The algal symbionts of corals:

Biodiversity, specificity and significance to global climate change.

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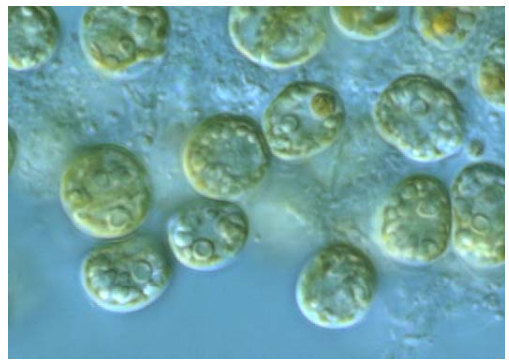
In the tropics, the Scleractinia and their relatives are composed of two extremely different organisms



The association

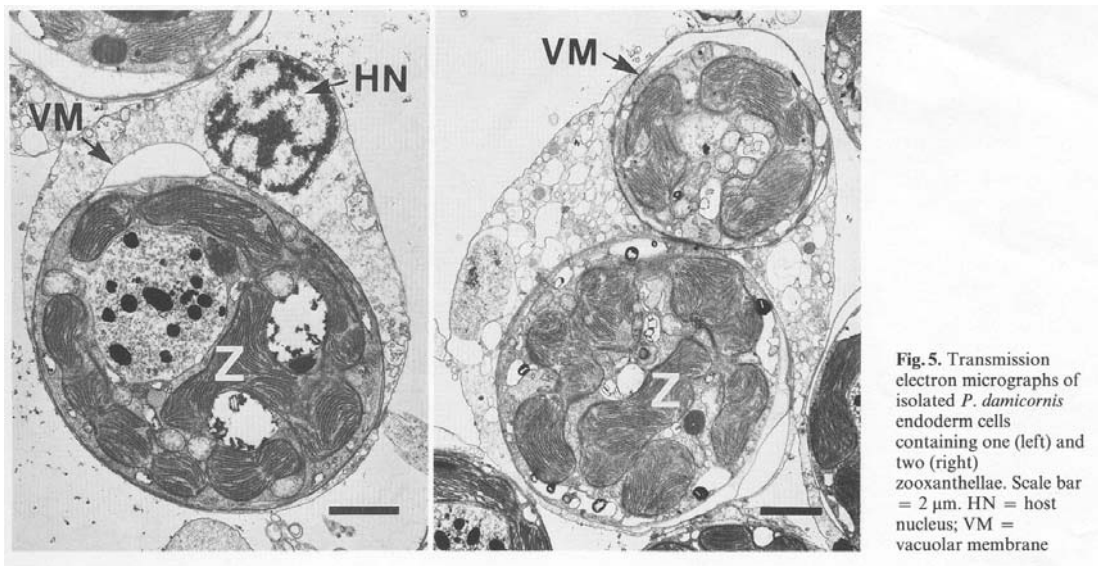


Fig. 5. Transmission electron micrographs of isolated *P. damicornis* endoderm cells containing one (left) and two (right) zooxanthellae. Scale bar = 2 µm. HN = host nucleus; VM = vacuolar membrane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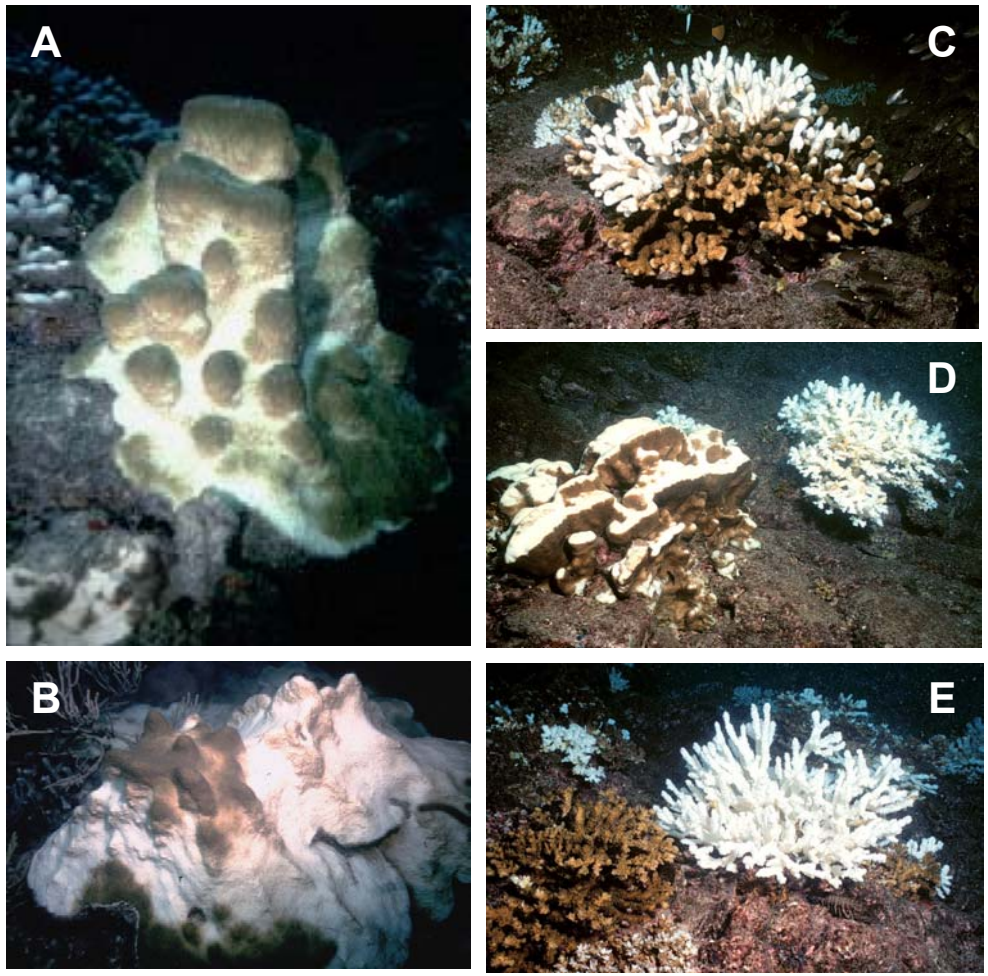
Survival of corals to global warming may depend on the relative susceptibilities of holosymbionts to thermal stress



