PICES-2017, Vladivostok, Russia

Winner or loser: sea cucumber's future in a CHANGING OCEAN

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28 Sept. 2017

Our ocean is changing !

- LOCAL scale (Human activity)
  - Pollution
  - Eutrophication
  - Hypoxia
  - ……
- GLOBAL scale (Climate change)
  - Ocean acidification
  - Ocean warming
  - Sea-level rise
  - ……

Ocean acidification—$p$$CO_2$ elevated, pH decreased

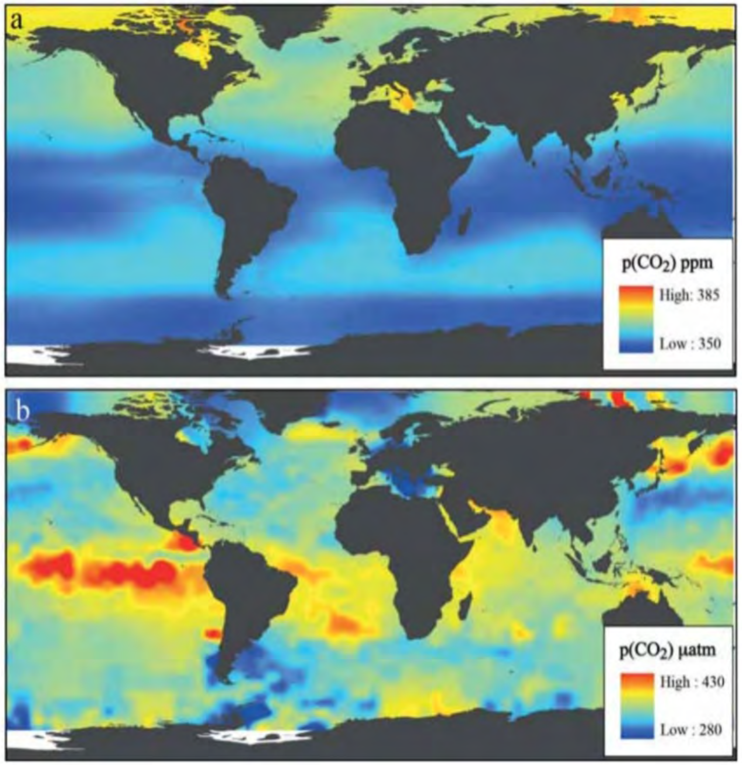


Figure 3.1 Carbon dioxide concentrations over the ocean. A. Atmospheric p(CO_2) levels (ppm). B. Surface p(CO_2) (µatm). Note the change in scale among plots. Data from Takahashi *et al.* (2009).

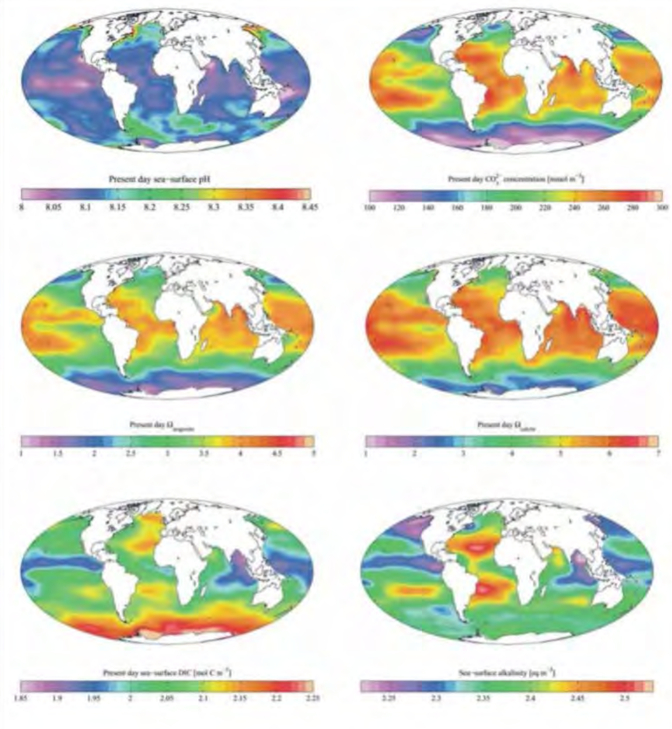


Figure 3.2 Distribution of ocean carbonate system parameters over the world ocean during the 1990's. Total dissolved inorganic carbon (DIC) and A_T (total alkalinity) are from the GLODAP database (Key *et al.*, 2004), and represent surface water (0 m) of the open ocean. Other carbonate system parameters were calculated from DIC and A_T using the *csys* software (see main text) and temperature (Stephens *et al.*, 2001) and salinity (Boyer *et al.*, 2001) from the World Ocean Atlas database. Plots courtesy of Andrew Yool.

✓The atmospheric CO_2 concentration could reach 750- 1000 ppm, which would reduce the global surface water pH by 0.3-0.4 units, by the end of the 21st century (RCP8.5, IPCC 2013).

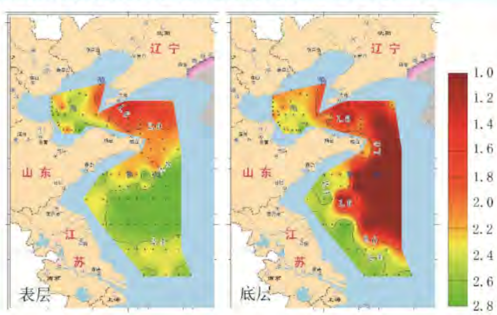
✓In highly dynamic coastal or upwelling areas these changes could be even greater (Cai et al., 2011; Hofmann et al. 2011).

In Bohai and Yellow Seas of China

渤、黄海的酸化状况

全球范围内大气CO_2浓度持续增高，海洋不断吸收CO_2，导致表层海水pH值下降，该现象称为“海洋酸化”。许多海洋生物的骨骼或外壳以碳酸钙为主要成分，其形成依赖于海水碳酸盐系统的状态。海洋酸化导致海水碳酸盐系统发生变化，损伤海洋生物形成钙质骨骼和外壳的能力，进而影响整个海洋生态系统的结构和功能。海水文石饱和度*（$\Omega_{\text{文石}}$）是表征海水酸化对海洋生物危害的重要指标，当$\Omega_{\text{文石}} < 2.0$，大多数海洋生物的钙化作用受到抑制，难以形成钙质骨骼和外壳；若$\Omega_{\text{文石}}$降至1.0，则已形成的钙质骨骼和外壳也将趋于溶解。

在过度开发和富营养化等多重环境压力的共同作用下，近海海域成为响应全球大气CO_2升高及其次生趋势性海水酸化现象的敏感区。2011~2012年渤、黄海海域海水酸化状况试点性监测结果表明，大部分监测海域连片出现底层海水$\Omega_{\text{文石}} < 2.0$的海水酸化现象，其中秋季（11月）最为严重。在黄海中部，底层海水$\Omega_{\text{文石}}$的最低值仅为1.0，达到生物钙质骨骼和外壳溶解的临界点。而在黄海北部西侧海域，表层水体甚至也出现$\Omega_{\text{文石}} < 2.0$的现象，最低可达1.5，表明黄海北部的海水酸化问题已相当突出。



2012年11月渤、黄海海域表层和底层水体文石饱和度（$\Omega_{\text{文石}}$）分布

Bulletin of China's marine environment

Article — Chinese Science Bulletin
Oceanology
March 2012 Vol.57 No.9: 1062–1068
doi: 10.1007/s11434-011-4949-2

Coastal acidification in summer bottom oxygen-depleted waters in northwestern-northern Bohai Sea from June to August in 2011

ZHAI WeiDong[1,2*], ZHAO HuaDe[1,2], ZHENG Nan[1] & XU Yi[2]

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doi:10.5194/bg-11-1103-2014

Biogeosciences
Open Access

Subsurface pH and carbonate saturation state of aragonite on the Chinese side of the North Yellow Sea: seasonal variations and controls

W.-D. Zhai[1,2], N. Zheng[1], C. Huo[1], Y. Xu[2], H.-D. Zhao[1,2], Y.-W. Li[1,*], K.-P. Zang[1], J.-Y. Wang[1], and X.-M. Xu[1]

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Revised: 13 December 2013 – Accepted: 12 January 2014 – Published: 26 February 2014

Effects of OA on species and ecosystems

- Ocean acidification are predicted to alter marine ecosystems due to differences in the relative sensitivities of species to elevated CO_2 and the subsequent effects on intra- and inter-specific interactions.
- The fossil record of past mass extinctions provides clear evidence of the rising CO_2 impacts on regional scales and over vast timescales.
- Evidence already exists for changes in community composition or function, as shown in present day areas with naturally high pCO_2, or reveal smaller-scale changes within guilds as even similar species respond differentially to this climate stressor.

