Contribution of algal symbionts to the adaptive capacity of reef corals

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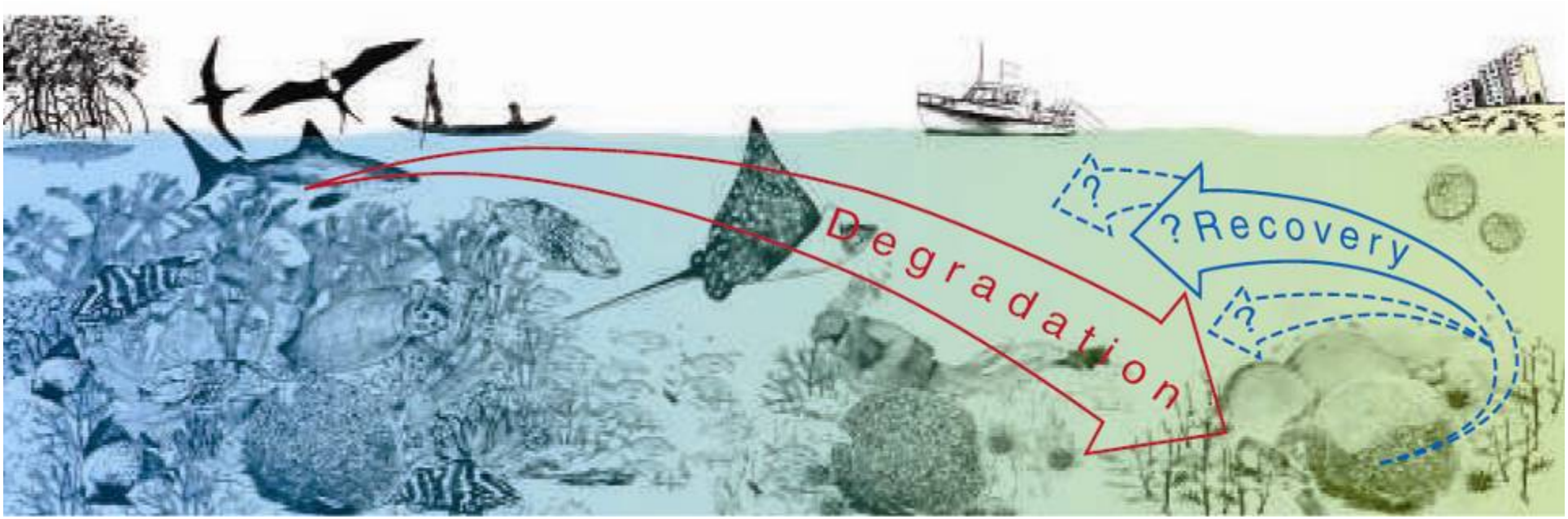
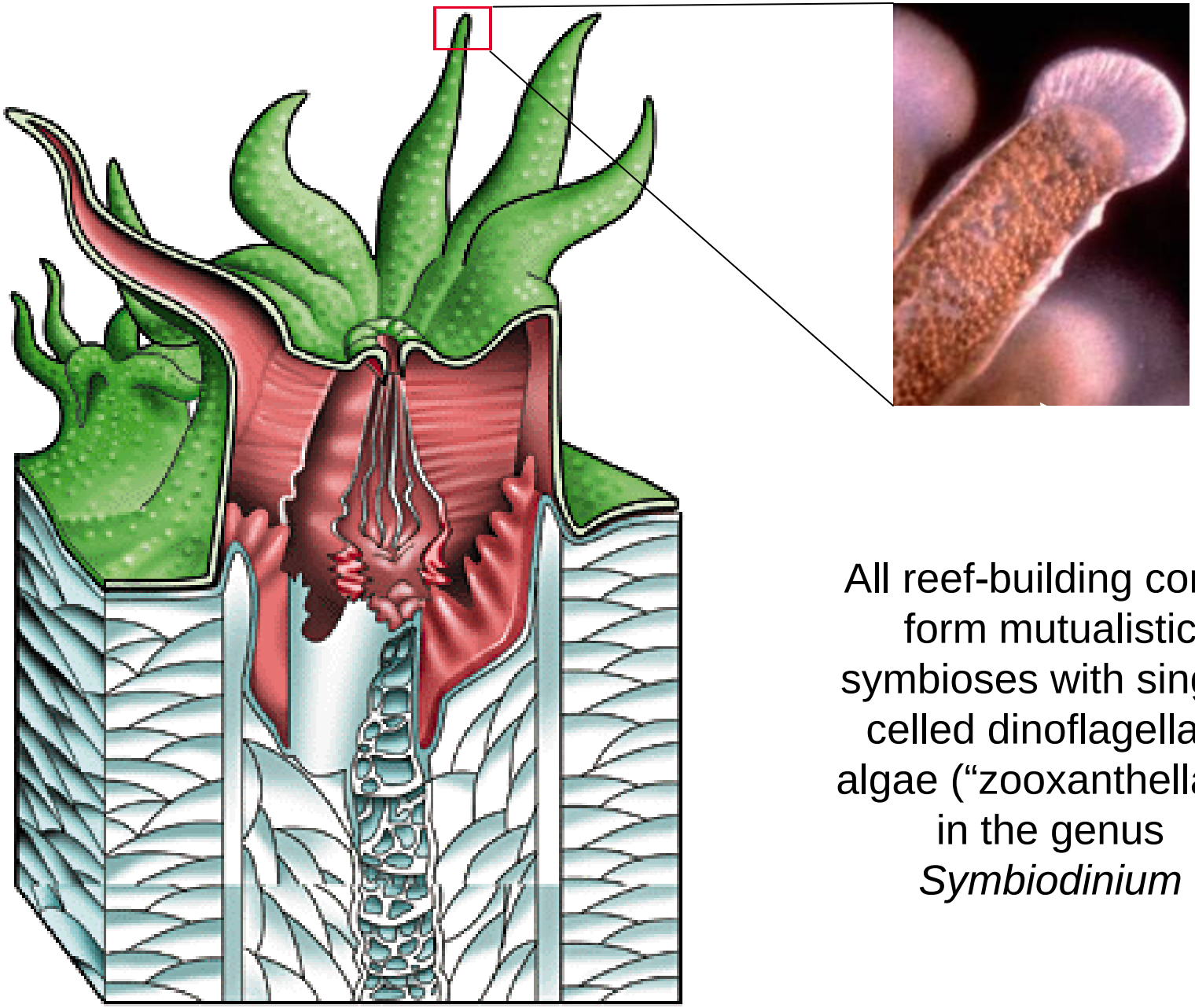
Reversing the trajectory of decline…



Pandolfi et al. (2005)

