recovered during late spring/early summer in (a) Casco Bay estuary, (b) Barnstable harbor, and (c) Long Island sound and all show marked undersaturation from the sediment–water interface to depths of 2–3 cm. Maximum undersaturation occurs adjacent to the SWI in each case with $\Omega_{aragonite}$ values ranging from ~0.2 to 0.4. Overlying water saturation states are shown by the dark arrow and are supersaturated in each case.



0.4 mm live M. mercenaria
Live M. mercenaria plug-1
250
200
150
100
50
0
0
5
10
15
20
25
Time (days)
Omega aragonite = 0.4
Omega aragonite = 0.6
Omega aragonite = 1. 6



0.6 mm live M. mercenaria
Live M. mercenaria plug-1
175
150
125
100
75
50
25
0
0
8
16
24
32
Time (days)
Omega aragonite = 0.4
Omega aragonite = 0.6
Omega aragonite = 1. 6


0.6 mm *M. mercenaria*
Shell Weight (μg)
225
200
175
150
125
100
75
50
25
0
0
10
20
30
40
Time (days)
Omega aragonite = 0.4
Omega aragonite = 0.6
Omega aragonite = 1. 6

# Research → focus on the little guys……

- What will lower pH in estuarine water do to planktonic clams before they set to underlying sediments?
- The small, post-set clams are VERY prone to dissolution.

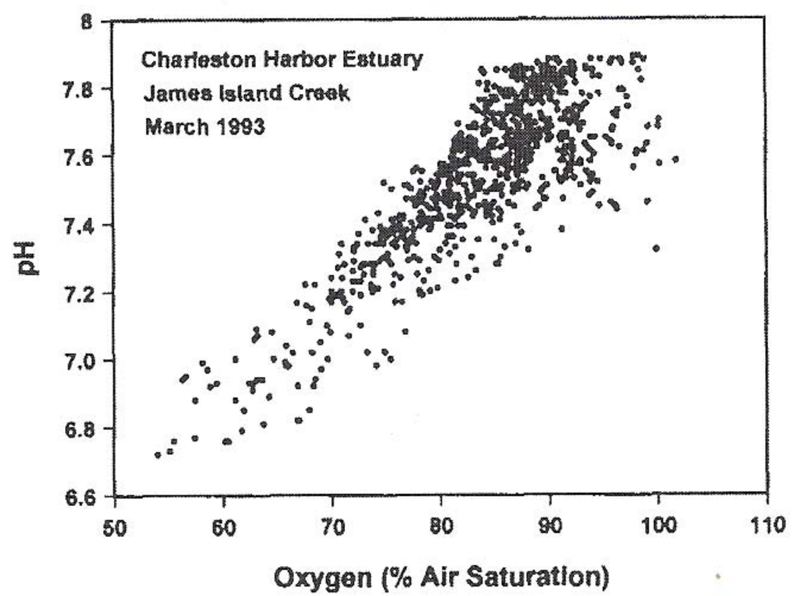


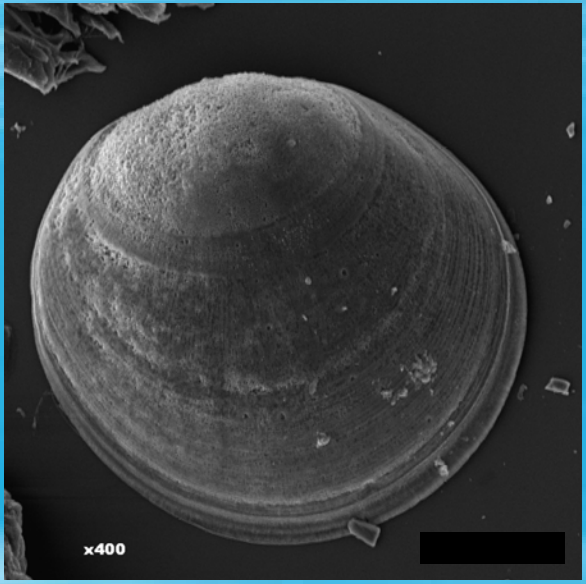

Fig. 1. Oxygen and pH in water samples taken from James Island Creek in the Charleston Harbor Estuary in March 1993. The high correlation between these two variables suggests that changes in pH are explained largely by respiratory production or photosynthetic consumption of $CO_2$. Data provided by Phillip Dustan, College of Charleston from work supported by the Charleston Harbor Project.