Save Our Seas!

Sea cucumbers (Holothurians), worm-like soft-bodied echinoderms

- Key components in marine ecosystem.
- Inhabit almost all marine habitats from tropical to polar areas, from the shores to deep ocean trenches.
- Dominate the biomass in benthic communities.

Ecological significance

- play an important role in recycling nutrients and carbonate as ecosystem engineers (Uthicke 2001; Schneider et al. 2011).
- used in integrated multitrophic aquaculture systems worldwide (Yuan et al. 2015b; Zomora et al. 2016).

SEDIMENT BIOTURBATION AND IMPACT OF FEEDING ACTIVITY OF *HOLOTHURIA* (*HALODEIMA*) *ATRA* AND *STICHOPUS CHLORONOTUS*, TWO SEDIMENT FEEDING HOLOTHURIANS, AT LIZARD ISLAND, GREAT BARRIER REEF

Sven Uthicke

ABSTRACT

In aquarium experiments and during field observations, *Holothuria* (*Halodeima*) *atra* (Jaeger, 1883) and *Stichopus chloronotus* (Brandt, 1835) consumed an average of 67 and 59 g dry wt of sediment individual^{-1} d^{-1}, respectively. A model calculation showed that a mixed population of both species on a reef flat near Lizard Island, GBR has the potential to rework about 4600 kg dry wt yr^{-1} 1000 m^{-2} which is approximately the weight of the upper 5 mm of sediment in this area. Gut content analyses showed no significant decrease in phycopigments (chlorophylls *a* and *c* and fucoxanthin) during gut passage. In both species the oesophagus pigment content was similar to the concentration in sediments directly in front of the individuals. However, pigment content in front of *S. chloronotus* and in all gut segments of this species were significantly higher than the corresponding values in *H. atra* suggesting patch selectivity in the former species. Extremely low meiofauna contents in holothurian guts indicated that meiofauna play a negligible part in the nutrition of *H. atra* and *S. chloronotus*. In contrast, the ratio of living to dead diatoms was significantly lower in the guts of both holothurian species compared to the adjacent sediment, indicating digestion of the ingested diatoms. In aquarium experiments, feeding and bioturbation activity of both species significantly reduced microalgal biomass (measured as chlorophyll *a* concentrations) in sediments inoculated with diatoms or cyanobacterial mats.

REVIEWS IN Aquaculture

Reviews in Aquaculture (2016) **0**, 1–18 doi: 10.1111/raq.12147

Role of deposit-feeding sea cucumbers in integrated multitrophic aquaculture: progress, problems, potential and future challenges

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1 Leigh Marine Laboratory, Institute of Marine Science, University of Auckland, Warkworth, New Zealand
2 State Oceanic Administration, National Marine Environmental Monitoring Center, Dalian, China
3 Division of Tropical Environments and Societies, College of Marine and Environmental Sciences, Centre for Sustainable Tropical Fisheries and Aquaculture, James Cook University, Townsville, Australia
4 Alfred-Wegener-Institute, Helmholtz Center for Polar and Marine Research, Bremerhaven, Germany

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, G04032, doi:10.1029/2011JG001755, 2011

Potential influence of sea cucumbers on coral reef $CaCO_3$ budget: A case study at One Tree Reef

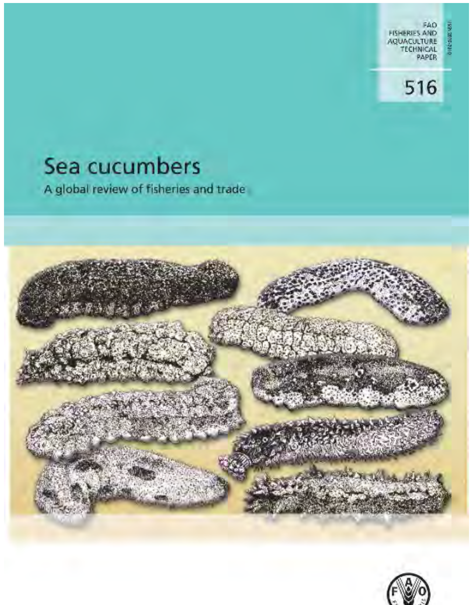
Kenneth Schneider,[1] Jacob Silverman,[2] Erika Woolsey,[3,4] Hampus Eriksson,[3,5] Maria Byrne,[3] and Ken Caldeira[1]

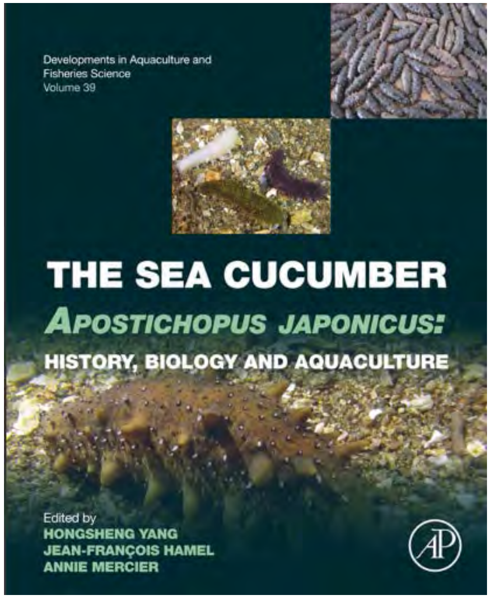
Received 11 May 2011; revised 11 October 2011; accepted 22 October 2011; published 23 December 2011.

[1] To endure, coral reefs must accumulate $CaCO_3$ at a rate greater or equal than the sum of mechanically, biologically, and chemically mediated erosion rates. We investigated the potential role of holothurians on the $CaCO_3$ balance of a coral reef. These deposit feeders process carbonate sand and rubble through their digestive tract and dissolve $CaCO_3$ as part of their digestive process. In aquarium incubations with *Stichopus herrmanni* and *Holothuria leucospilota* total alkalinity increased by 97 ± 13 and 47 ± 7 μmol kg^{-1}, respectively. This increase was due to $CaCO_3$ dissolution, 81 ± 13 and 34 ± 6 μmol kg^{-1} and ammonia secretion, 16 ± 2 and 14 ± 2 μmol kg^{-1}, respectively, for these species. Surveys conducted at a long-term monitoring site of community calcification (DK13) on One Tree Reef indicated that the density of sea cucumbers was approximately 1 individual m^{-2}. We used these data and data from surveys at Shark Alley to estimate the dissolution of $CaCO_3$ by the sea cucumbers at both sites. At DK13 the sea cucumber population was estimated to be responsible for nearly 50% of the nighttime $CaCO_3$ dissolution, while in Shark Alley for most of the nighttime dissolution. Thus, in a healthy reef, bioeroders dissolution of $CaCO_3$ sediment appears to be an important component of the natural $CaCO_3$ turnover and a substantial source of alkalinity as well. This additional alkalinity could partially buffer changes in seawater pH associated with increasing atmospheric CO_2 locally, thus reducing the impact of ocean acidification on coral growth.