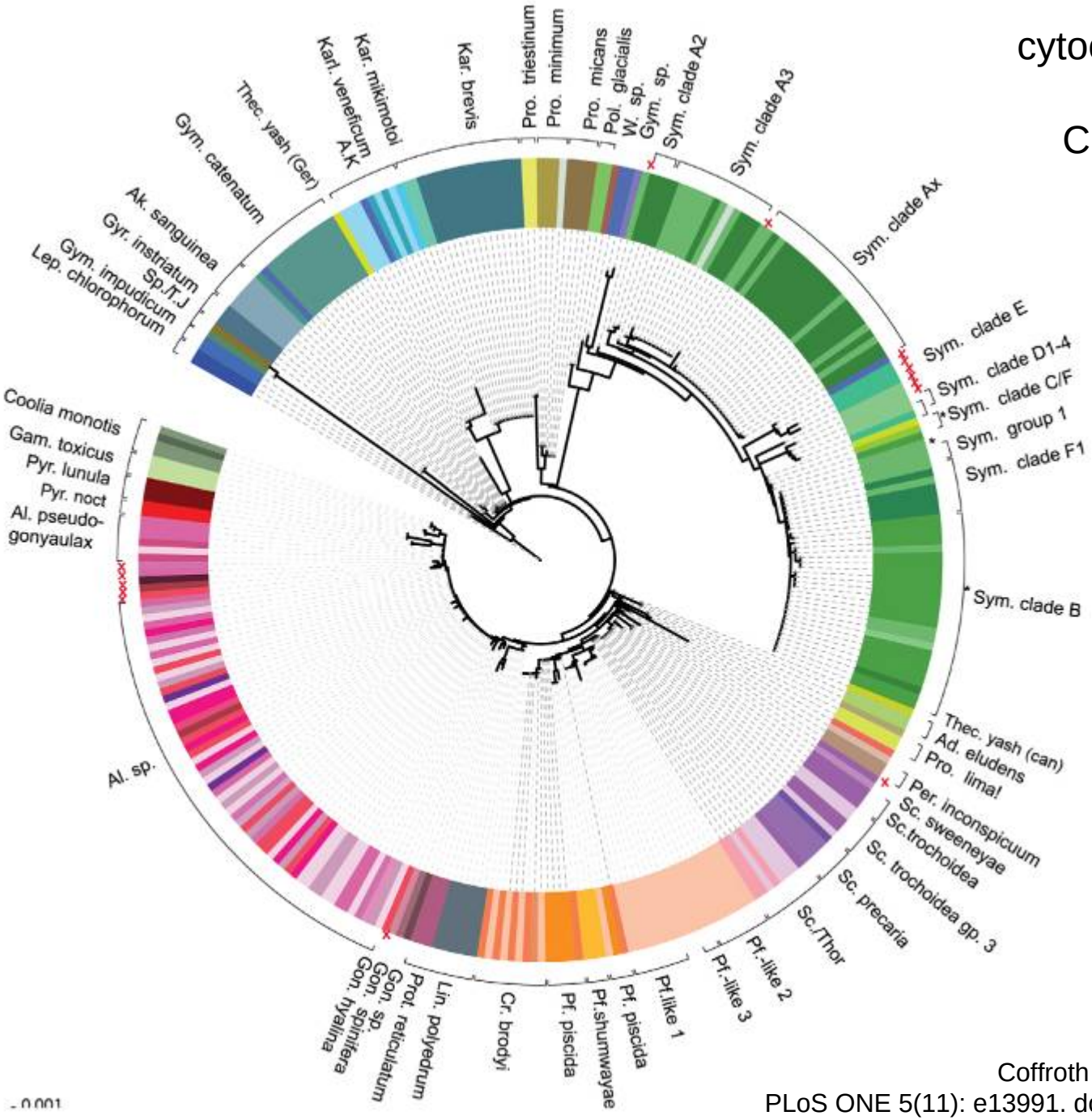
Fortune is not satisfied with inflicting one calamity - Publilius Syrus, 42 B.C.

The **Necessary** but **Insufficient** components of coral reef recovery…



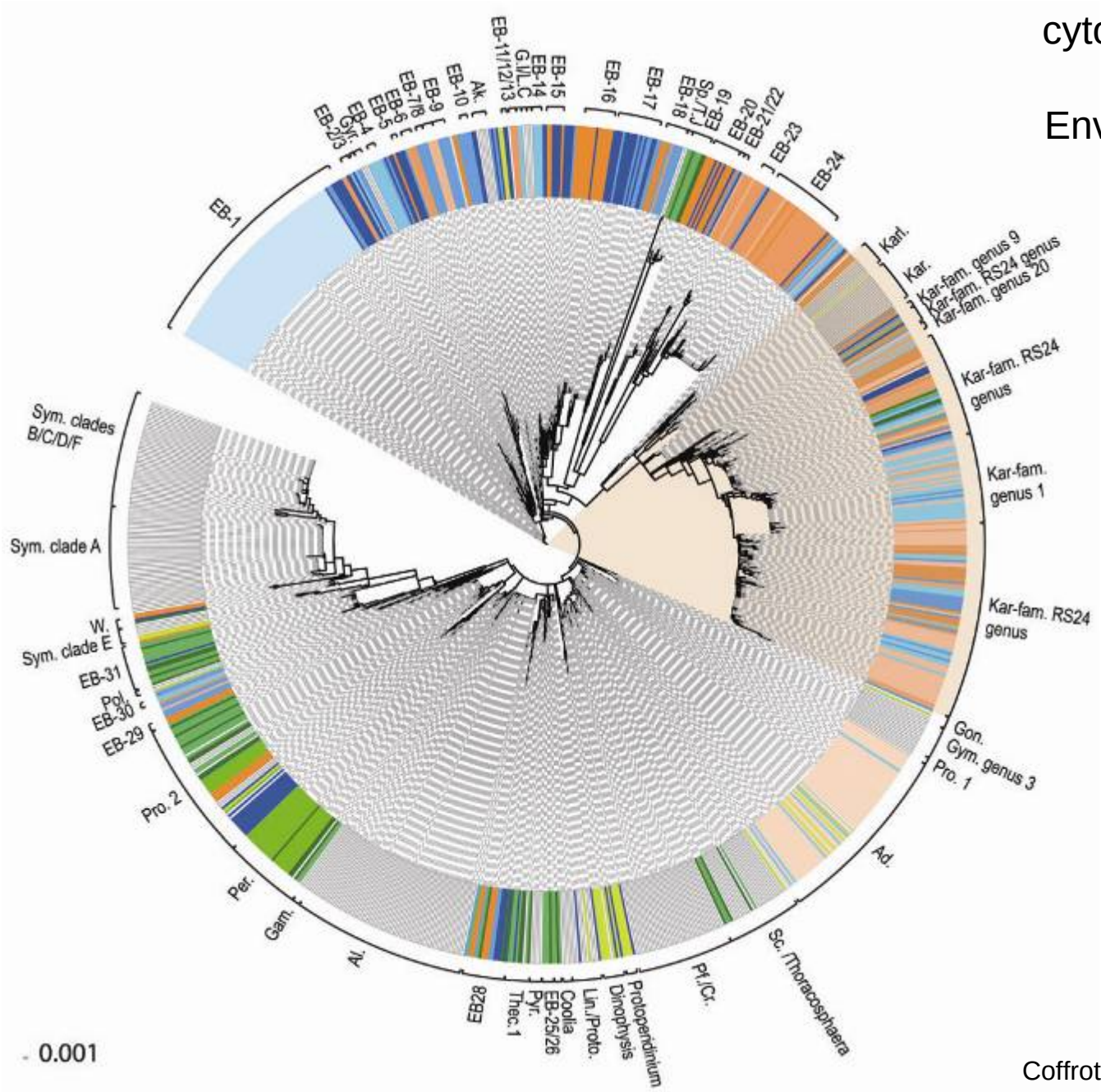
All reef-building corals form mutualistic symbioses with single-celled dinoflagellate algae (“zooxanthellae”) in the genus *Symbiodinium*

cytochrome *c* oxidase 1 (COI) Culture collections



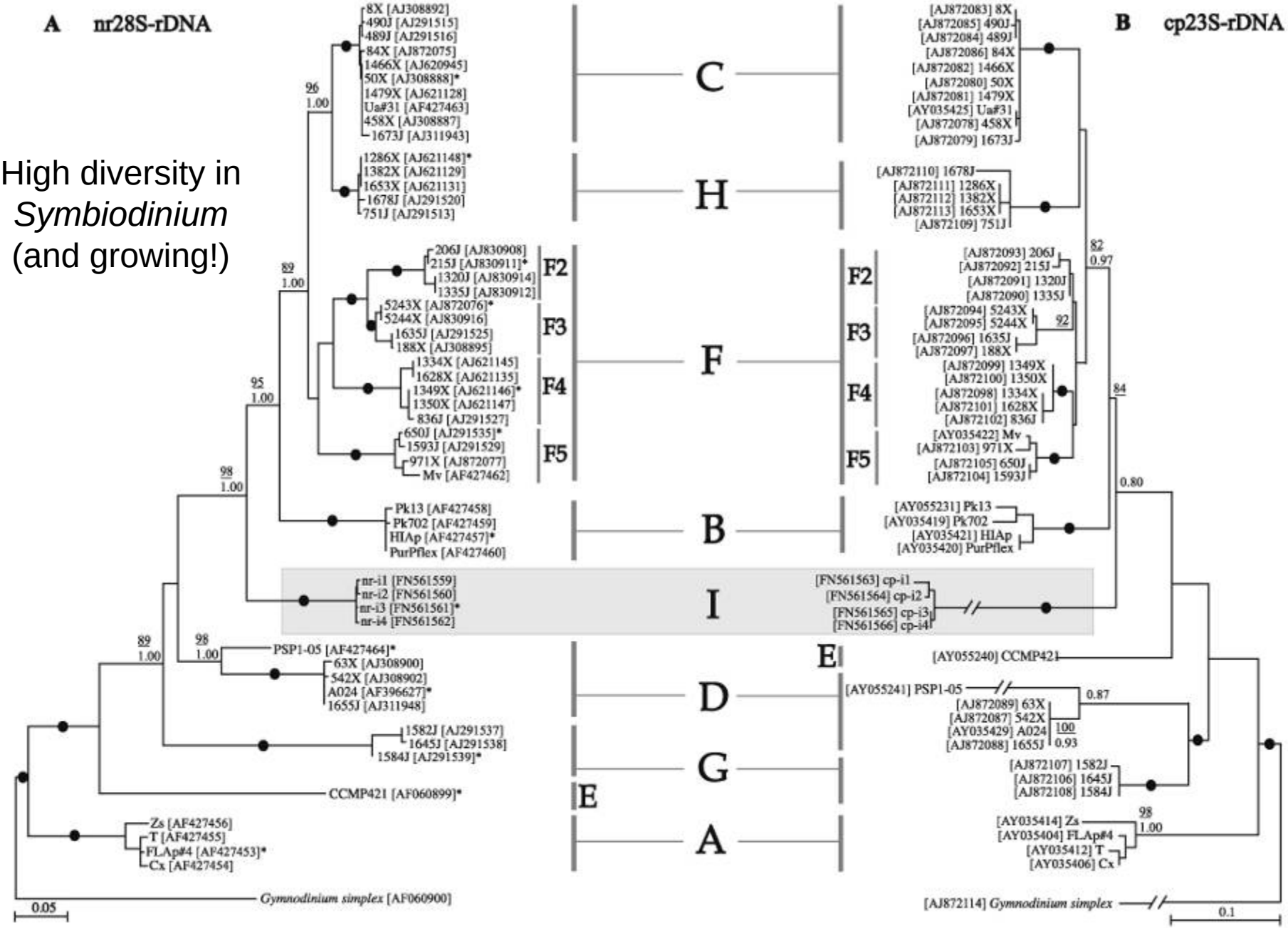
Stern RF, Horak A, Andrew RL, Coffroth M-A, Andersen RA, et al. (2010) PLoS ONE 5(11): e13991. doi:10.1371/journal.pone.0013991