From Burnett, L.E., 1997, *Amer. Zool.*

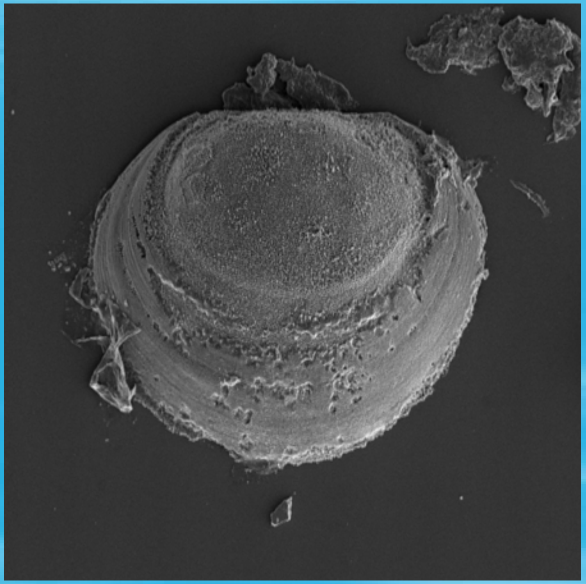
# 2006 Commercial Shellfish Harvest (0-3 miles, NMFS/NOAA Report 2006)

| Shellfish | Metric Tons | Value ($1,000) |
|---|---|---|
| Quahog | 3,954 | $51,818 |
| Geoduck | 1,136 | $20,957 |
| Manila | 405 | $13,145 |
| Ocean Quahog | 4,957 | $6,448 |
| Soft Shell | 1,725 | $23,025 |
| Surf Clam | 7,995 | $10,250 |
| Conch | 992 | $7,230 |
| Mussels | 1,569 | $5,141 |
| Oysters | 12,403 | $121,720 |
| Scallops | 94 | $2,169 |
| Total= | **35,230** | **$261,903** |

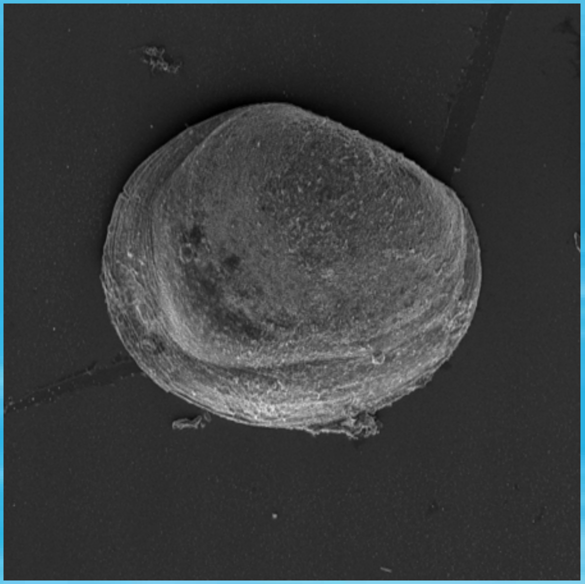
SEM's of larval-stage *M. mercenaria* reared in undersaturated seawater.
Size ≈ 100μm, mag. = 370-400X, pH = 7.5, $\Omega_{aragonite}$ = 0.5.