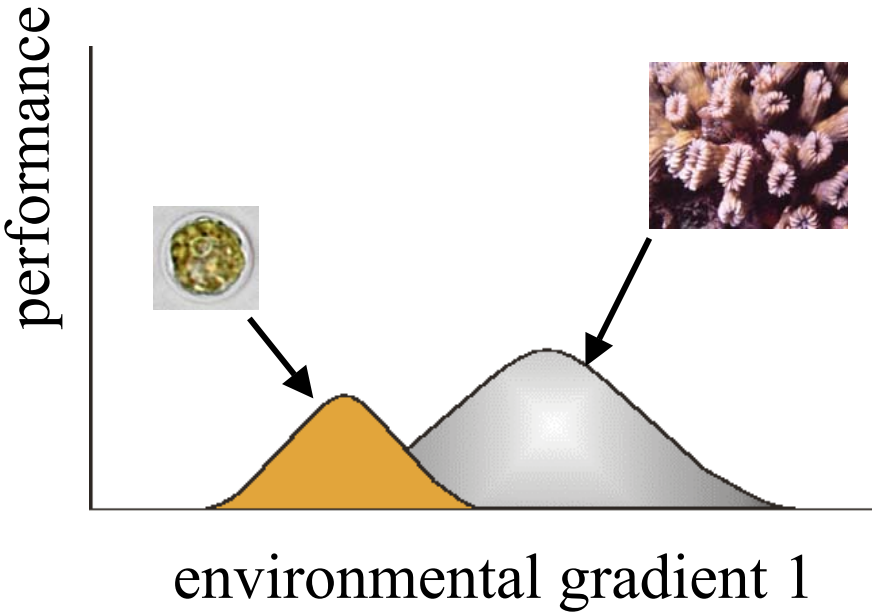
Montastraea
Caribbean Panama
(Rowan et al. 1997)

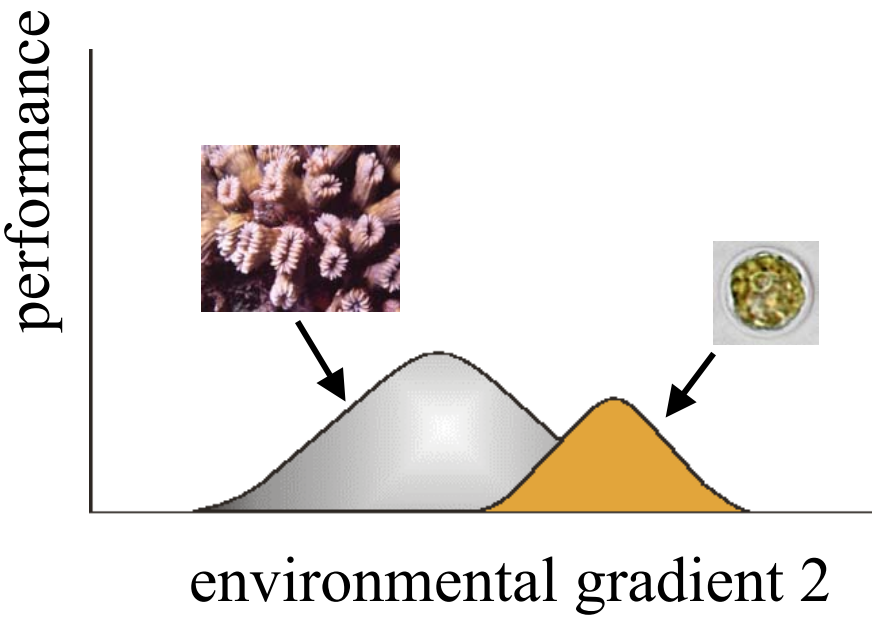
Pocillopora
Pacific Panama
(Glynn et al. 2001)