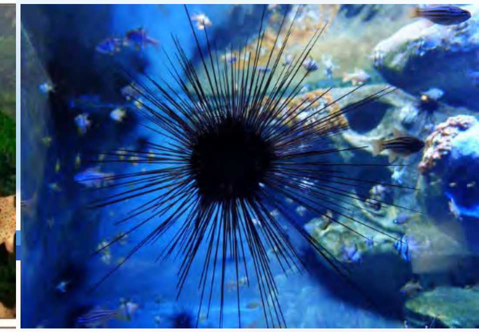
Economic significance

- approximately 1200 known sea cucumbers, of which 70 are harvested worldwide.
- have been used for centuries throughout Asia in traditional medicines and health foods (Yang et al. 2015).
- a market value of >5 billion US$ per annum in China alone (Zhang et al. 2015).





Interesting features



- sea cucumbers are less-calcified compared with other echinoderms such as sea urchins.
- ocean acidification (partly) caused previous mass extinction such as the Permo-Triassic event, but sea cucumbers survived (Knoll et al. 2007；Clarkson et al., 2015).

REPORT

Ocean acidification and the Permo-Triassic mass extinction

M. O. Clarkson[1,*,†], S. A. Kasemann[2], R. A. Wood[1], T. M. Lenton[3], S. J. Daines[3], S. Richoz[4], F. Ohnemueller[2], A. Meixner[2], S. W. Poulton[5], E. T. Tipper[5]

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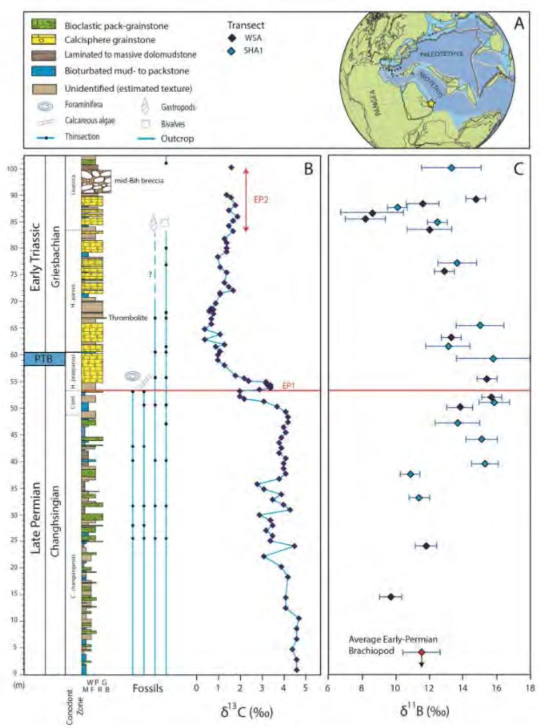
Science 10 Apr 2015:
Vol. 348, Issue 6231, pp. 229-232
DOI: 10.1126/science.aaa0193



OA study has been sharply increased in the last 10 years

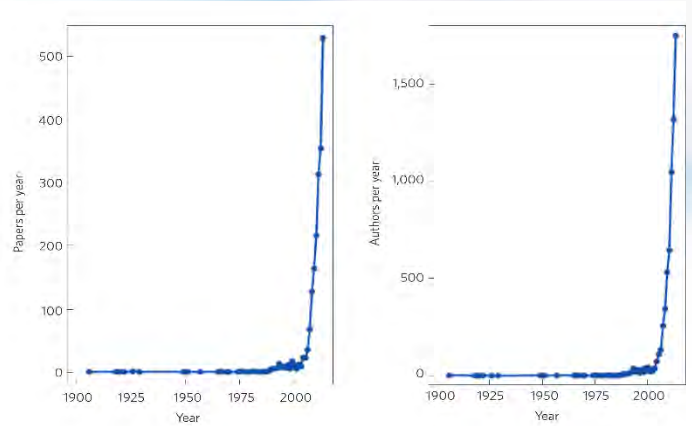
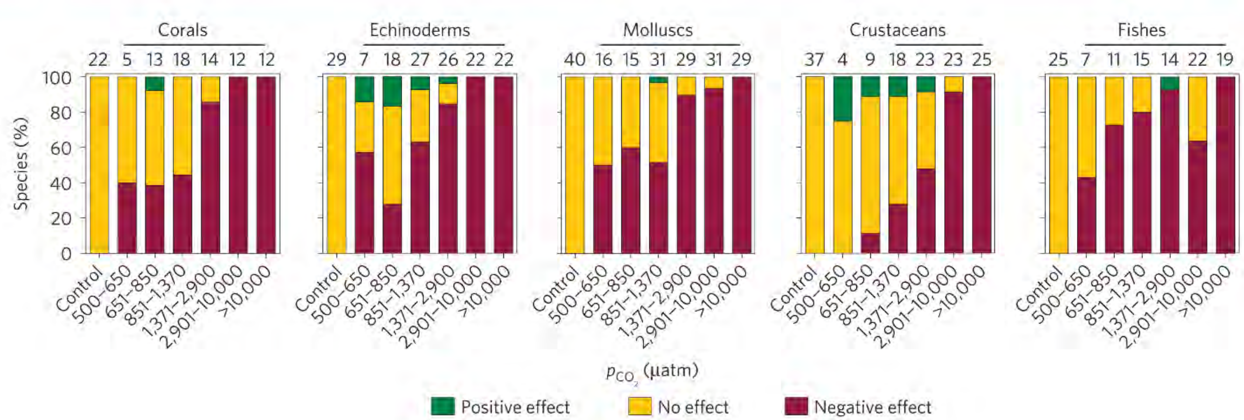


Figure 1 | The number of papers published and number of authors publishing on ocean acidification per yea from 1900 to present (data from ref. 15.). The number of papers increased by 35% per year between 2000 and 2013 compared with an increase of 4.8% per year for all scientific fields (Web of Science database).

NATURE CLIMATE CHANGE DOI: 10.1038/NCLIMATE1982 ARTICLES



Sea cucumbers have been understudied.

Limited work on early-life stages in *Holothuria* spp. and *Apostichopus japonicus* (Morita et al. 2010; Yuan et al. 2015), acid-base physiology in *H. scabra* and *H. parva* (Collard et al. 2014), effects on the bioenergetic trade-offs of *A. japonicus* (Yuan et al. 2016), and carry-over effects of *Cucumaria frondosa* (Verkaik et al., 2016).

Research progress----species level

1. Gonad development
2. Early development
3. Acid-base balance
4. Feeding and energy trade-offs
5. Anti-predation behavior
6. Skeletal responses

1.Gonad development

Vol. 557: 189–206, 2016
doi: 10.3354/meps11868
MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser
Published September 28

Carry-over effects of ocean acidification in a cold-water lecithotrophic holothuroid

Katie Verkaik[1], Jean-François Hamel[2], Annie Mercier[1,*]

[1]Department of Ocean Sciences, Memorial University, St John's, Newfoundland and Labrador, A1C 5S7 Canada
[2]Society for the Exploration & Valuing of the Environment (SEVE), St Philips, Newfoundland and Labrador, A1M 2B7 Canada