T= 0 hours

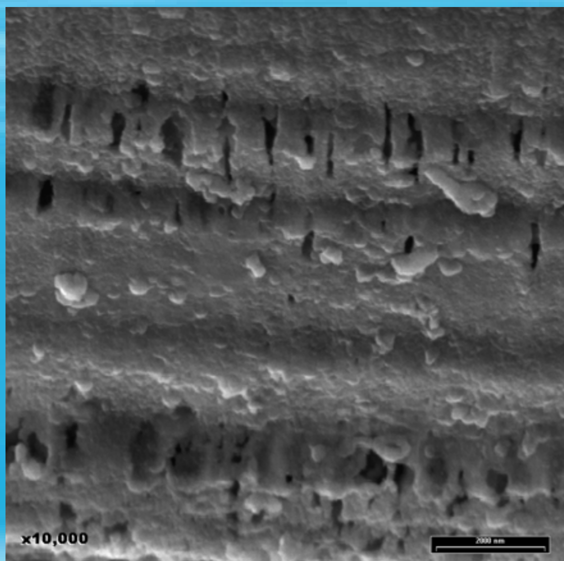


T = 24 hours

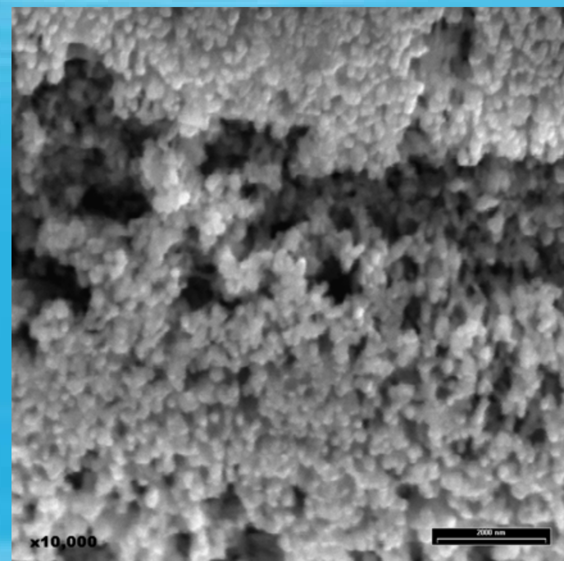


T = 72 hours

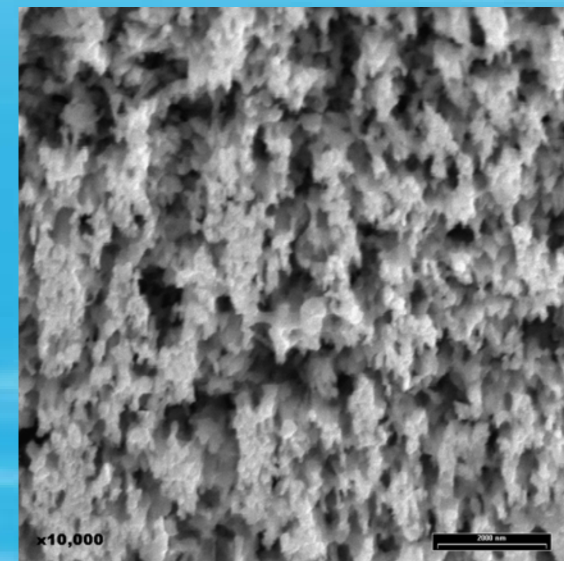
SEM’s of ventral-margin of *M. mercenaria* reared in undersaturated seawater.
Magnification = 10,000X