Bleaching susceptibility linked with symbiont type

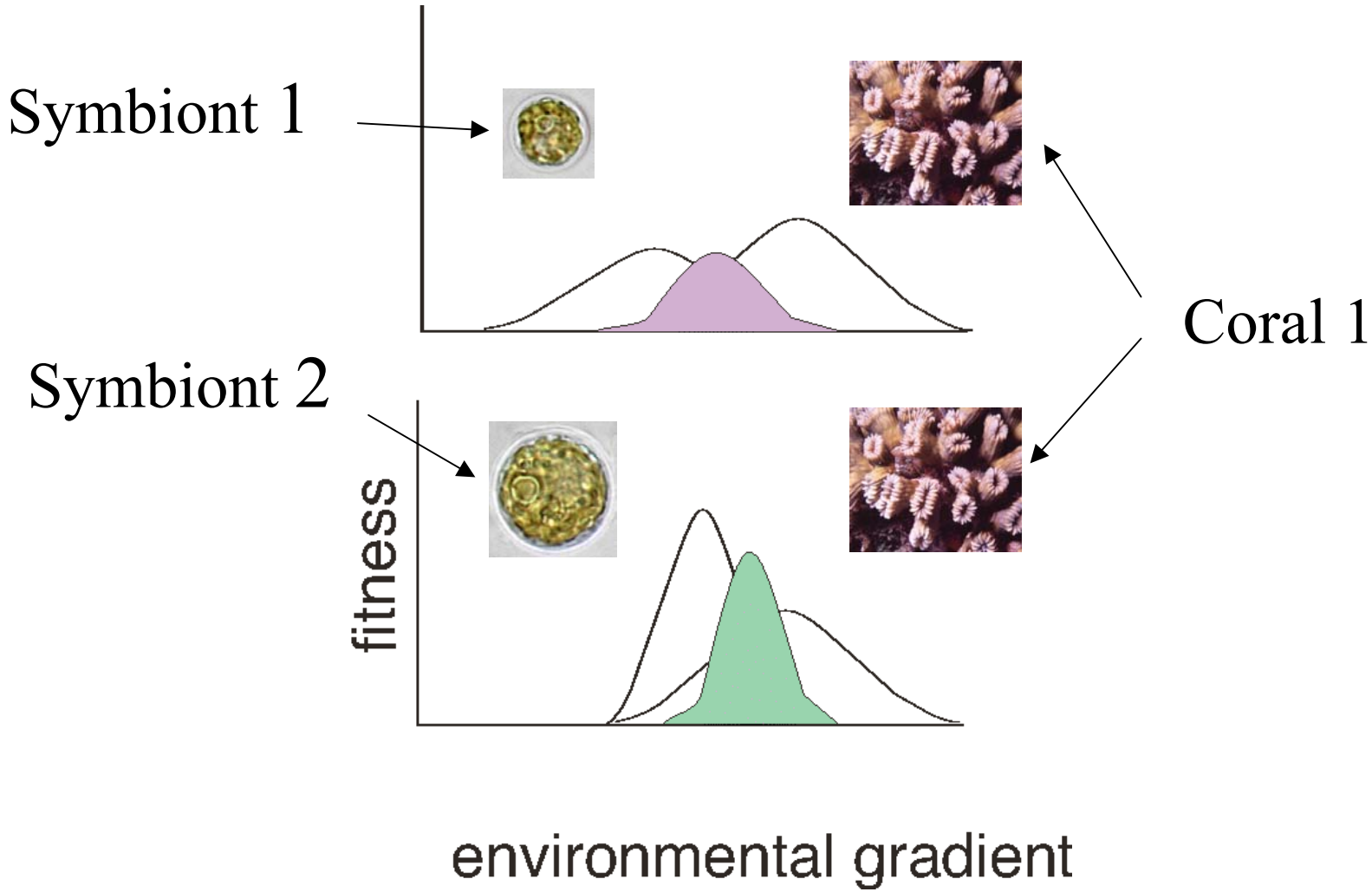
A knowledge of these distributions has helped understand variability in coral bleaching

Tolerance curves for coral host and dinoflagellate symbiont





holosymbiont



How might symbioses on reefs change following a bleaching event?

What are the implications for coral reef conservation?

Natural Selection (“Adaptation”)
- Higher mortality of bleaching-susceptible combinations

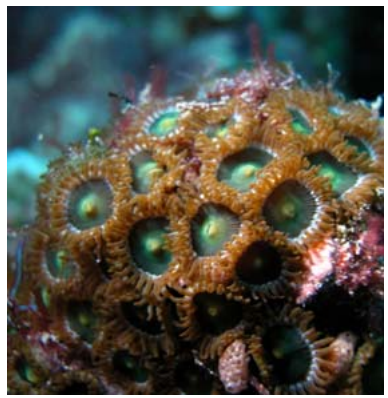
Symbiosis Recombination (“Acclimation”)
- Recovery of bleached colonies with different symbionts (the “Adaptive Bleaching Hypothesis”)

To answer these questions, we need the following:

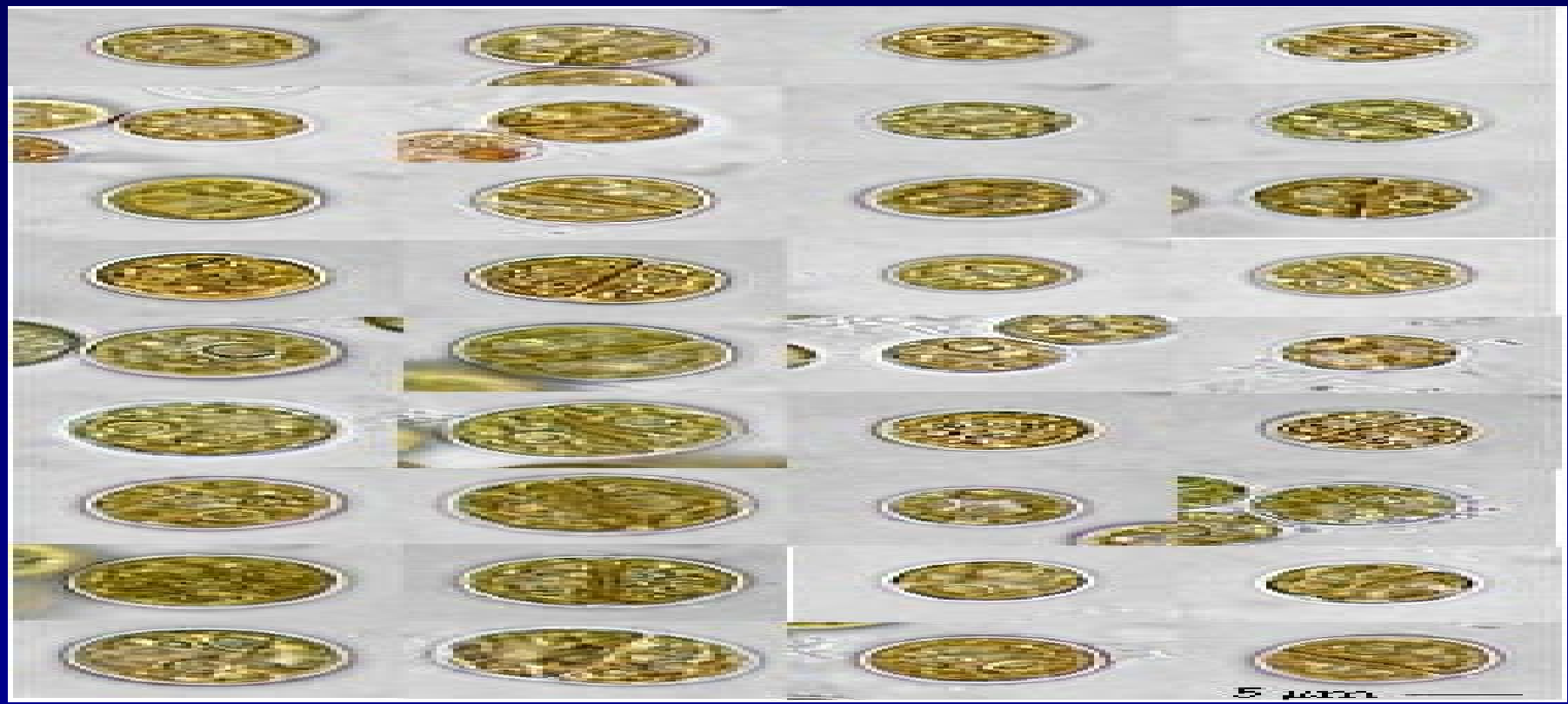
Information concerning their ecology and evolution