cytochrome *c* oxidase 1
(COI)
Environmental samples



Stern RF, Horak A, Andrew RL, Coffroth M-A, Andersen RA, et al. (2010) PLoS ONE 5(11): e13991. doi:10.1371/journal.pone.0013991

High diversity in *Symbiodinium* (and growing!)



Pochon & Gates (2010) *Mol. Phylogenet. Evol.* doi:10.1016/j.ympev.2010.03.040

Coral Bleaching as an Adaptive Mechanism

A testable hypothesis

Robert W. Buddemeier and Daphne G. Fautin

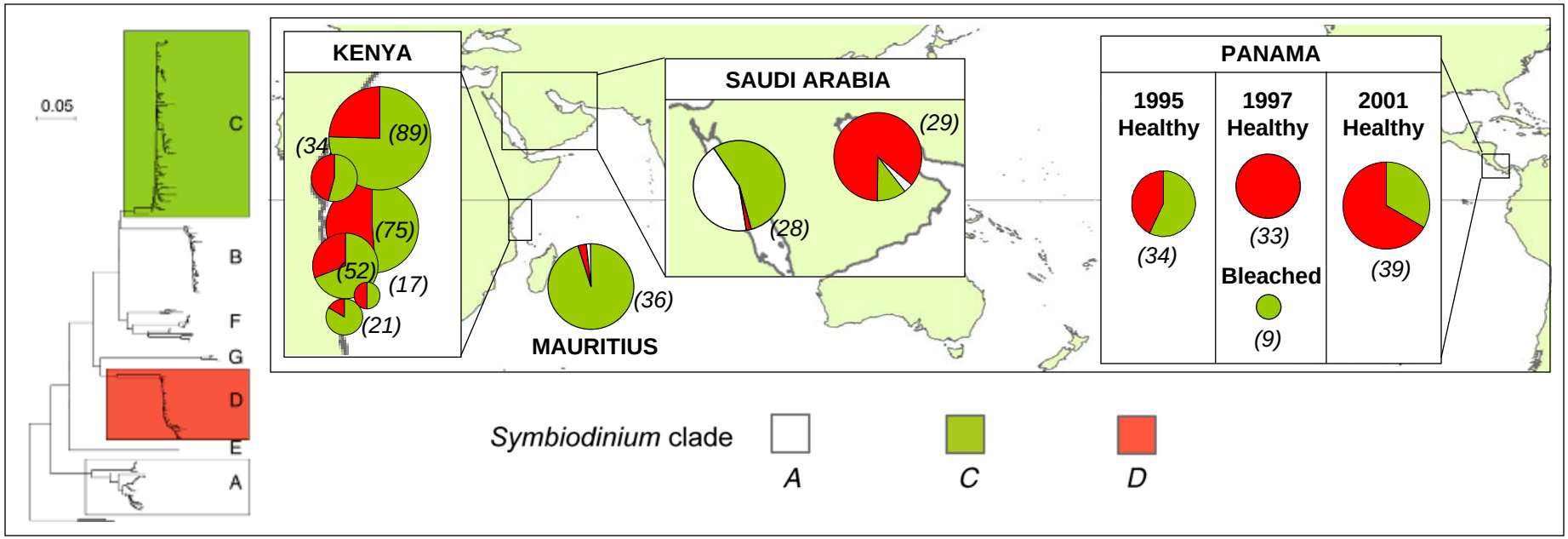
Bleaching in organisms such as hard and soft corals, giant clams, and sea anemones is the loss of pigment associated with their symbiotic algae (zooxanthellae). Bleaching can be the result of loss of the pigmented algae from the host or of loss of pigment from the algae. This article considers only the phenom-

We posit that bleaching allows a host to be repopulated with a different partner

temperature stress associated with either the 1982–1983 El Niño event or with the 1987 Caribbean warm event. However, partial or low-level bleaching also occurs in the absence of perceptible stress (Fisk and Done 1985, Gates 1990). Such background bleaching may well have been regarded as an unexceptional feature of coral reef

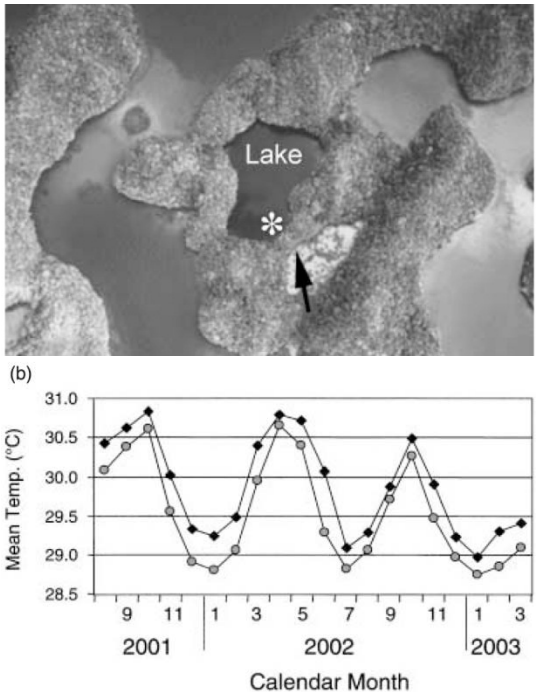
Buddemeier & Fautin (1993) *Bioscience*

Shifts in dominant algal symbiont communities following mass bleaching to favor thermotolerant *Symbiodinium* in clade *D*



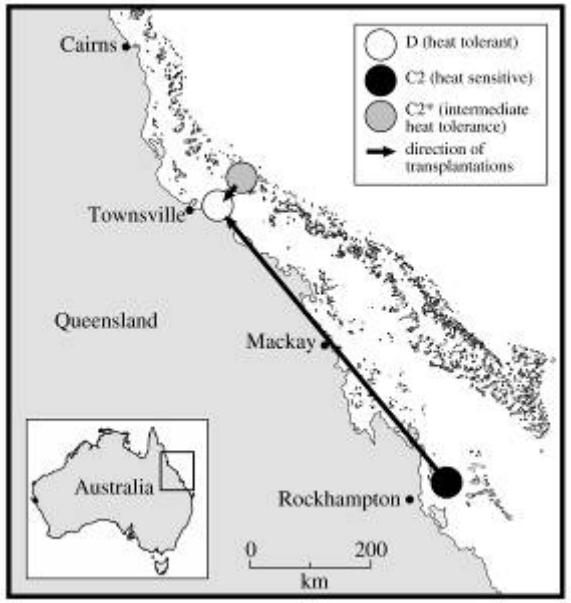
Evidence for an adaptive response of reef coral symbioses to climate change

Baker, Starger, McClanahan & Glynn (2004) *Nature* 430: 741
Rowan (2004) *Nature* 430: 742



2004: Corals from reefs in Palau with different thermal and bleaching histories have different symbionts