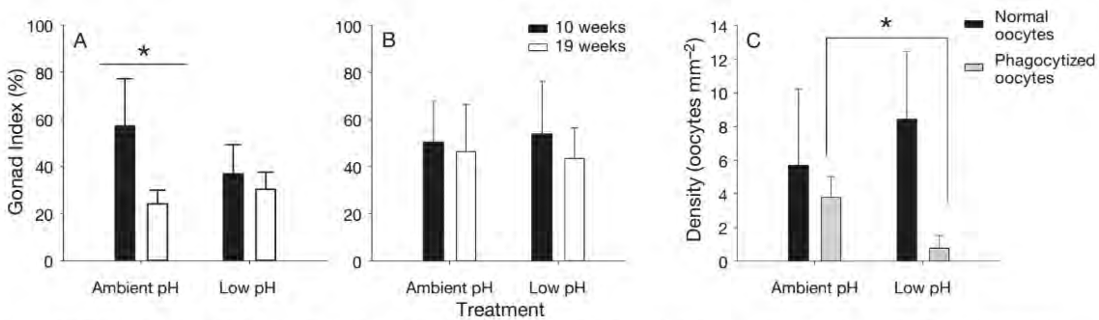


Fig. 2. *Cucumaria frondosa*. Gonad index in (A) males and (B) females at 10 wk (T_{10}; pre-spawning) and at the end of the experiment after 19 wk (T_{19}; post-spawning) under ambient and low pH treatments (n = 5 to 7); (C) number of normal and phagocytized oocytes at T_{19} in both treatments (n = 3). All data are shown as mean ± SD. The asterisk (*) in (A) identifies statistically significant differences between time points for that treatment; refer to text for statistical results. The asterisk in (C) shows statistically significant differences between treatments in the number of phagocytized oocytes; refer to text for statistical results

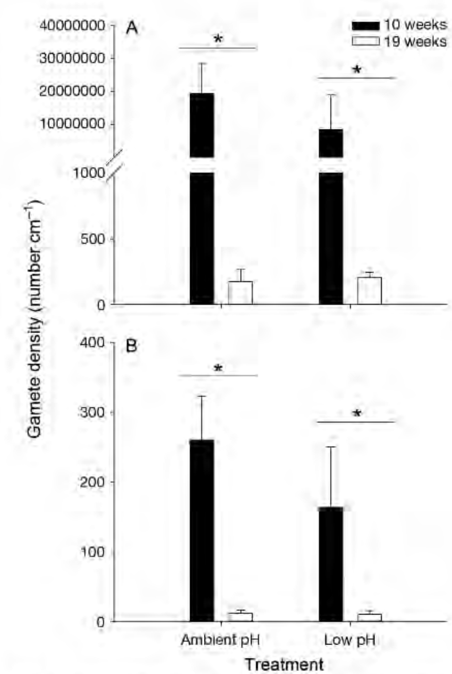


Fig. 3. *Cucumaria frondosa*. Gamete density at T_{10} and T_{19} for (A) males and (B) females (n = 5 to 7). Data are shown as mean ± SD. Asterisks (*) identify statistically significant differences between time points; refer to text for statistical results

Gonad index decreased and oocyte density lowered in 10-week exposure

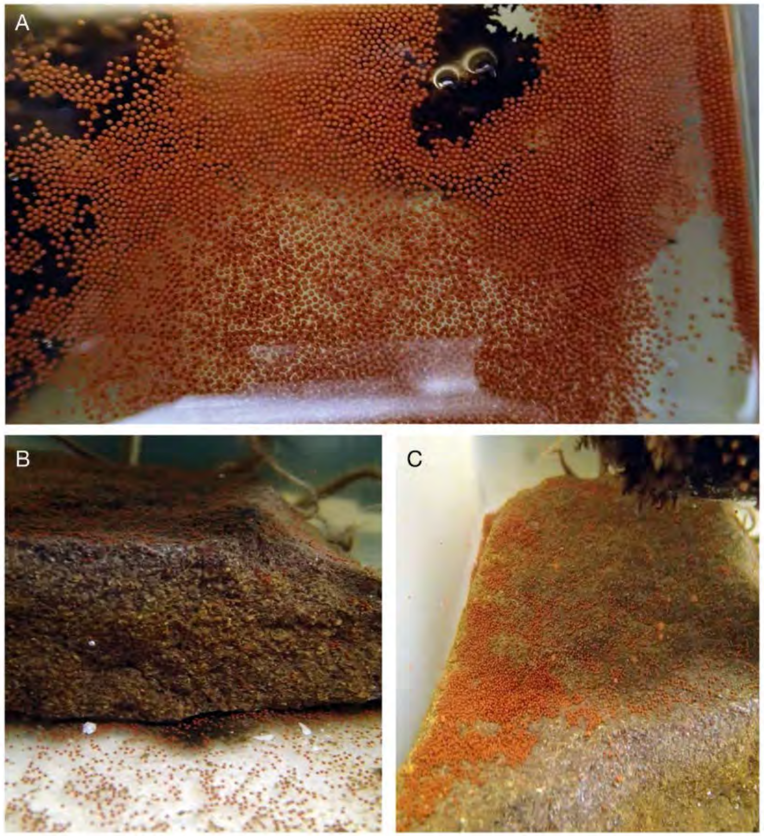


Fig. 5. *Cucumaria frondosa*. Spawning observed during the study: (A) positively buoyant oocytes released under ambient pH floated to the water surface; (B,C) negatively-buoyant oocytes sank to the bottom of the tanks under low pH conditions. The red-orange oocytes measure between 500 and 600 μm

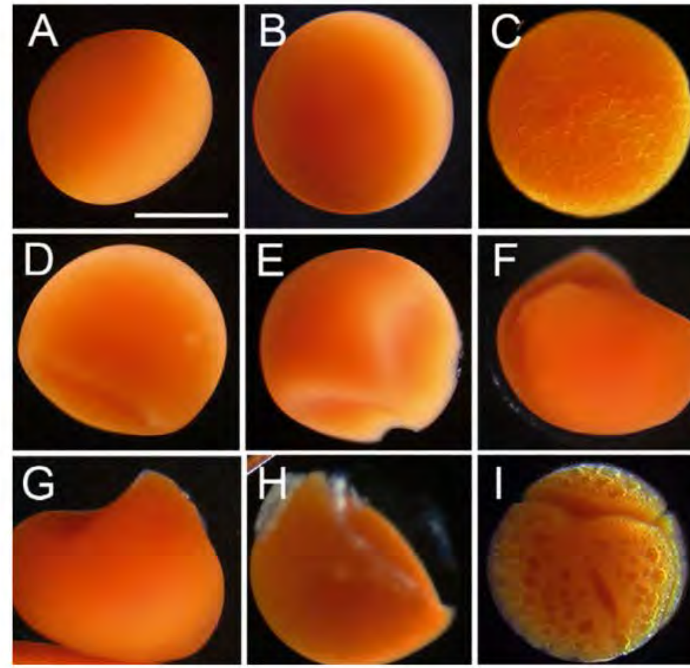
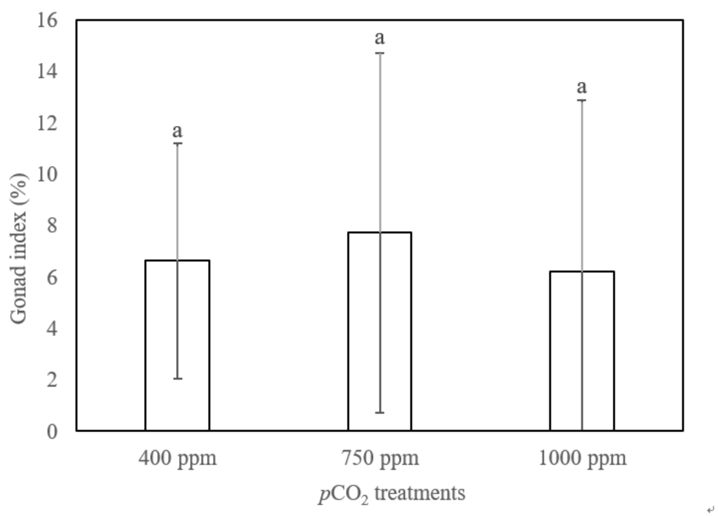


Fig. 6. Comparison of development of *Cucumaria frondosa* under ambient pH (A–C) and low pH conditions (D–I): (A) unfertilized egg; (B) newly fertilized egg; (C) late blastula; (D–H) irregularly shaped oocytes; (I) dividing oocyte showing irregular dimpled surface. Scale bar in (A) represents 300 μm and applies to all panels

Oocyte quality and egg performance changed in *Cucumaria frondosa* (Verkaik et al., 2016).