- Geographic and ecological distributions
- Response to environmental stress
- Host-symbiont specificity
- Evolutionary relationships

Host Diversity

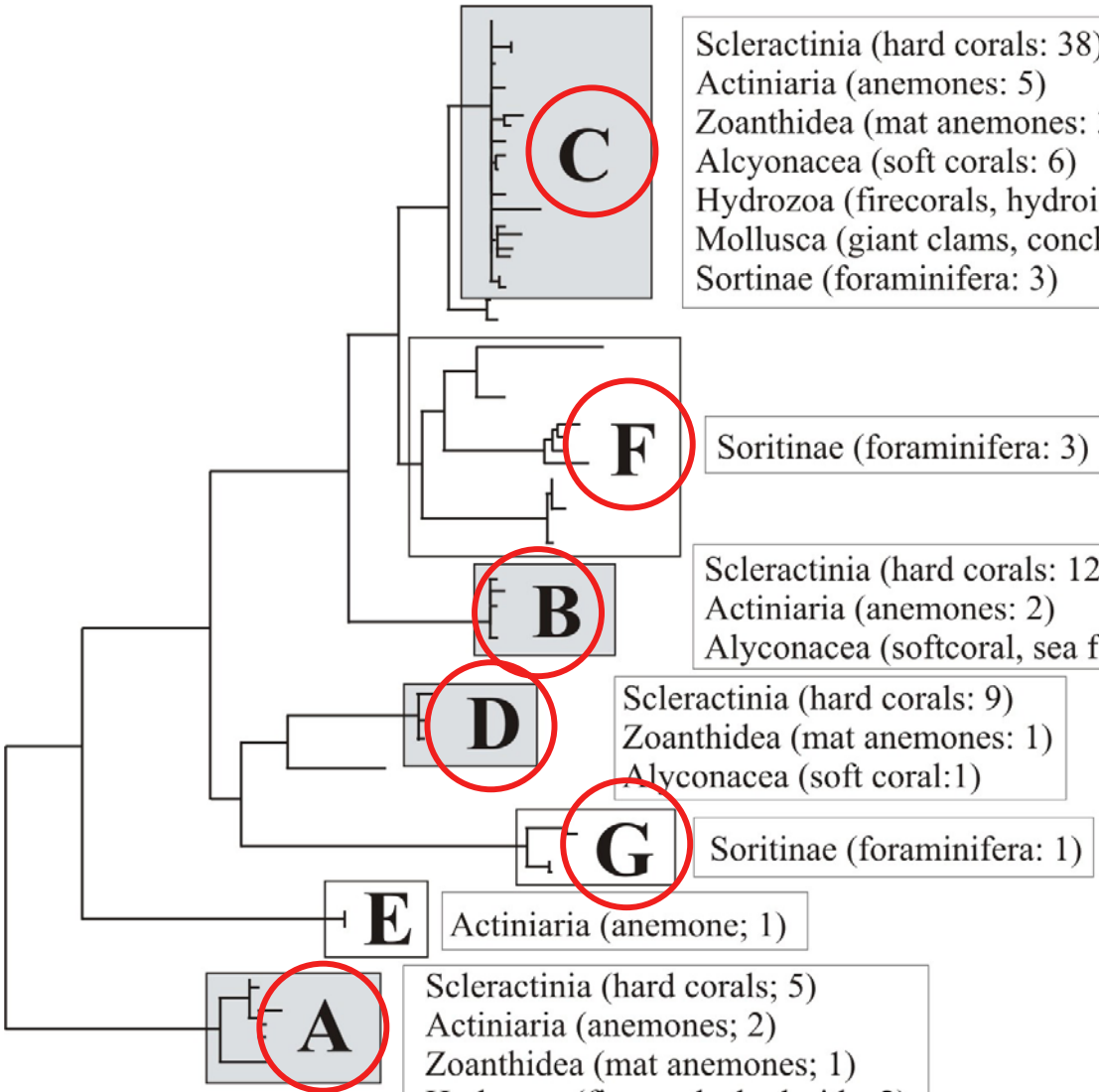


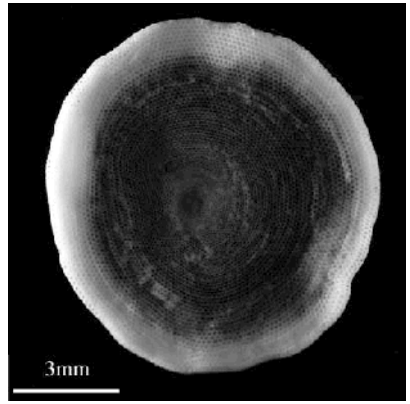
Diversity of the dinoflagellate symbiont