Fabricius, Mieog, Colin, Idip, Van Oppen (2004)
Mol. Ecol. 13: 2445-2458



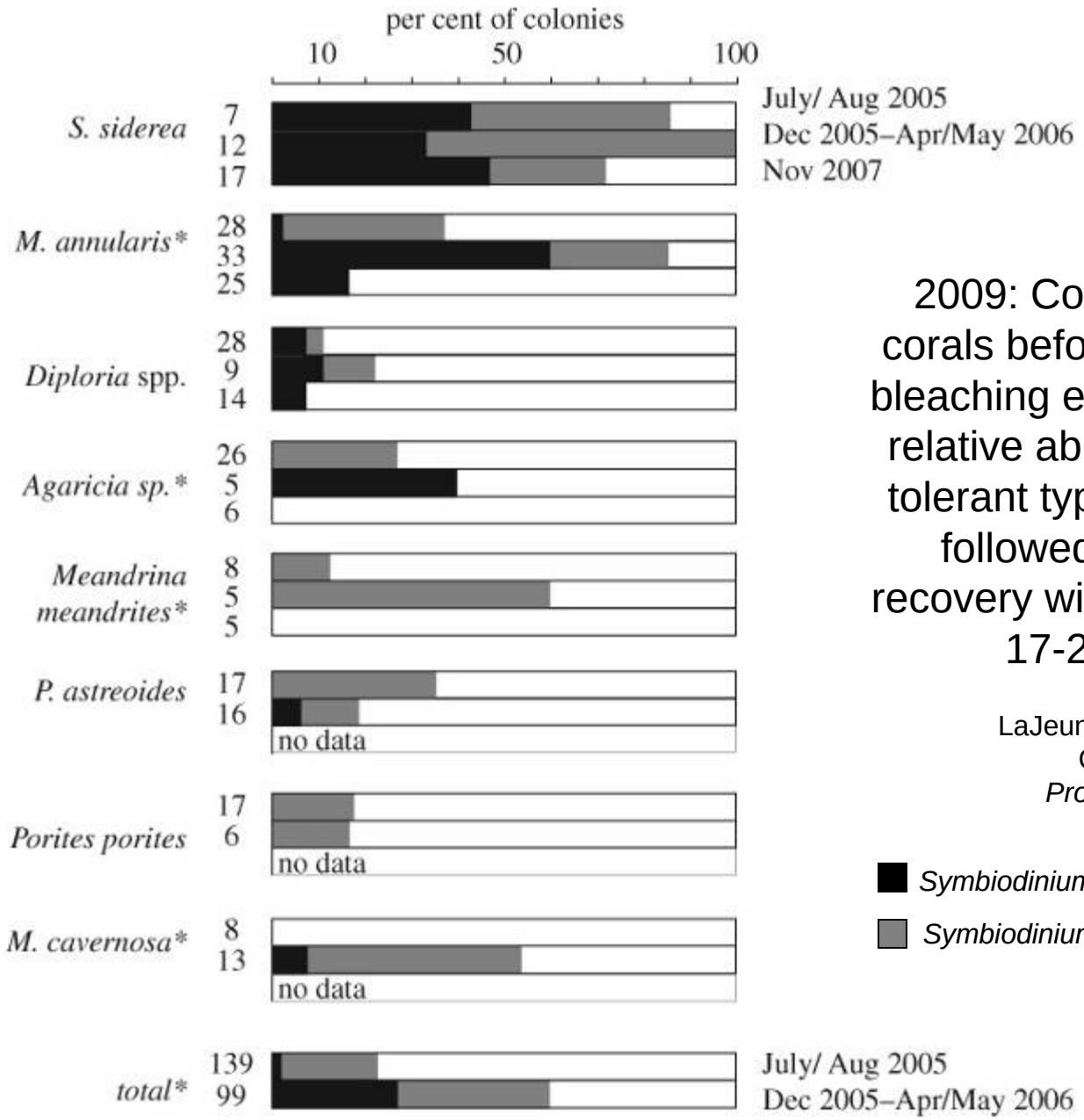
2006: Transplantation experiments between different thermal environments result in changes in symbiont communities, accompanied by a 1.5°C increase in thermal tolerance

Berkelmans & Van Oppen (2006)
P. R. Soc. Lond. B. 273: 2305-2312

Acropora millepora

2008: Individually tagged colonies followed during a bleaching event show dramatic shuffling of symbiont communities to favor more thermally tolerant types

Jones, Berkelmans, Van Oppen, Mieog, Sinclair (2008)
P. R. Soc. Lond. B



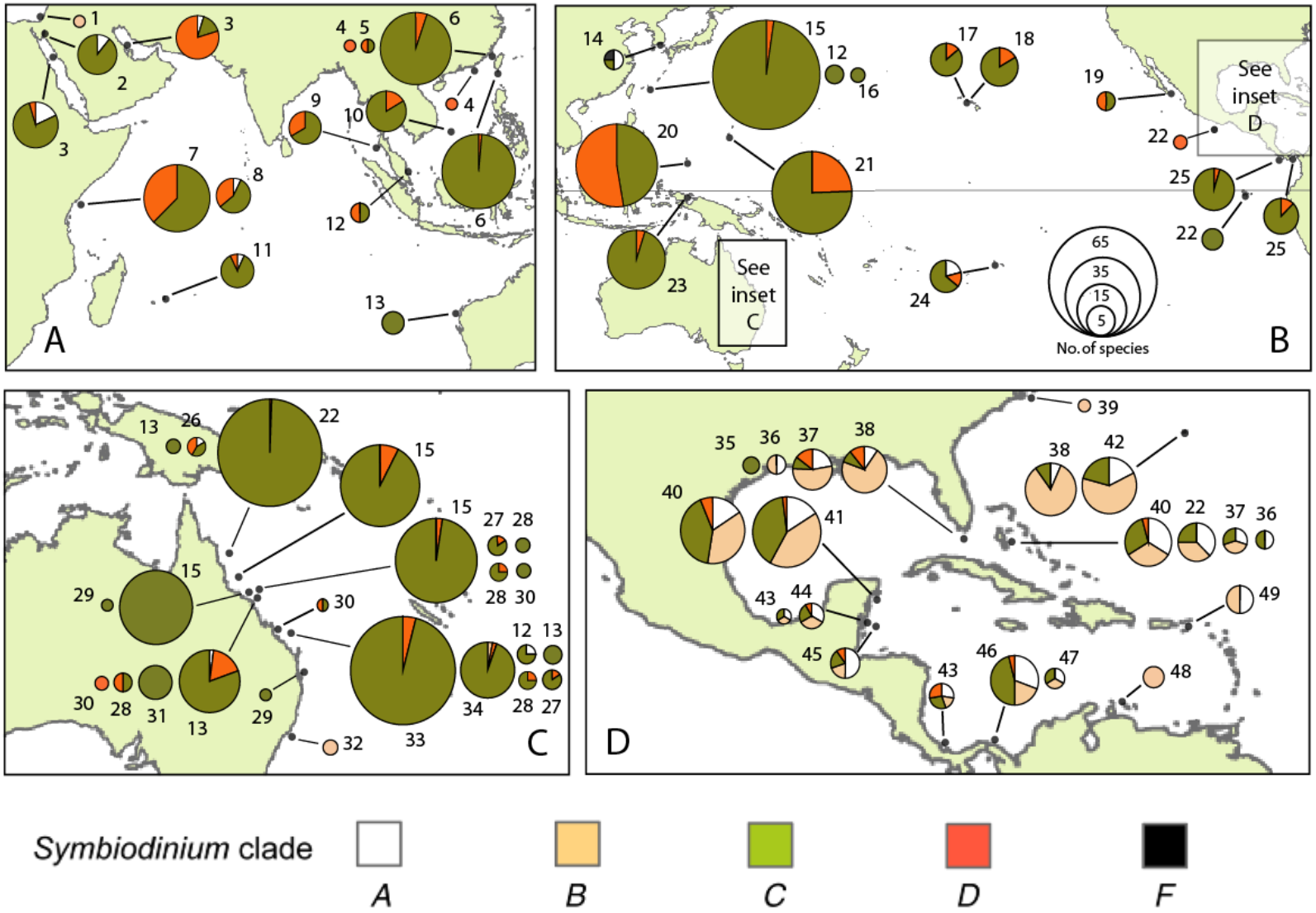
2009: Community surveys of corals before, during and after a bleaching event show increase in relative abundance of thermally tolerant types during bleaching, followed in most cases by recovery with “normal” symbionts 17-24 months later

