Corals and climate change

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Photos: T. Nakamura
Corals and climate change

Reef resilience

Adjustments

Climate change

Reproduction

Corals

A coral’s life cycle

Broadcasters

Brooders

Egg and sperm bundles

Hermaphrodites

Wallace (1999) Staghorn corals of the world

Photo: P. Harrison
Males > Females

Yossi Loya and Kazuhiro Sakai (2008)
Proc Royal Soc B 275: 2335-2345
Why mass spawning?

What is the long-term advantage (i.e., the adaptive significance) of mass spawning?

Spawning occurs during calm seasons
Hypothesis: there is a strong relationship between synchronous spawning and calm seasons

Global analysis – Tropical Microwave Imager (TMI) data, randomly selected pixel in reef vicinity, for each month (from 1999 to 2007)

- Great Barrier Reef (latitude 19°S)
- Okinawa (26°N)
- Palau (7°N)
- Kenya (3°S)
- Galápagos (0°)
- Ningaloo (21°S)
- Florida Keys (24°S)

Spawning period = -1.9773 + 1.4773 \times x; 0.95 Conf.Int.

\[
\begin{align*}
\text{adj. } R^2 &= 0.809, \quad p = 0.005
\end{align*}
\]
Repercussions:

Mass spawning during seasonally calm periods agrees with genetic evidence of local retention.

... most recruitment is local (10s km), but there is also, albeit infrequent, connectivity over large distances.

Darwin’s dilemma

How do coral reefs thrive in low nutrient environments?
Darwin’s dilemma: how do coral reefs thrive in low nutrient environments?

Symbiosis

Sustainability – a model system with over 245 million years of success
Light intensity

Porites sillimanian

Low-light

High-light

Sunlight

Light resource

Surface area

Large light resource

Same surface

Light resource
Persistence of coral reefs

1) Natural beauty and diversity
2) Coral reefs are important physical structures
3) Corals reefs supply goods and services to humans

Global Climate Change

Global warming is:

... the unusually rapid increase in Earth’s average surface temperature over the past century primarily because of the release of greenhouse gases by people that are burning fossil fuels.
Joseph Fourier’s argument was the earth’s atmosphere acted like the glass of a hot-house


Jean Baptiste Joseph Fourier : March 21, 1768 - May 16, 1830

Svante August Arrhenius, Feb 19, 1859- Oct 2, 1927


CO₂ - rate of change!

“The rate of change is 100 times faster than anything seen in the past hundreds of millennia”
Increase in CO₂

- Rise in air temperature
- Rise in ocean temperature
- Decrease in ocean pH
- Melting of ice caps (on land) = sea-level rise

Last 20 years – average increase of 0.5°C

Webster et al 2005. Science
Santer et al 2006. PNAS 103: 13905-13910

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IPCC 2007
Present location of reefs

Present Region > 18°C (64°F)

Thriving Acropora cervicornis populations off Ft. Lauderdale after 4000-year hiatus

Bill Precht

Thermocline/NCODS Degree Heating Weeks for Last 12 Weeks - 10/28/2006
Photosynthesis

Normal temperatures

Light Reactions

\[ \text{H}_2\text{O} \rightarrow \text{O}_2 \rightarrow \text{CO}_2 \rightarrow \text{Organic C} \]

Dark Reactions

\[ \text{O}_2 \rightarrow \text{Active Oxygen} \]

BLEACHING

Oxidative DAMAGE

Capacity overwhelmed

Slide: Hoegh-Guldberg

Symbiotic dysfunction

Southern Japan, 1998

Starvation
More bleaching and coral death in shallow habitats than in deep habitats

Favia favus

~ 20% Photosynthetic Active Radiation

3 m

More bleaching and coral death in shallow habitats than in deep habitats

~ 20% Photosynthetic Active Radiation

3 m
Ecology and Evolution

Climate-change refugia in the sheltered bays of Palau: analogs of future reefs

Robert van Woesik, Peter Houk, Aidité L. Heschel, Jacques W. Idechong, Steven Victor & Yimmyng Gollan

van Woesik et al 2012 Ecology and Evol

Clear reciprocity between temperature & light

Corals experience light & temperature in a similar manner

Light

Temperature
Clear reciprocity between temperature & light

Corals experience light & temperature in a similar manner

Florida’s coral reefs

van Woesik

van Woesik

2005, 69-day composite temperature map


Caribbean is a disease hotspot

Are diseases increasing?