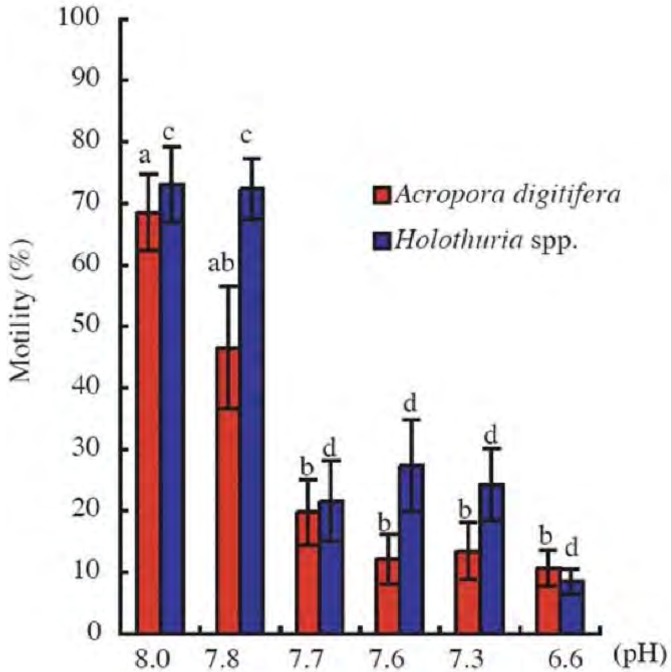
No obvious GI changes in *Holothuria forskali* occurred during a long-term period of 22 wks(Yuan et al., unpublished).

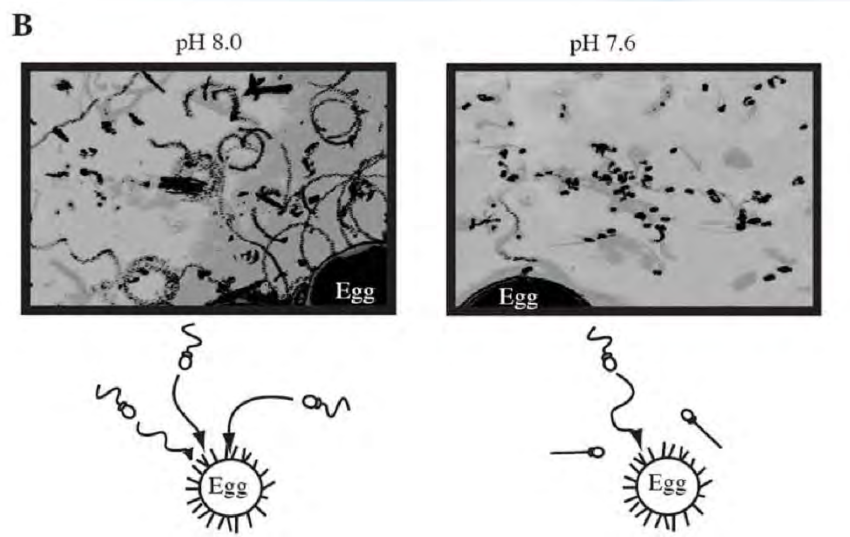
2.Early development

Zygote 18 (May), pp. 103–107. © Cambridge University Press 2009
doi:10.1017/S0967199409990177 First Published Online 20 November 2009

Ocean acidification reduces sperm flagellar motility in broadcast spawning reef invertebrates

Masaya Morita[2,5], *Ryota Suwa*[1,5], *Akira Iguchi*[2,5], *Masako Nakamura*[2], *Kazuaki Shimada*[3], *Kazuhiko Sakai*[2] *and Atsushi Suzuki*[4]
Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus, Okinawa; Ocean Research Institute, University of Tokyo, Tokyo; and Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan





A significant decrease in flagellar motility was detected with reductions in 73% of sperm motile at pH8.0, 72% at pH 7.8, less 30% at pH <7.7

Holothuria spp. (Marita et al., 2009)

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Impact of CO_2-driven acidification on the development of the sea cucumber *Apostichopus japonicus* (Selenka) (Echinodermata: Holothuroidea)

Xiutang Yuan[a,*], Senlin Shao[a], Sam Dupont[b], Leiming Meng[a], Yongjian Liu[a], Lijun Wang[a]

[a] National Marine Environmental Monitoring Center, State Oceanic Administration, Dalian 116023, PR China

[b] University of Gothenburg, The Sven Lovén Centre for Marine Sciences – Kristineberg, Fiskebäckskil 45178, Sweden

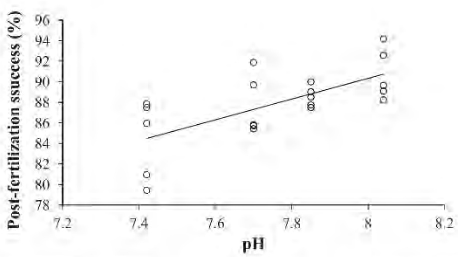


Fig. 1. Relationship between pH_{NBS} and post-fertilization success (%). Each dot represents a replicated culture.

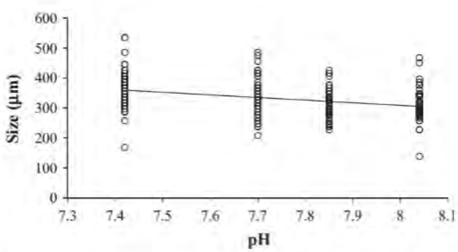


Fig. 4. Relationship between pH_{NBS} and larval body length (µm) for the doliolaria stage at day 11 post-fertilization. Each dot represents a larva.

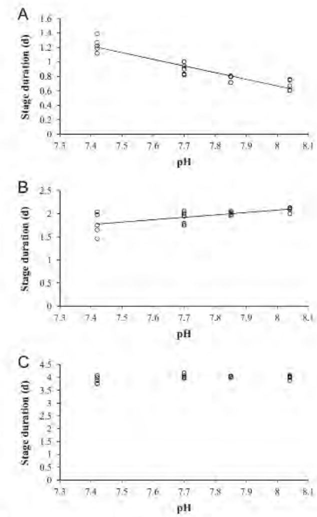


Fig. 2. Relationship between pH_{NBS} and stage duration (d) for (A) early-auricularia, (B) mid-auricularia, and (C) late-auricularia stages. Each dot represents a replicated culture.

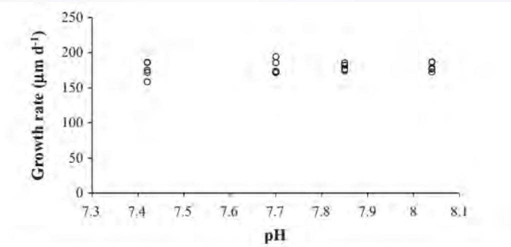


Fig. 3. Relationship between pH_{NBS} and larval growth rate (µm d^{-1}). Each dot represents the regression coefficient extracted from the significant linear relationship between time (day) and body length (µm), for each culture (see regressions in Table S1).

A. japonicus **(Yuan et al., 2015)**

- The impact of pH on developmental time was stage dependent: (i) stage duration linearly increased with decreasing pH in early-auricularia stage; (ii) decreased linearly with pH in the mid-auricularia stage; but (iii) had no effect on the late-auricularia stage.
- Overall, there was no significant effect of pH on the auricularia growth rate. At the end of the experiment, the size of the doliolaria larvae linearly increased with decreasing pH.
- In conclusion, a 0.62 unit decrease in pH had relatively small effects on *A. japonicas* early life-history compared to other echinoderms, leading to a maximum of 6% decrease in post-fertilization success and subtle effects on growth and development.