LaJeunesse, Smith, Finney & Oxenford (2009)
Proc. R. Soc. Lond. B

■ *Symbiodinium* D1a detectable using DGGE

■ *Symbiodinium* D1a detectable using qPCR

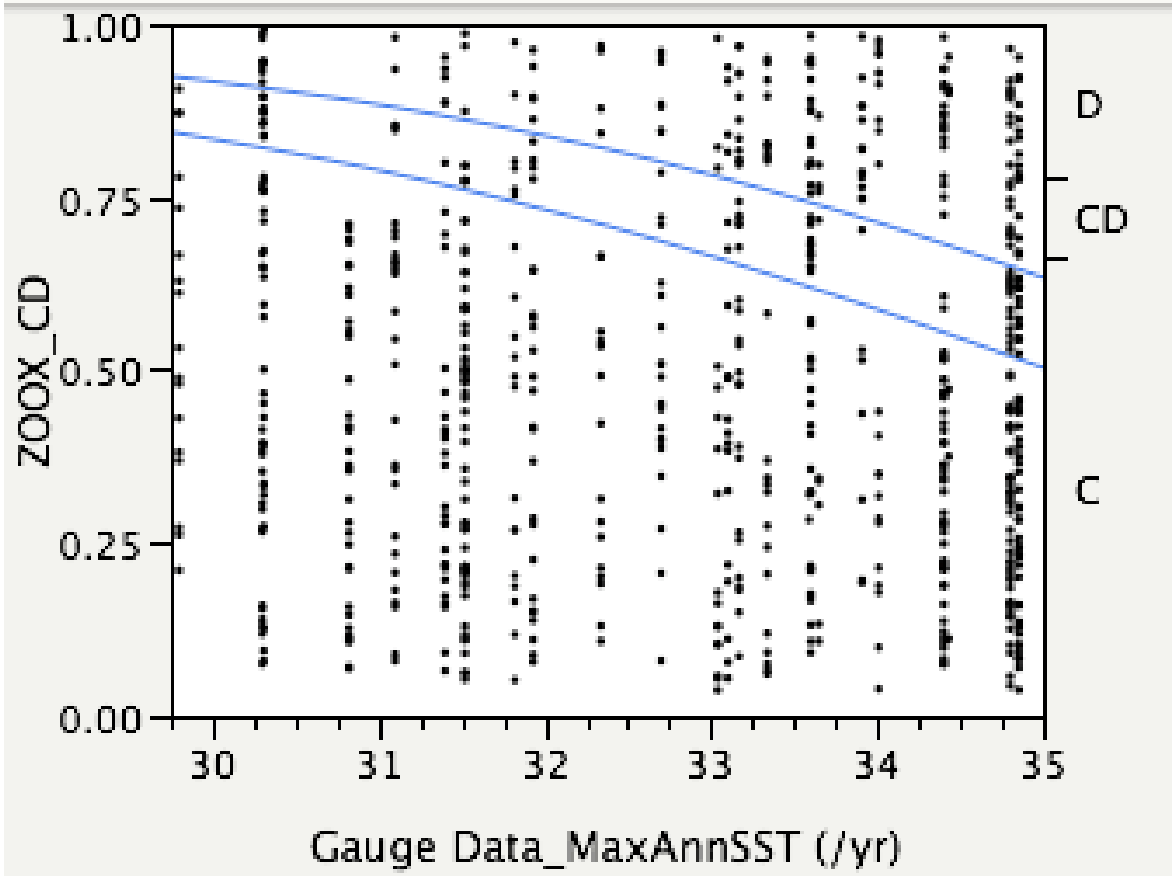
Global **A**ssessment of **D**iversity in **ZOOX**anthellae (GADZOOX)



Global distribution of *Symbiodinium* in scleractinian corals

Van Oppen, Baker, Coffroth & Willis (2009) In: *Coral Bleaching* (Springer Ecological Studies, vol. 25)

Symbiont communities show shifts in favor of clade D at higher temperatures

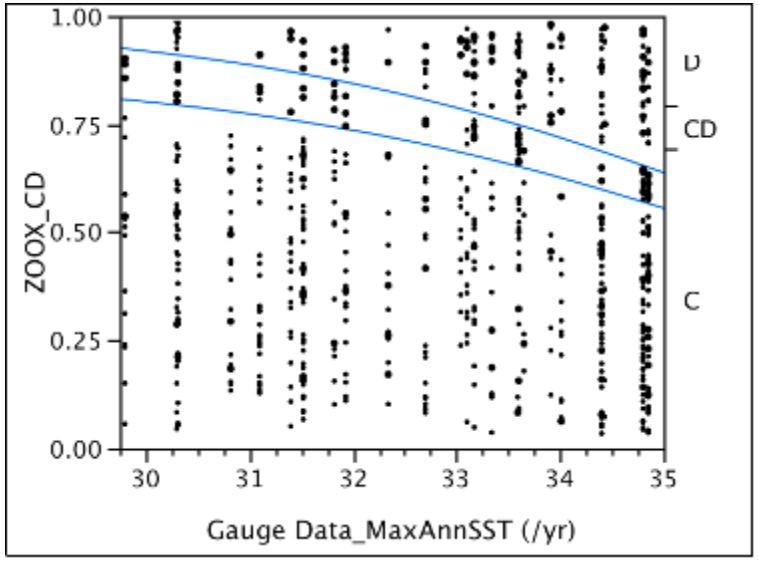


Long-term (10-year) sampling in Kenya, 4 coral taxa, N=743 samples

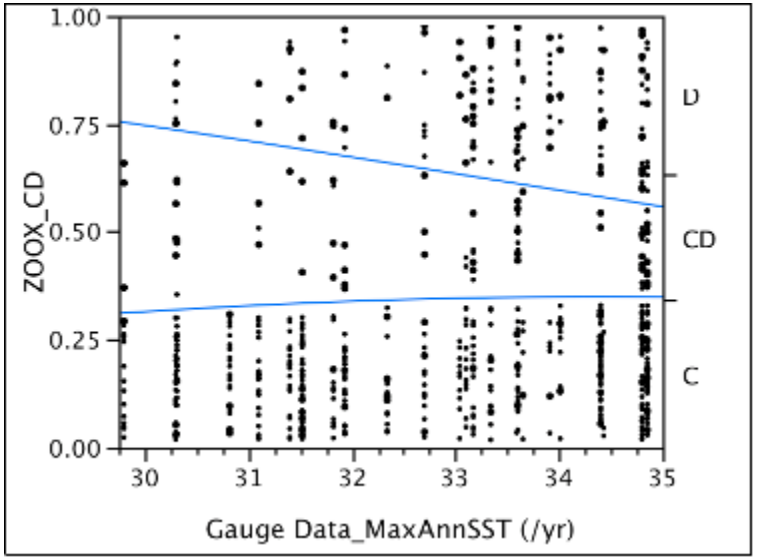
Nominal logistic fit for all species, for max annual temperature from gauges

Baker, McClanahan, Maina, Boonstra (accepted with revision) *Mar. Ecol. Prog. Ser.*

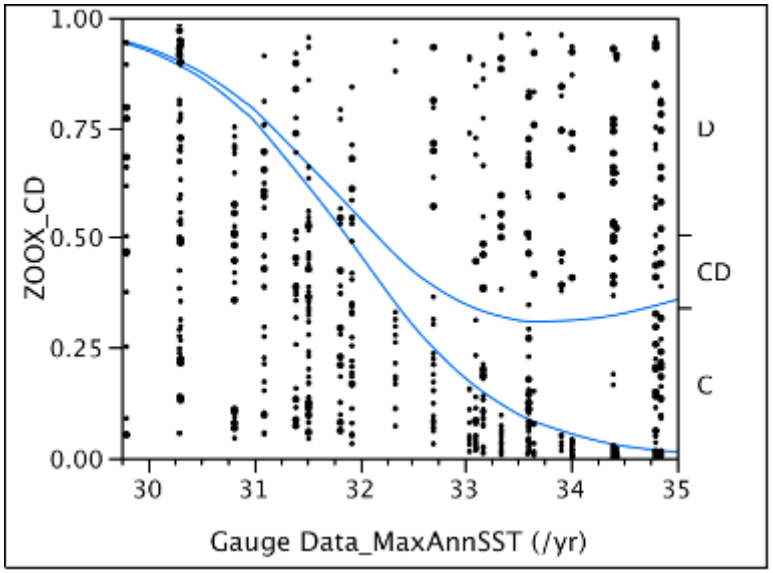
Corals vary in their capacity to experience symbiont shifts