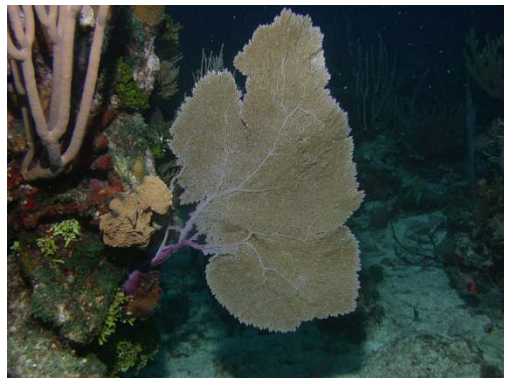


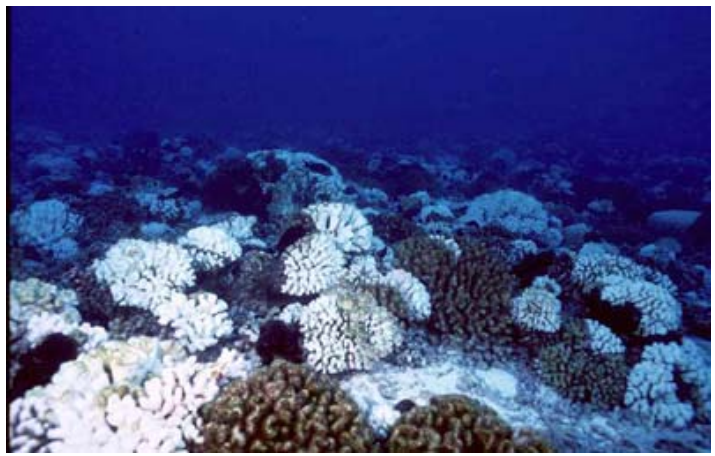
Symbiodinium clades

Host classification: genera







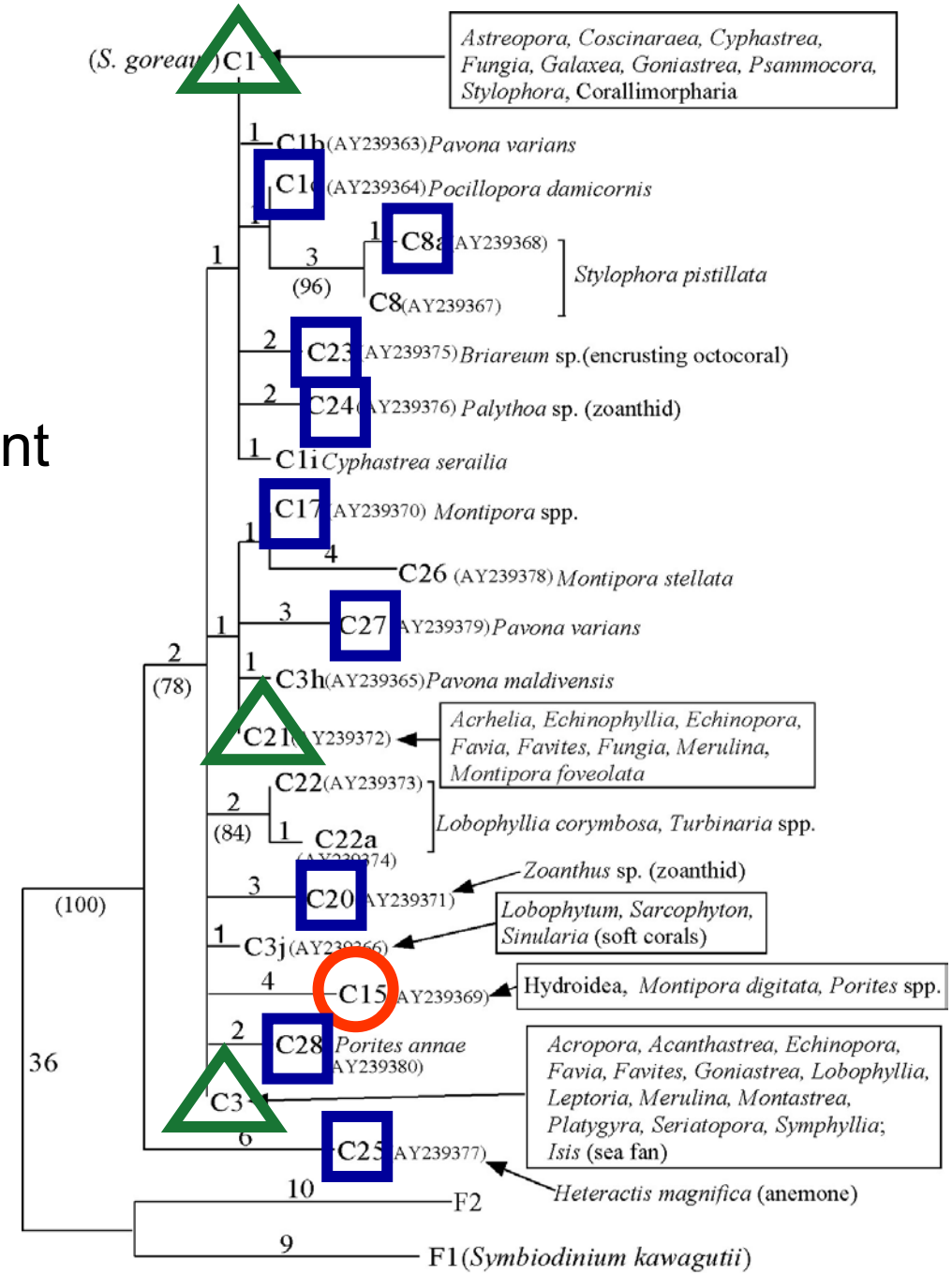


generalists

specialists

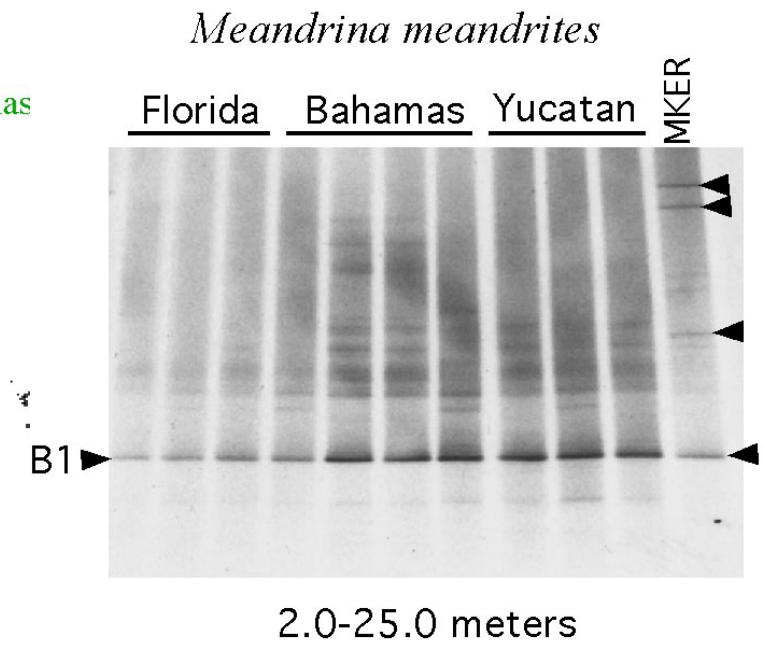
thermally tolerant