3.Colemic acid-base balance

Comparative Biochemistry and Physiology, Part A 166 (2013) 199–206

Contents lists available at SciVerse ScienceDirect

Comparative Biochemistry and Physiology, Part A

journal homepage: www.elsevier.com/locate/cbpa

Buffer capacity of the coelomic fluid in echinoderms

Marie Collard [a,b,*,1], Kim Laitat [a,1], Laure Moulin [a,c], Ana I. Catarino [a], Philippe Grosjean [c], Philippe Dubois [a]

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[b] Laboratorium voor Analytische Chemie, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium
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Environ Sci Pollut Res (2014) 21:13602–13614
DOI 10.1007/s11356-014-3259-z

RESEARCH ARTICLE

Acid–base physiology response to ocean acidification of two ecologically and economically important holothuroids from contrasting habitats, *Holothuria scabra* and *Holothuria parva*

Marie Collard · Igor Eeckhaut · Frank Dehairs · Philippe Dubois

Sea cucumbers surprisingly showed no or a very low compensation of fluid pH under acidification, suggesting that more efficient gas exchange structure may be present in holothurians (Collard et al., 2013; 2014).

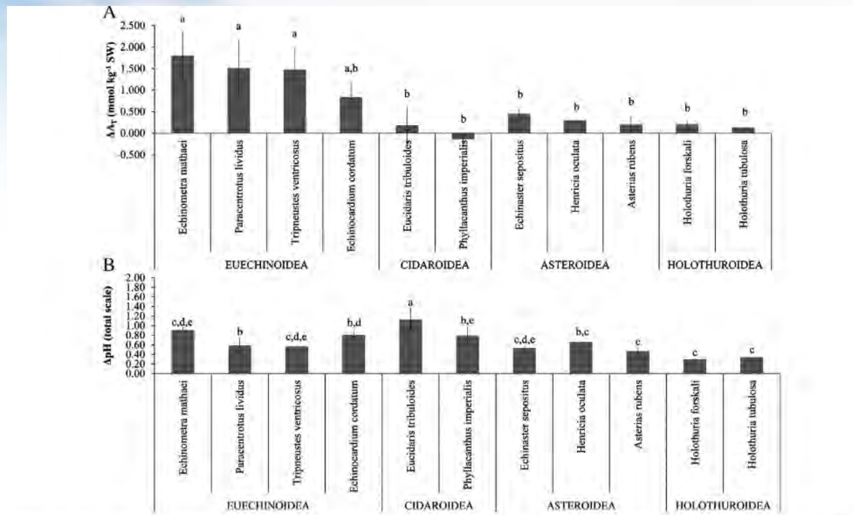


Fig. 1. ΔA_T ($A_{T\text{-}CF} - A_{T\text{-}SW}$) (A) and ΔpH ($pH_{SW} - pH_{CF}$) (B) for different species of the phylum Echinodermata (mean ± SD). Mean values sharing the same letter are not significantly different (one-way ANOVA associated to a Tukey test for multiple comparisons; $\alpha = 0.05$).

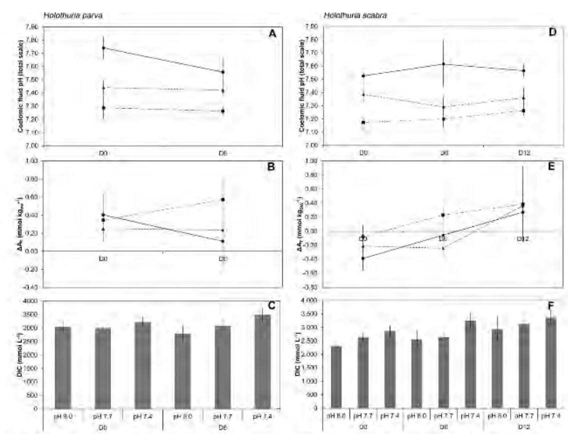
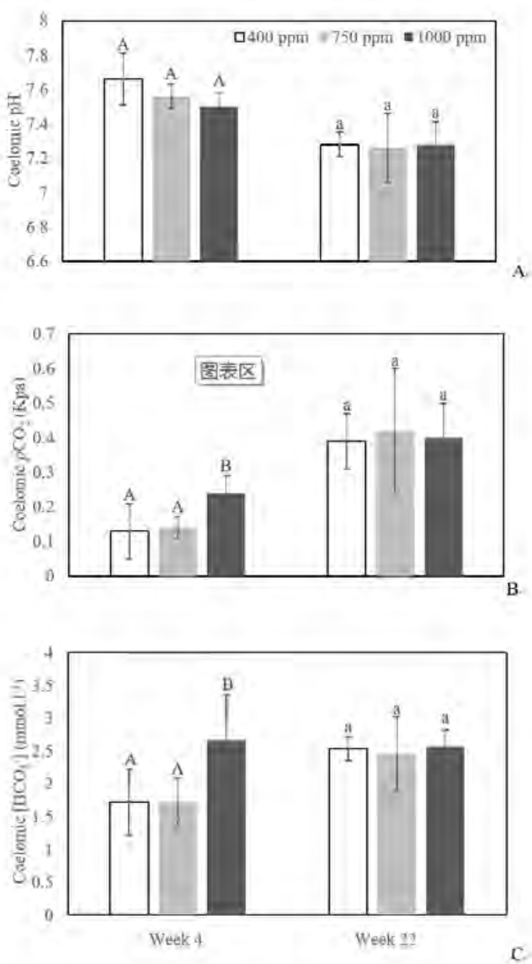


Fig. 1 Physiological parameters of the coelomic fluid according to time. **a** Coelomic fluid pH (mean±SD; total scale) of *H. parva*. **b** Delta alkalinity (mean±SD; ΔA_T; A_T of the coelomic fluid − A_T of the seawater) of *H. parva*. **c** Dissolved inorganic carbon (mean±SD; DIC) of *H. parva*. **d** Coelomic fluid pH (mean±SD; total scale) of *H. scabra*. **e** ΔA_T (mean±SD) of *H. scabra*. **f** DIC (mean±SD) of *H. scabra*. *D* days of exposure to experimental pH (after a gradual decrease). Treatment pH 8.0: *solid line, round markers*; treatment pH 7.7: *dashed line, triangle markers*; treatment pH 7.4: *dashed and dotted line, square markers*. The number of samples is reported in Table S1



◆*H. forskali* did not show an obvious acidosis in its coelemic fluid at both weeks 4 and 22 when exposed to elevated pCO_2, although accompanied by a marked but slight increase in coelomic pCO_2 and $[HCO_3^-]$ at week 4 in 1000 ppm treatment.

◆illustrating a slight or weak compensation in bicarbonate buffer system after a slow and long-time (4 weeks) acclimation (Yuan et al., unpublished).

4.Bioenergetic trade-offs

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RESEARCH ARTICLE

Bioenergetic trade-offs in the sea cucumber *Apostichopus japonicus* (Echinodermata: Holothuroidea) in response to CO_2-driven ocean acidification