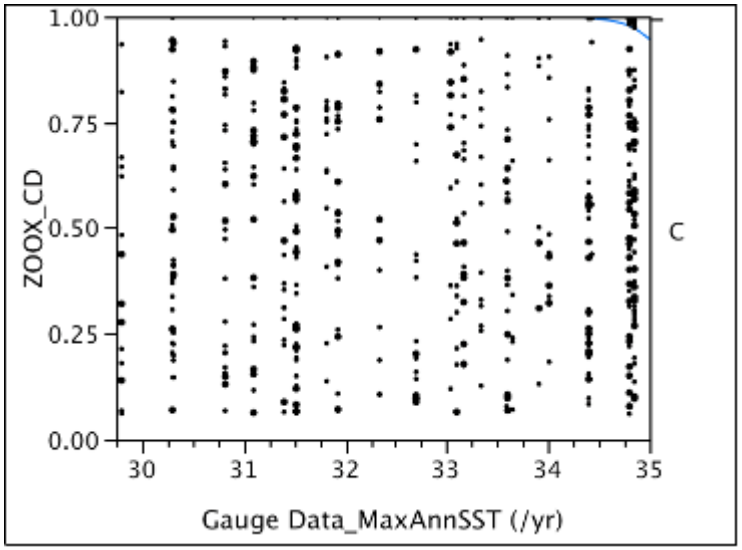
Acropora



Pavona



Pocillopora



Porites

Specificity barriers weakened in extreme environments?

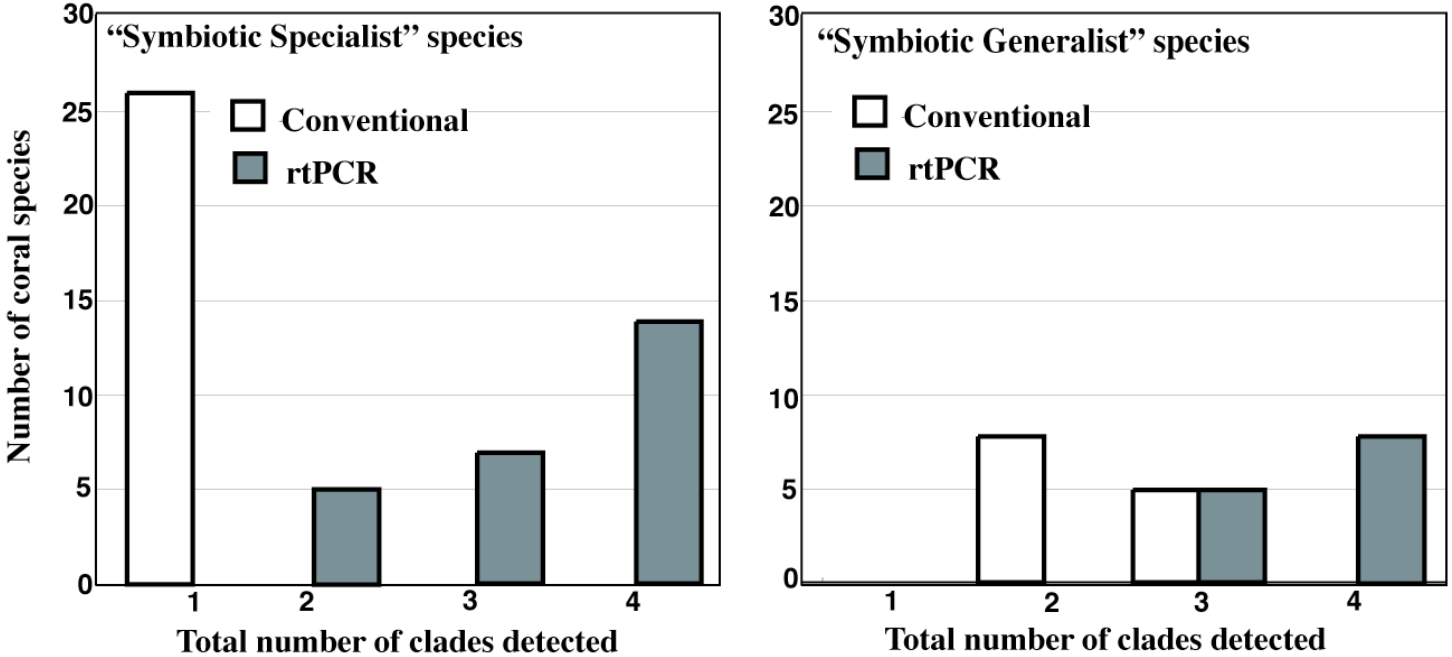
Porites commonly hosts C15 (and related types) in the Indo-Pacific

In the Persian/Arabian Gulf, multiple *Symbiodinium* clades, as well as mixed communities of various C-types within colonies, suggests symbiont fidelity may be reduced under extreme conditions

Also shows that **hosting *Symbiodinium* in clade D is not a prerequisite for survival at extreme high temperatures**

Baker, Wiedenmann, Riegl, Burt, Foster, & Jones (unpubl.)

Are corals limited to hosting 'specific' symbionts?



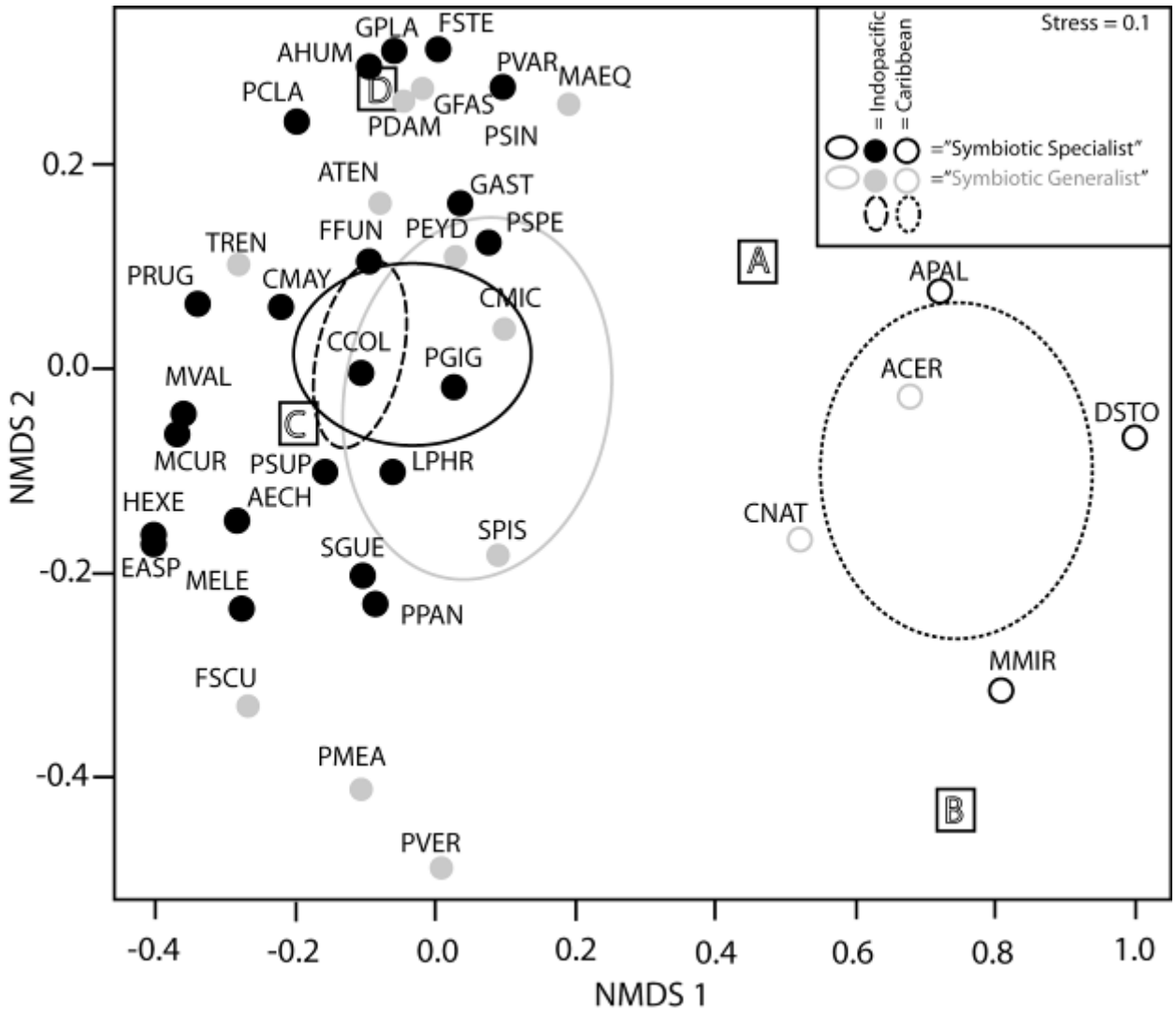
Using quantitative PCR:
Overall (N=39 species)