Diseases: over 30 diseases described, only 3 with a specific pathogen... (in 25 years of research)

Compromised-host hypothesis

Do the fishes care?

Yes! Fishes aggregate around reef-building corals

Munday et al. 2008, Fish & Fisheries 9: 261-285

Another issue

Rising atmospheric CO₂ concentrations over the past two centuries have led to greater CO₂ uptake by the oceans.

NOAA image
IPCC 2013


Ries 2011 Nature Climate Change 1: 294-295
Effects of ocean acidification on the dissolution rates of reef-coral skeletons

Perforate

Imperforate

Loss of calcium carbonate (g)

Surface area (cm²)

Perforate corals

Imperforate corals
Message:
The higher the cover of live corals the greater the chance of reef growth.
The Republic of the Marshall Islands

Parts of Majuro are only 30 cm above sea level

March 5, 2014 (King Tides)
More Storms?

Global storms 150 years

Tracks and Intensity of All Tropical Storms

Saffir-Simpson Hurricane Intensity Scale
Tropical storms

Before

After


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Before Bonnie

After Bonnie

Hurricane Bonnie 2004

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Before Bonnie

After Bonnie

Hurricane Bonnie 2004
**2005 Temperature stress**

- **In-situ temp data from Harold Hudson**

**Global time series for 1970-2004**

- **Katrina**
- **Rita**

**Intensity of hurricanes**

- **Saffir-Simpson scale (categories 1 to 5)**

- **P. J. Webster et al., Science 309, 1844-1846 (2005)**
Hurricane Wilma, 2005

Puerto Morelos - Mexico

Coral Reefs

• Protect the coastline
• Biodiversity hotspots
• Recreation & tourism
• Fishing grounds....

Reproduction

Reef resilience

Corals and climate change

Corals

Adaptation

Climate change
Will refuges save reefs?

• Where are the refuges?
  • Deep reefs?
  • Habitats that experience low temperatures?
  • Habitats that experience strong currents?

Can corals adapt?

Do corals have the ability to rapidly evolve tolerance to changes in ocean temperature that are likely by the end of the current century?
Driving question

Which coral populations are destined to become the ‘winners’ and which populations are destined to become the ‘losers’?


Hierarchy of tolerance

- Leptastrea - Ophisthaster spp. (Encrusting)
- Gonipatra aspera (Encrusting - Massive)
- Porites lutze (Massive)
- Porites cylindrica (Branching)
- Acropora spp. (Branching)
- Pocillopora damicornis (Branching)
- Millepora intricata (Branching)

Differential reproduction is at the ‘heart’ of adaptation

Adaptation involves differential-reproductive rates on different individuals within populations.

Annual reproduction (recombination) = biannual in tropics

Thermal event filter

10 years of recovery
Only alleles experiencing persistent selection pressure may attain high frequency.

Reproduction events

Thermal event filter

2-3 years of recovery

Reproduction

Coral resilience

Coral and climate change

Adjustments

Climate change

Resilience-based management

- Conservation and sustainable use
- Halt and reverse pollution
- Watershed management
- Protect biodiversity & connectivity
- Prevent over-fishing
- Increase stability of desirable states

Resilience - a framework for management response to climate change

Sea temperatures
- Reduce rate & magnitude of change

Reef condition
- Increase resilience

Refugia

Water quality

Biodiversity

Connectivity
Recommendations

1. Establish and strictly enforce networks of Marine Protected Areas that include No-Take Areas.
2. Control terrestrial discharge on coral reefs (from rivers and local sources).
3. Need regional and global action to reduce effects of climate change.

“Healthy reefs may keep up with sea level rise”
“Degraded reefs will not keep up”

Resilient systems are self-sustaining!
The degree to which global warming changes life on Earth depends on our decisions.

Conclusions

- Projected changes in climate may drive temperature and seawater chemistry to levels outside the envelope of modern reef experience.
- Some reef organisms will adapt to climate change more than others — some will be winners, while others will be losers.
- Local connectivity suggests that local protection and management will lead to local benefits. Action and protection may buy time for adaptation.

Evolution of the system

Selective pressure
Evolve toward synchronization