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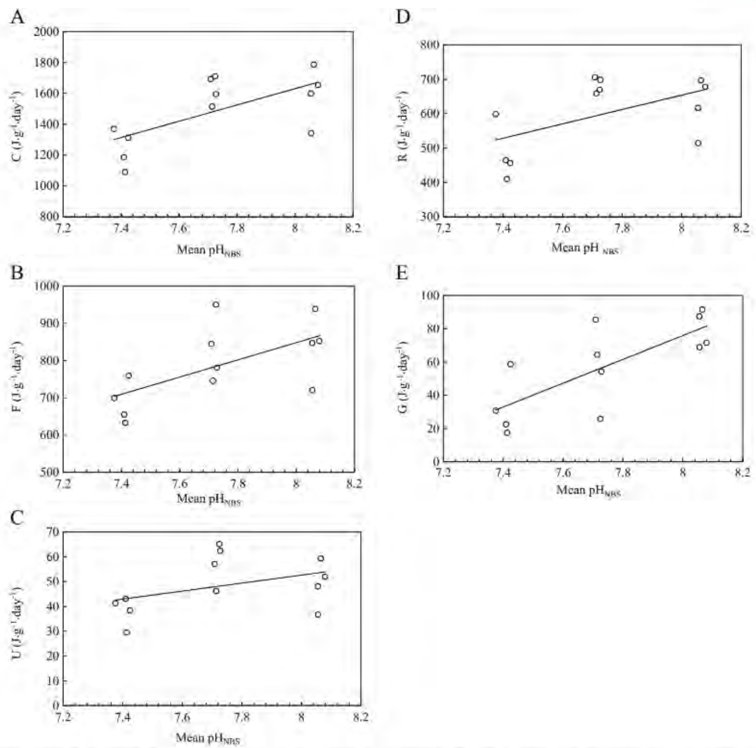
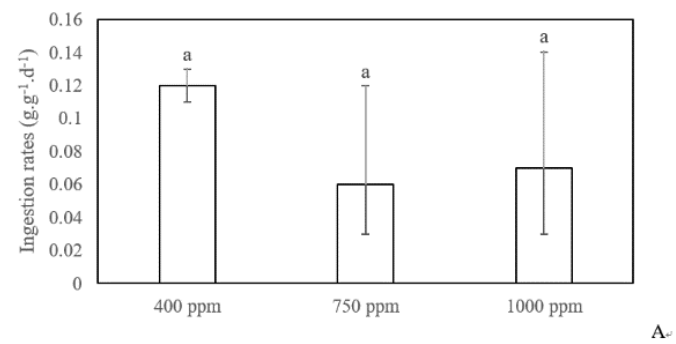
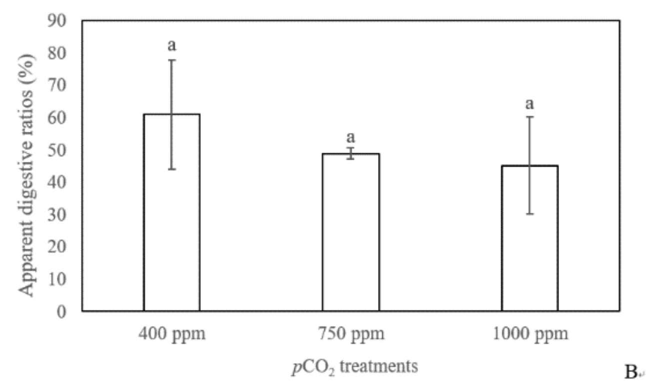


Fig. 2 Relationship between pH_{NBS} and energetic parameters ($J \cdot g^{-1} \cdot day^{-1}$) of sea cucumber *A. japonicus* during 60 days of exposure to different pH levels. Each *dot* represents each culture. *C* is the energy consumed in food, *F* is the energy discharged in feces, *U* is the energy lost in excretion, *R* is the energy lost for respiration, and *G* is the energy deposited into growth

A. japonicus (Yuan et al., 2016)





*Holothuria forskali (*Yuan et al., unpublished)

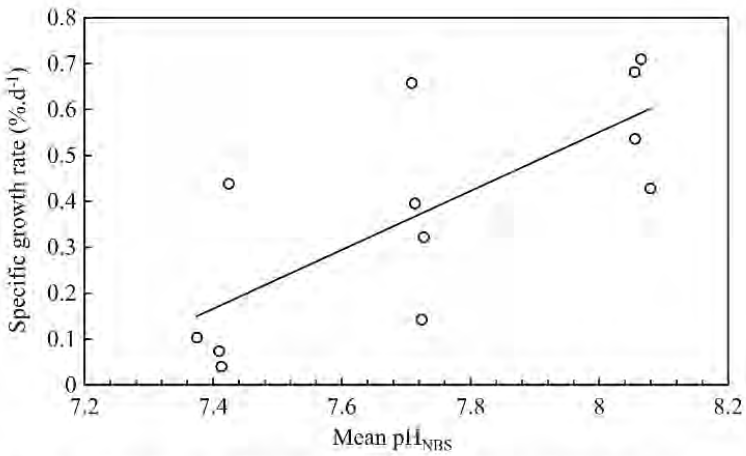


Fig. 1 Relationship between pH_{NBS} and specific growth rates (SGR, $\%\cdot day^{-1}$) of sea cucumber *A. japonicus* during 60 days of exposure to different pH levels. Each *dot* represents each culture

Table 2 Energy allocation of *A. japonicus* exposed to different pH levels during 60-day experiment

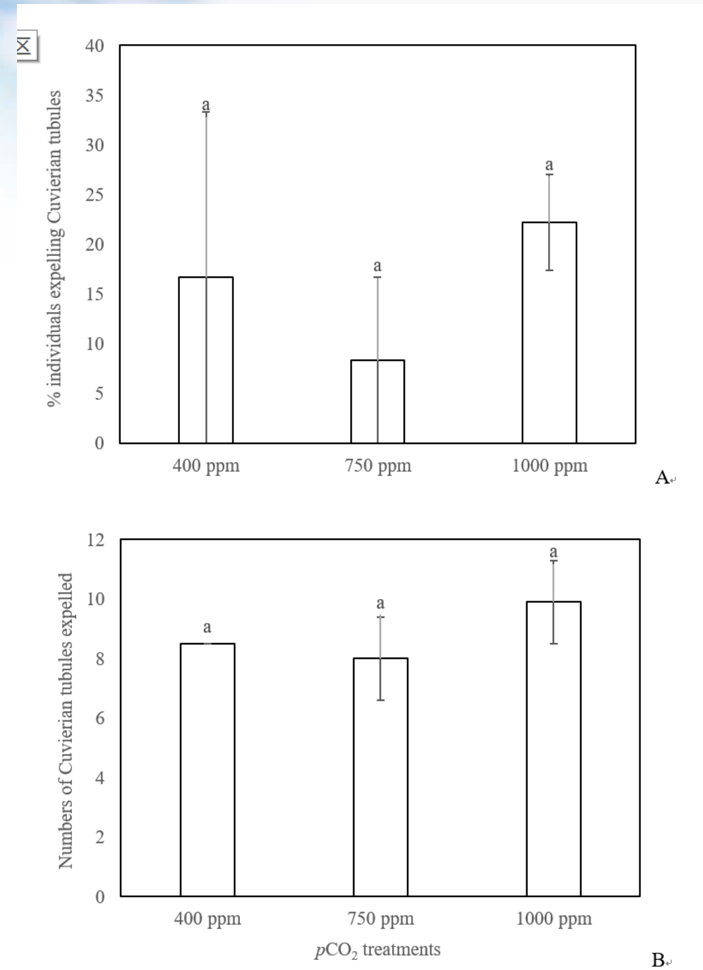
Effective pH	*C*	*F* ($\%C^{-1}$)	*U* ($\%C^{-1}$)	*R* ($\%C^{-1}$)	*G* ($\%C^{-1}$)
8.06	100	52.7 ± 0.9^{ab}	3.1 ± 0.1^{a}	39.2 ± 1.2^{a}	5.0 ± 0.5^{b}
7.72	100	50.9 ± 3.1^{a}	3.5 ± 0.4^{a}	42.0 ± 2.1^{a}	3.6 ± 1.5^{ab}
7.41	100	55.6 ± 3.3^{b}	3.1 ± 0.4^{a}	38.8 ± 3.7^{a}	2.6 ± 1.3^{a}

Values (expressed as mean ± SD, $n = 4$) with different letters in the same column were significantly different from each other (*$p < 0.05$, Tukey's test). *C* is the energy consumed in food, *G* is the energy deposited into growth, *F* is the energy lost in feces, *U* is the energy lost in excretion, and *R* is the energy loss for respiration