All 39 species host (at least) two *Symbiodinium* clades (C+D)
(N=4-12 per species)

'Symbiotic specialists'(N=26 species)
21 (81%) host clades A+C+D or B+C+D
14 (54%) host A+B+C+D

'Symbiotic generalists'(N=13 species)
13 (100%) host clades A+C+D or B+C+D
8 (62%) host A+B+C+D

Silverstein, Correa & Baker (2012) *Proc. R. Soc Lond. B*

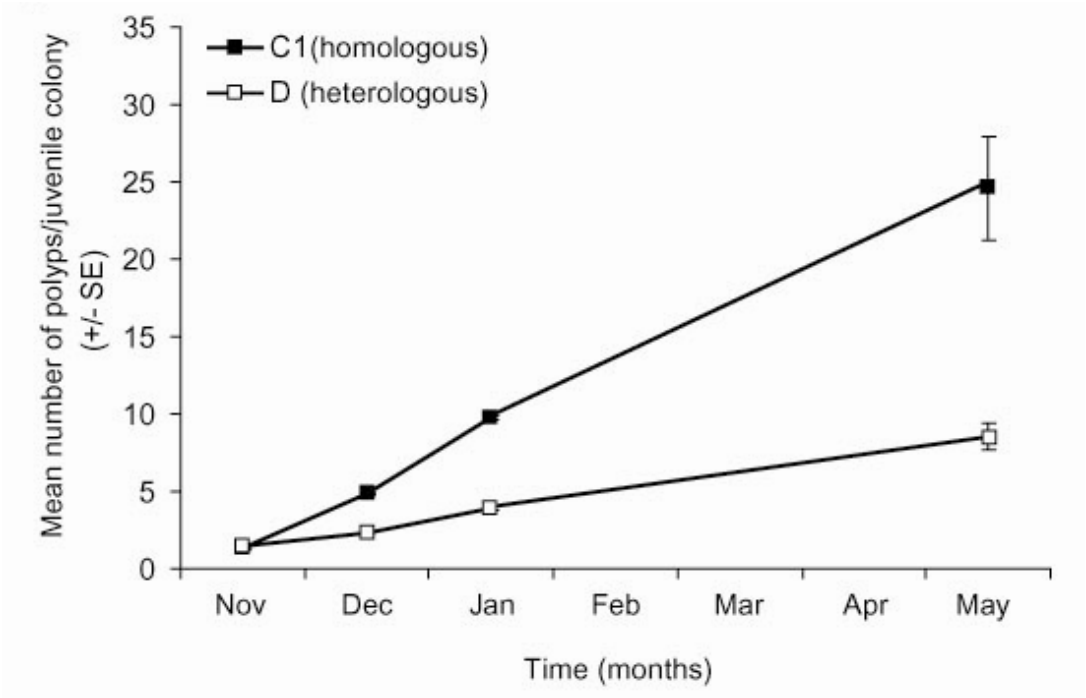


Ordination plots (NMDS) and Analysis of Similarity (ANOSIM)
Indo-Pacific significantly different from Caribbean *(dotted ellipses, p=0.001, R^2= 0.49)*
No evidence for symbiotic ‘specialists’ vs. ‘generalists’ *(solid ellipses, p=0.73, R^2=0.009)*

Silverstein, Correa & Baker (2012) *Proc. R. Soc Lond. B*

Are there tradeoffs to hosting thermotolerant *Symbiodinium*?

Acropora juveniles artificially infected with *Symbiodinium* in clade C vs. D on GBR



Little et al. 2004
Nature

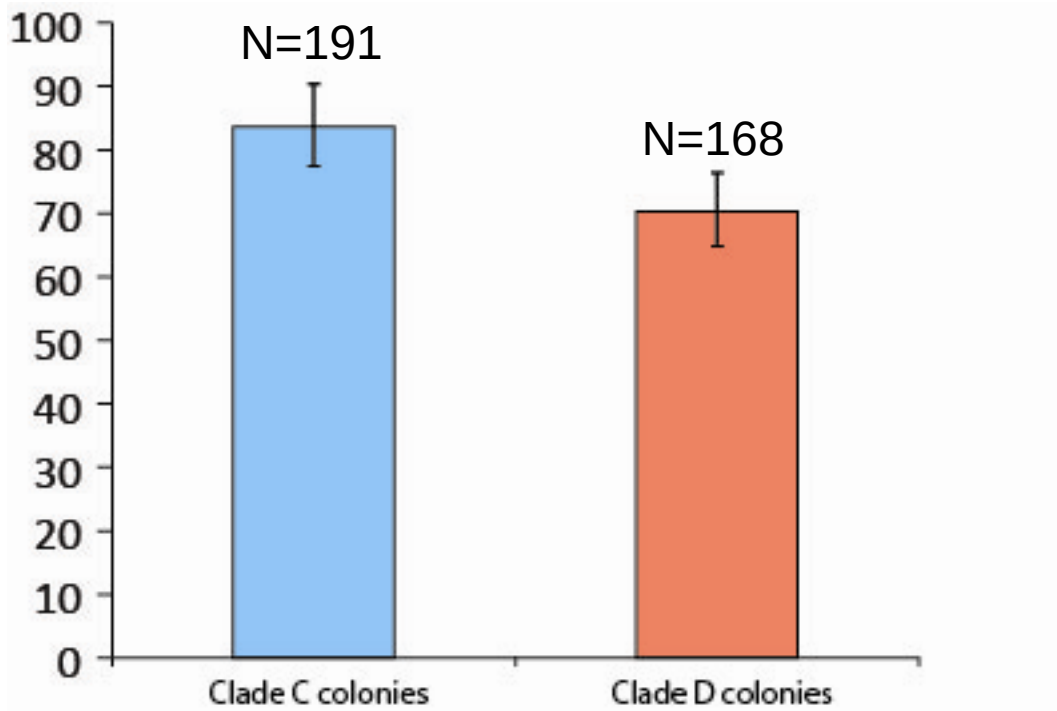
Clade C juveniles budded new polyps 2-3 time faster grew ~19% faster than clade D colonies (P=0.0013, t-test)

Acropora millepora with clade D also have 26% less lipids and 28% smaller eggs than those with clade C
(Jones & Berkelmans 2011 J. Mar Biol.)

Change in buoyant weight of *Pocillopora damicornis* nubbins hosting *Symbiodinium* clade C vs D

Common gardened in laboratory (26.5^{o}C) for ~4 months

Change in buoyant weight (%)



Cunning, Capo & Baker (unpubl.)

Clade C colonies grew ~19% faster than clade D colonies (P=0.0013, t-test)

Implications for coral calcification at elevated pCO2?