Clade C Diversity
GBR, heron Island

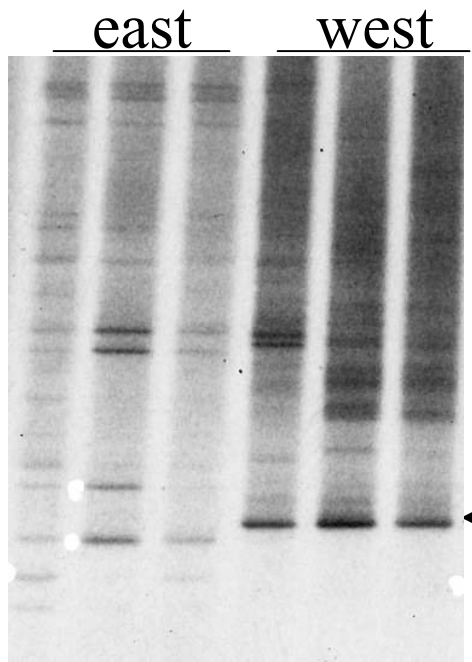


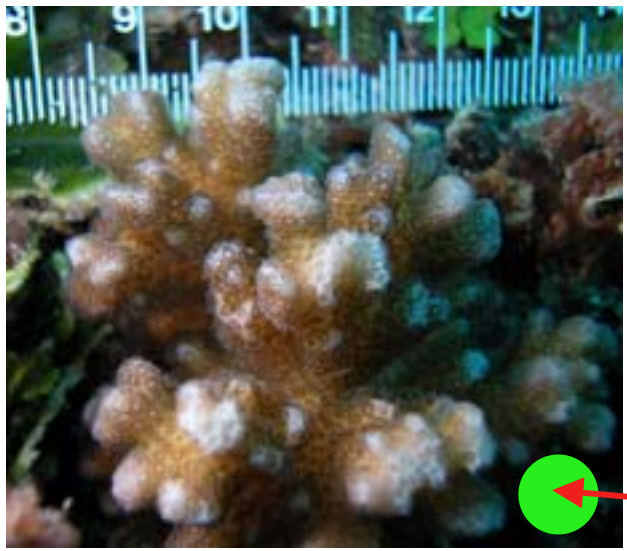
Host specificity

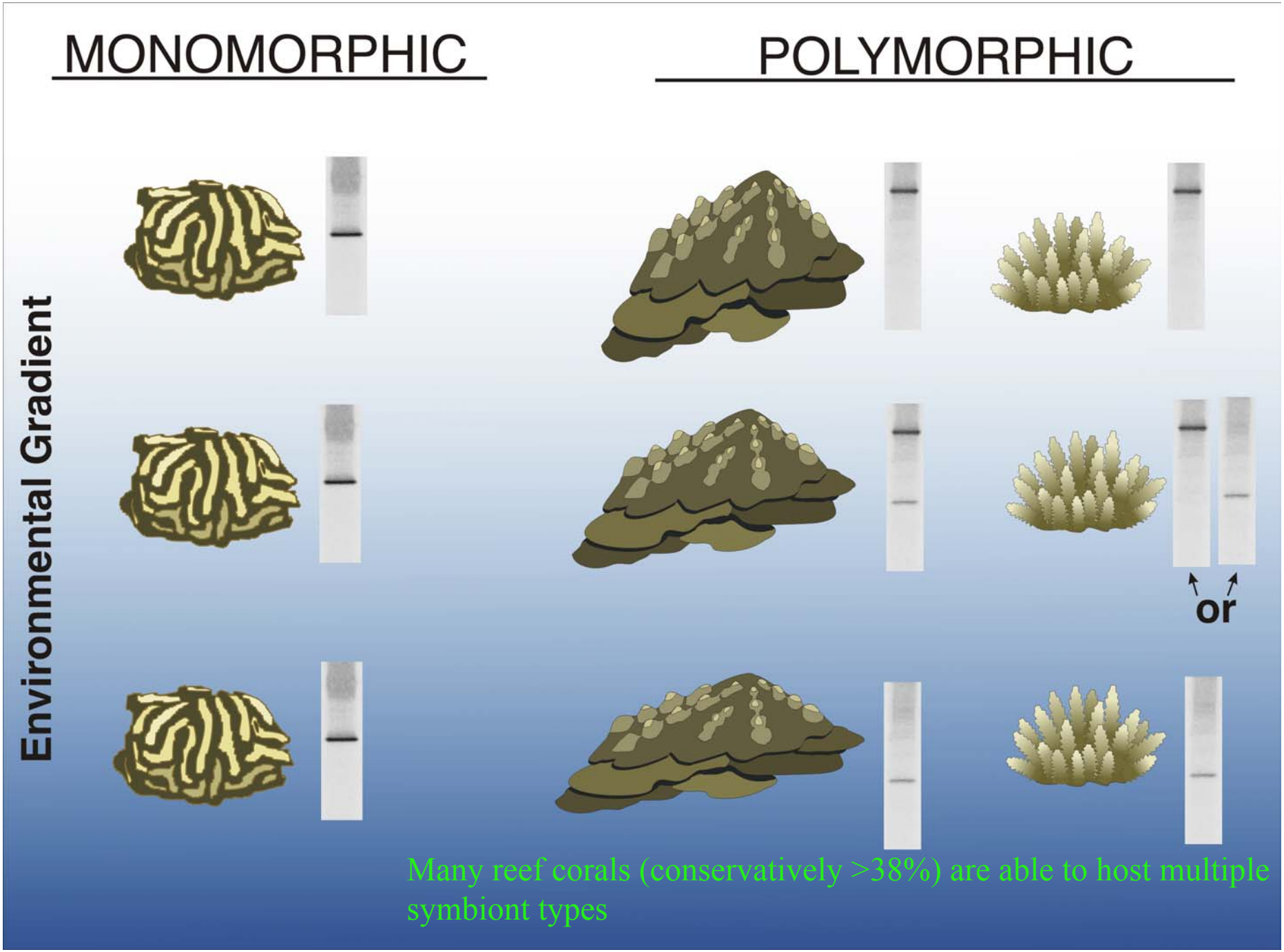
Some symbiont types have widespread distributions and are consistently found in certain host taxa.