A. japonicus **(Yuan et al., 2016)**

5. Anti-predation behavior

Cuvierian tubules



Holothuria forskali **(Yuan et al., unpublished)**

6. Skeletal responses

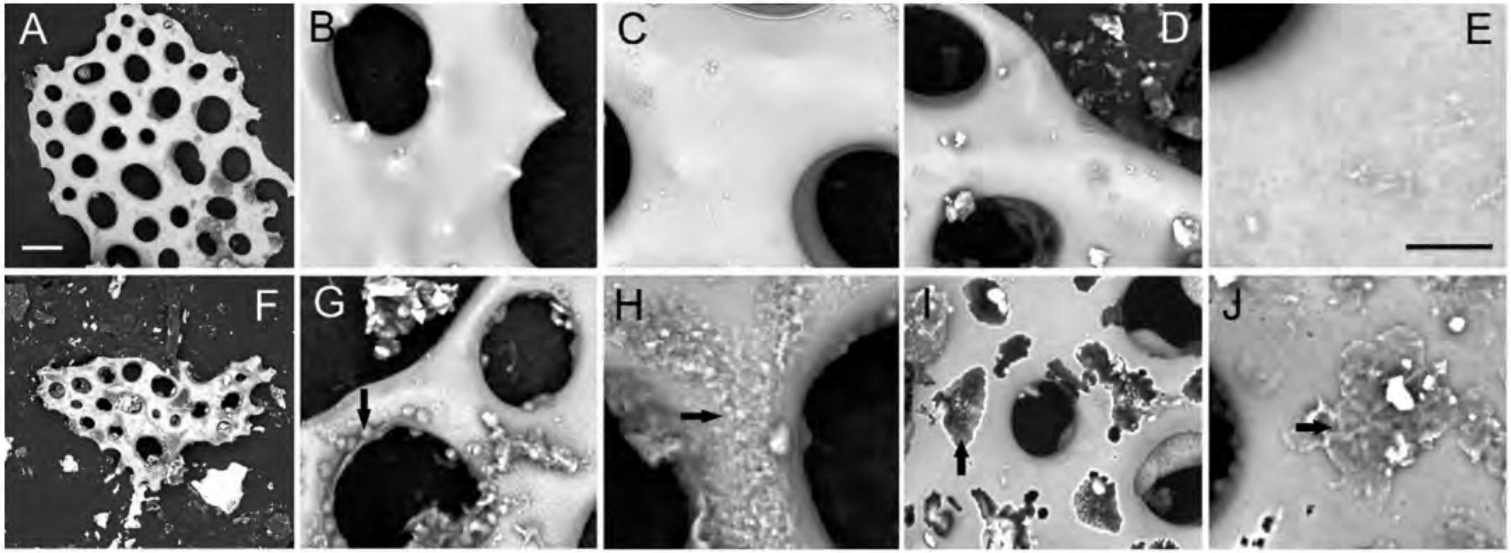
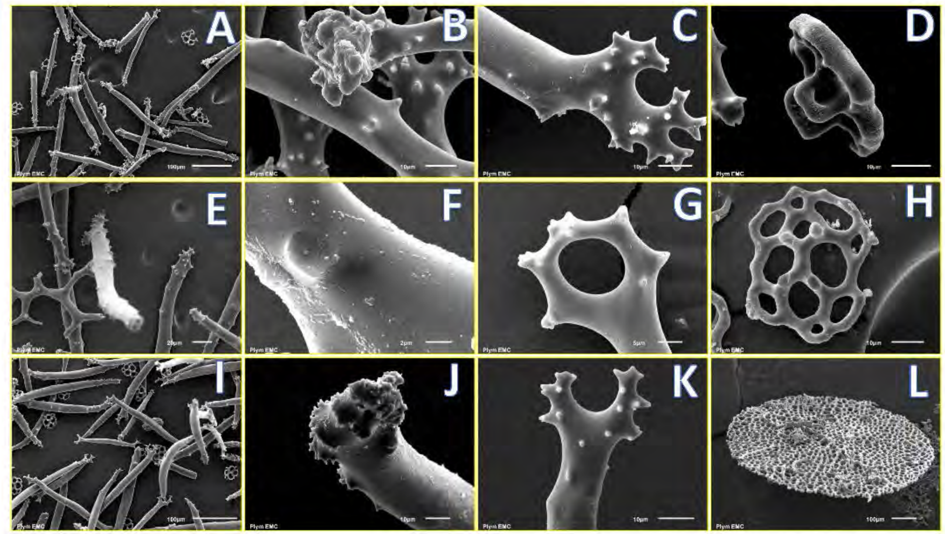


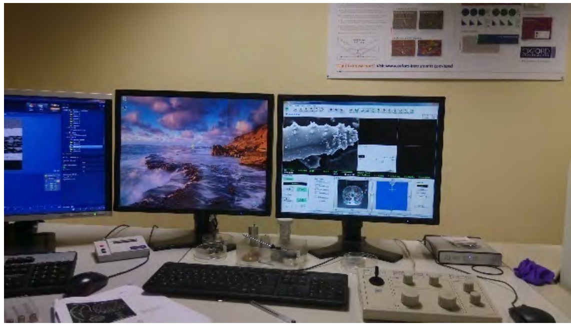
Fig. 8. Ossicles of *Cucumaria frondosa* under ambient pH (A–E), and low pH conditions (F–J). Arrows highlight abnormalities in low pH, showing (G) large calcified bumps and thinning centers, (H) an etched, texturized surface, (I) erosion of ossicle surface and (J) a texturized surface. Scale bar in (A) represents 40 µm and applies to (A) and (F); scale bar in (E) represents 5 µm and applies to all other panels

Cucumaria frondosa (Verkaik et al., 2016).

Table 2 Concentrations of Ca and Mg in ossicles and calcareous rings in *H. forskali* under different pCO_2 treatments. Values (expressed as mean ± SD, n = 3) with different letters in the same column were significantly different from each other ($p < 0.05$).

Treatments	Ossicles		Calcareous rings	
	Ca	Mg	Ca	Mg
400 ppm	27.54±0.91a	2.23±0.07a	26.72±1.80a	2.29±0.18a
750 ppm	26.75±1.70a	2.22±0.08a	28.68±0.29a	2.41±0.73a
1000 ppm	26.61±1.4 图表区	2.19±0.14a	28.14±0.62a	2.37±0.68a





Holothuria forskali **(Yuan et al., unpublished)**

Summary

- Limited researches of OA on sea cucumbers.
- High species-specific.
- Resilience of holothurians to OA compared to other echinoderms.
- The tolerance of sea cucumbers to OA could partially explain the resilience of sea cucumber (vs. high mortality in other echinoderm groups) during previous mass extinction partly caused by OA such as the Permo-Triassic event.

Winner or loser? ?

Not answer but give the question！

Future prospects

- Ocean acidification + warming
- More holothurian species studied (polar, temperate, tropical…)
- Trans-generational, carry-over effects
- Behavior (competition, predation, food chains…)
- From individuals to ecosystem
- Mesocosm-based, long-term test


Global Change Biology

Global Change Biology (2015), doi: 10.1111/gcb.13167

OPINION

Animal behaviour shapes the ecological effects of ocean acidification and warming: moving from individual to community-level responses

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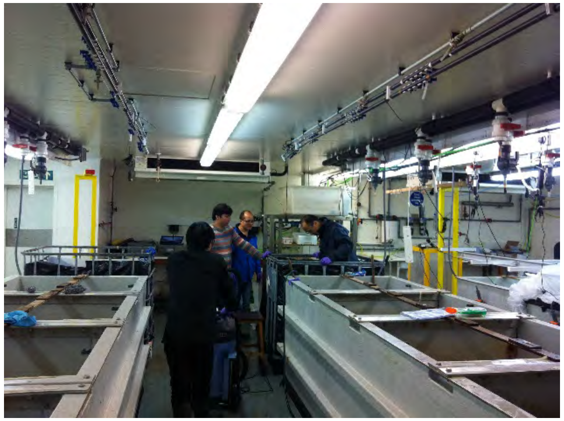

Acknowledgements


Myth?
Thanks!