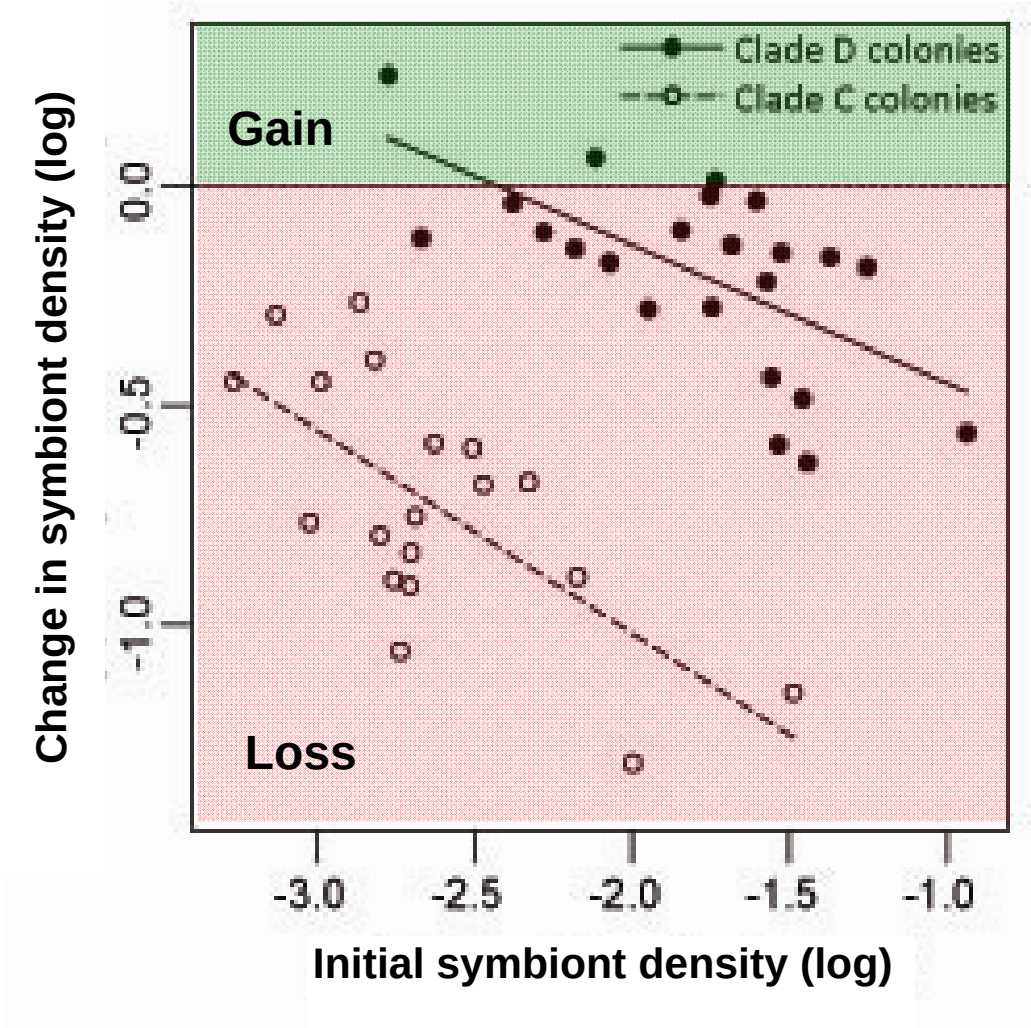
Symbiont abundance, as well as identity, influences thermotolerance

Actin-based qPCR assay

Uses **symbiont:host cell ratio** as alternative metric of symbiont density

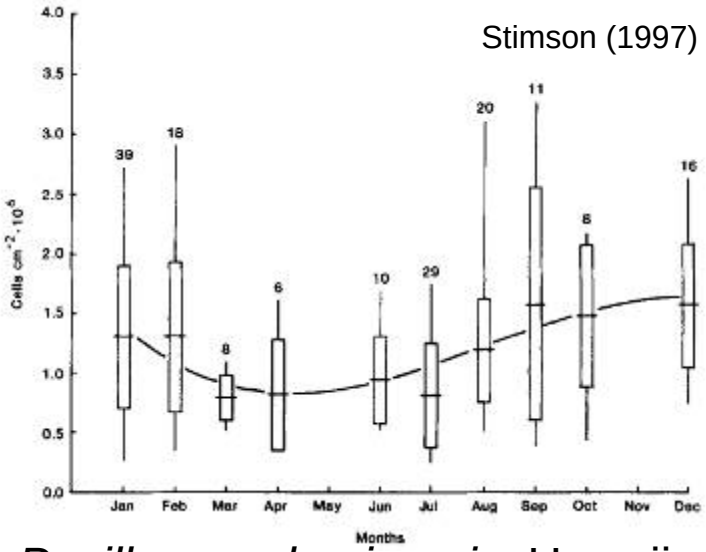
Shows that having **too many** algal symbionts **increases** the vulnerability of corals to bleaching

Implications for corals exposed to high nutrients, high pCO_2 (and perhaps even iron-rich African dust…)



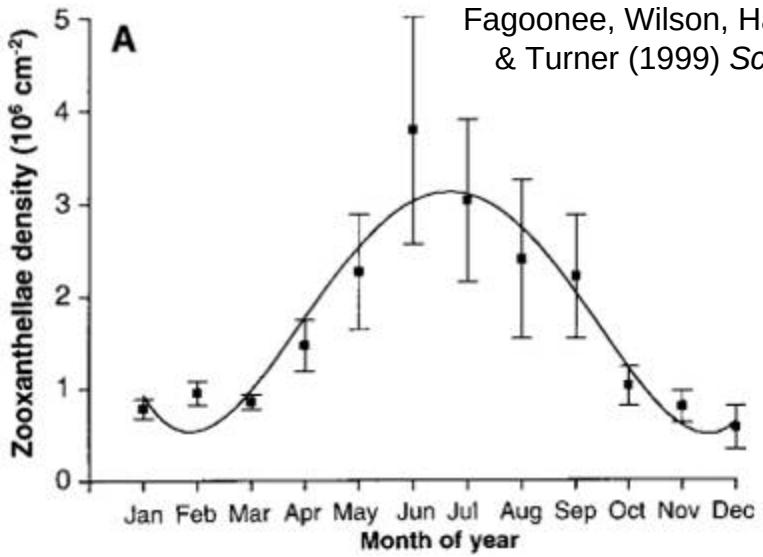
Cunning & Baker (in revision)

Stimson (1997) *JEMBE*



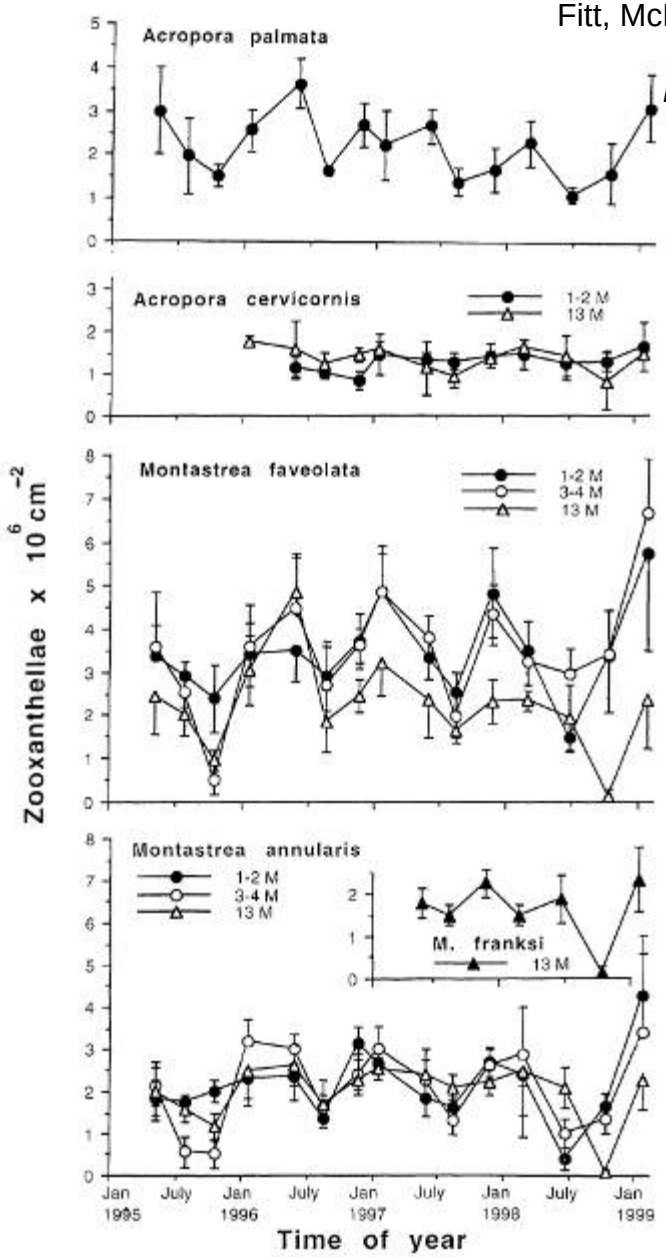
Pocillopora damicornis, Hawaii

Fagoonee, Wilson, Hassell & Turner (1999) *Science*



Acropora formosa, Mauritius

Fitt, McFarland, Warner & Chilcoat (2000) *Limnol. Oceanogr.*



Two Acropora, three Montastraea, Bahamas

Role of algal symbionts in coral adaptation

Adaptive benefits to corals:

•Changes in symbiont community structure can increase thermotolerance

•Different coral species vary in their capacity to experience symbiont shifts

Caveats:

•Increase in thermotolerance (1.5^{o}C) may not be enough to ensure long-term survival (based on modeling)

•Longevity of shifts unknown, but likely to be dependent on temperature regime

•Tradeoffs exist (e.g., reproduction, growth)

•Symbiont densities may also be important

•Host and other members of holobiont also important