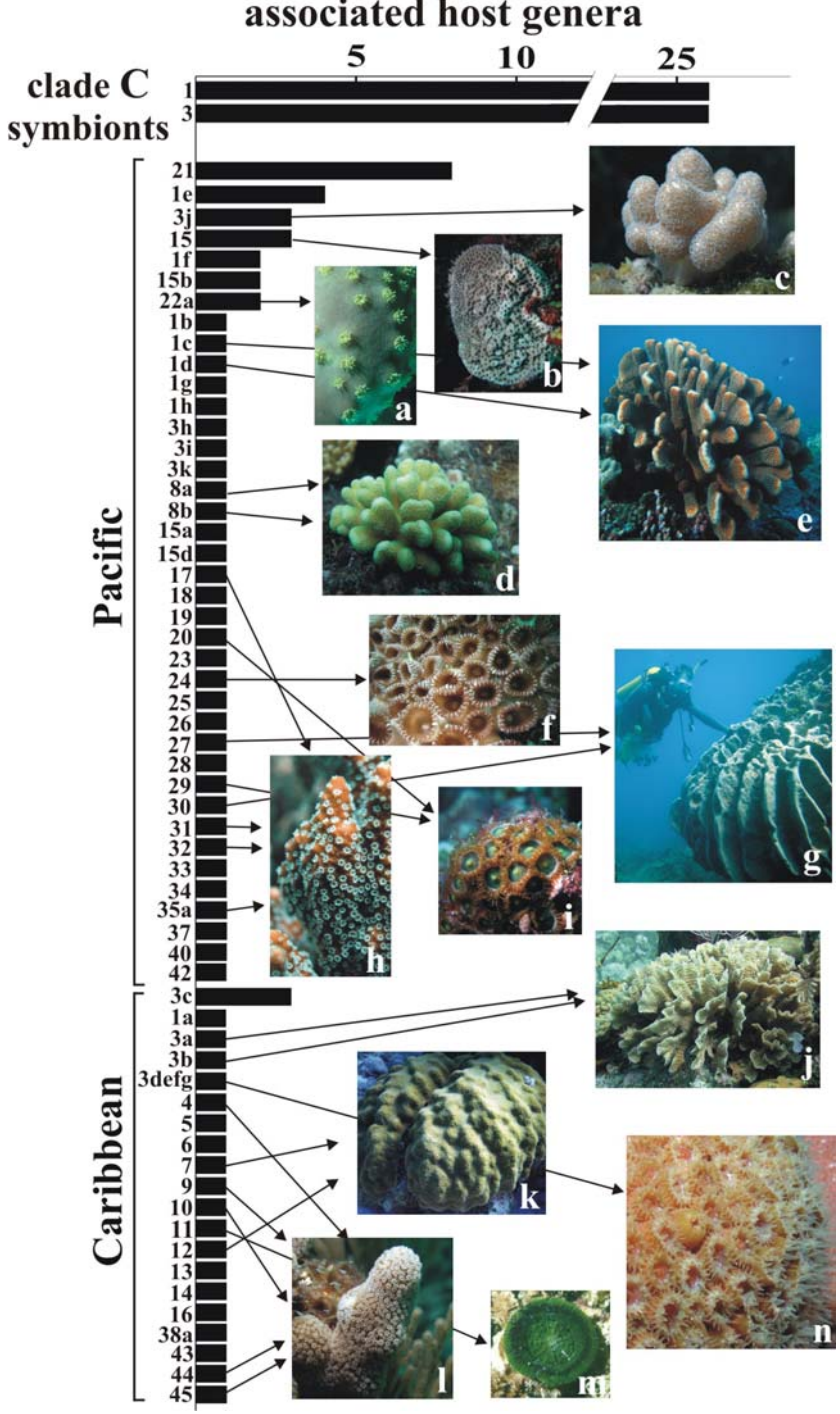
Other symbioses have limited host ranges and defined biogeographic distributions.