T= 0 hours

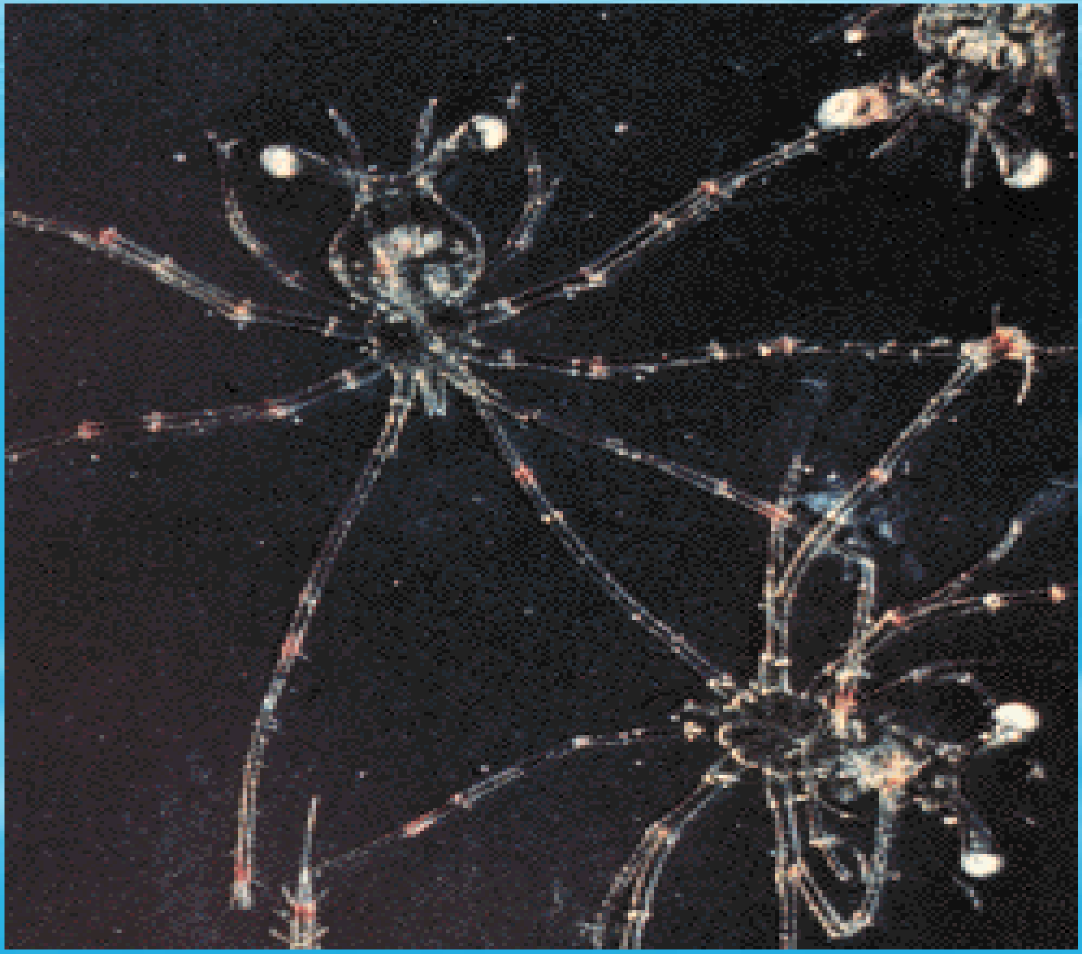



T = 24 hours



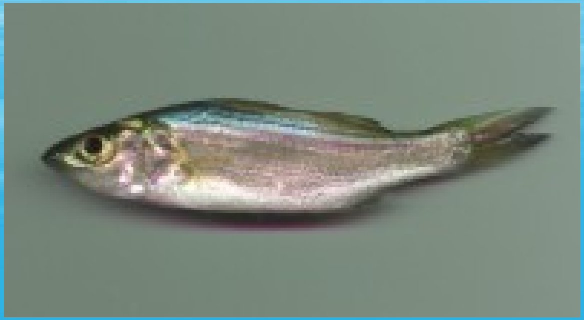

T = 72 hours

# How about planktonic lobster larvae ?



# How about the king crab?

Commercially important juvenile finfish?



# Ocean Acidification: Why Estuaries?

- Life in the oceans is dependent on estuaries.
  - Average net primary production = ~9000 kcal $m^{-2}$ $yr^{-1}$ (similar to avg. values of rainforest ).
  - 90% of all marine species live in coastal/estuarine environment.
  - 2/3 of all marine fish and shellfish rely on estuaries for spawning and juvenile development.
- Estuarine pH's are low and variable and tightly coupled to salinity, photosynthesis, carbon remineralization. Small additional decreases in pH will increase acidity to significant levels.
  - $PCO_2$'s can be so elevated during warm periods that they represent $CO_2$ source to atmosphere (e.g. Frankignoulle et al., 1996, 1998, *Limnol. Oceangr., Science*).
- Additional anthropogenic lowering of pH will take levels below already established thresholds for many marine species.
  - Coastal phytoplankton growth rates sig. influenced by changes in pH above and below equilibrium values (Hinga 2002, *Mar. Ecol. Prog. Ser.*).
  - pH of 7.3 fatal for marine mussel, *Mytilus galloprovincialis* (Michaelidis et al., 2005, Mar. Ecol. Prog. Ser.)
  - *Mercenaria mercenaria* clams from 1-1.2 mm showed growth rates < 50% that of clams deployed in sediments with higher pH conditions (Ringwood and Keppler, 2002, Estuaries).
  - pH of 7.1 resulted in significantly slower growth for *Mytilus edulis* (8.5-25 mm) than at pH >7.6 (Berge et al., 2006, *Chemosphere*)
- Dissolution mortality of at least some cabonate-bearing meiobenthos already occurs. Additional lowering of pH in water and sediments will exacerbate these processes.
  - High surface area/volume ratio makes small carbonate and non-carbonate organisms far more sensitive.

# Conclusions:

- Death by dissolution of small carbonate-bearing fauna is an active process in estuarine sediments where oxidation pathways tend to lower pH just at and below the SWI. These already existing processes will continue and be enhanced and provide an early warning system of things to come.

- Research is needed to focus on other bivalve species, and particularly, the planktonic stages of these and other organisms (survivorship, growth rates, calcification rates, standard metabolic rate measurements, threshold saturation states).

- Research is needed to focus on effects of prolonged lower pH on other small, non-carbonate, estuarine organisms (e.g. commerically important finfish; prolonged exposure to slightly lowered pH causes lower protein synthesis).

- Sub-lethal effects of prolonged exposure to lower pH needs to be considered (e.g. fecundity).

# Science is not done in a vacuum

- NSF, NASA, NOAA
- Bob and Josie Aller
- Roberta Marinelli
- Shannon Reilly
- George Waddbusser
- Aaron Oullet
- Julie Thomason
- Mike Gagne

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