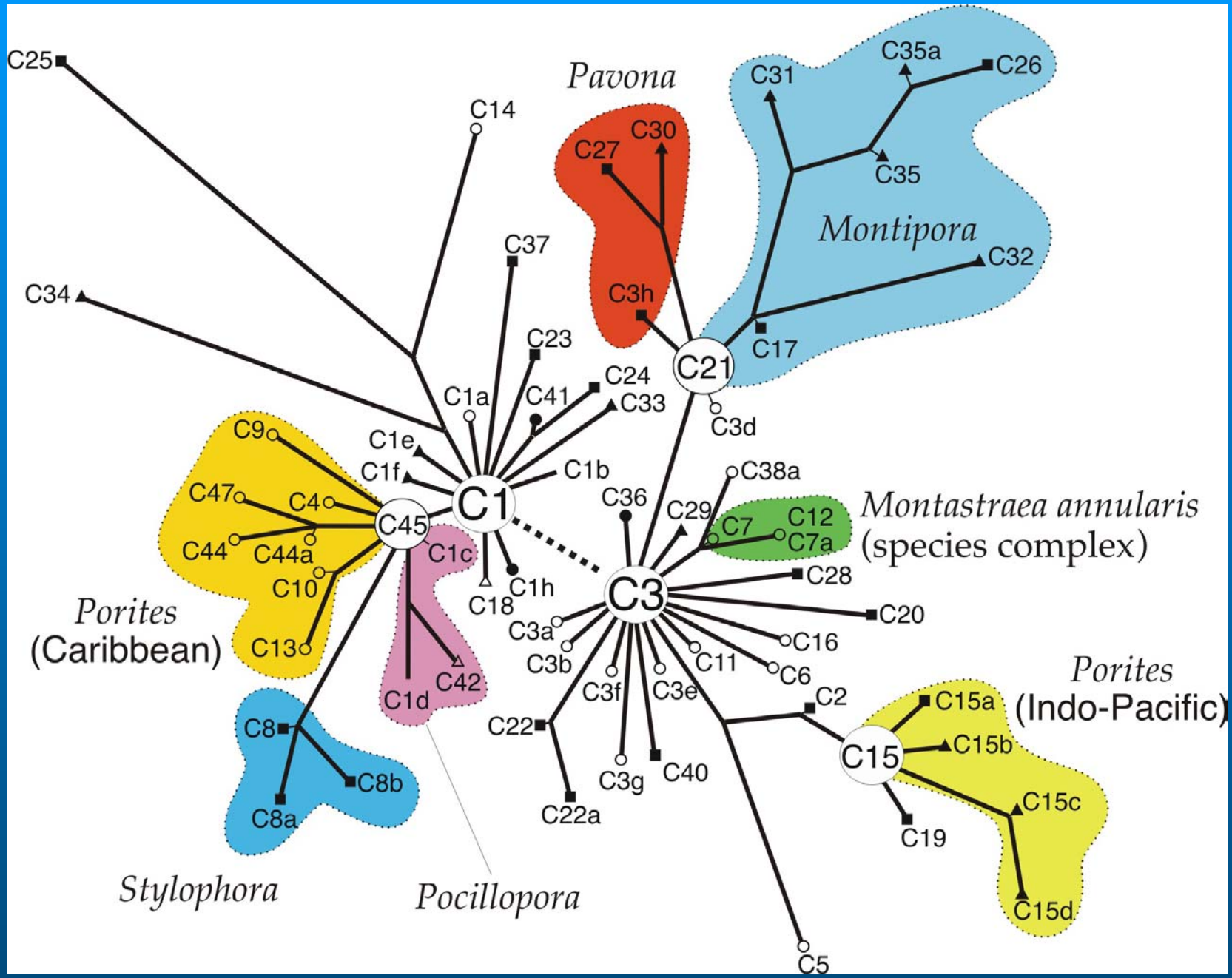


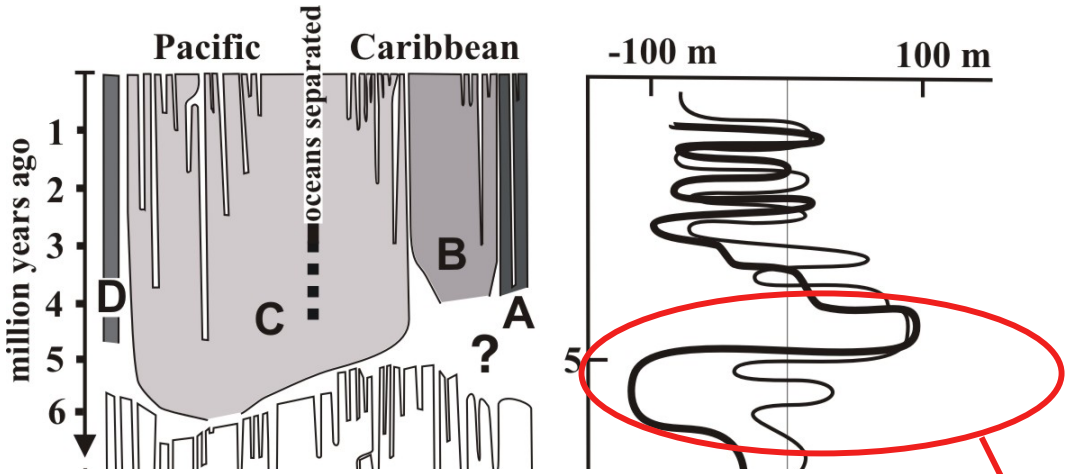

C1c/d


MONOMORPHIC
POLYMORPHIC
Environmental Gradient
or
Many reef corals (conservatively >38%) are able to host multiple symbiont types

Evolutionary patterns and processes


associated host genera
5
10
25
clade C symbionts
1
3
Pacific
21
1e
3j
15
1f
15b
22a
1b
1c
1d
1g
1h
3h
3i
3k
8a
8b
15a
15d
17
18
19
20
23
24
25
26
27
28
29
30
31
32
33
34
35a
37
40
42
Caribbean
3c
1a
3a
3b
3defg
4
5
6
7
9
10
11
12
13
14
16
38a
43
44
45
a
b
c
d
e
f
g
h
i
j
k
l
m
n


C25
C14
Pavona
C35a
C31
C26
C27
C30
C35
Montipora
C37
C32
C34
C3h
C23
C17
C21
C24
C1a
C41
C33
C3d
C9
C1e
C1f
C1b
C38a
C47
C4
C1
C36
C29
C12
C7
C7a
Montastraea annularis
(species complex)
C45
C44
C44a
C1c
C28
C10
C18
C1h
C3
C20
Porites
(Caribbean)
C3a
C16
C3b
C11
C6
C13
C42
C3f
C3e
C2
Porites
(Indo-Pacific)
C1d
C22
C15a
C8
C15b
C15
C3g
C40
C8b
C22a
C15c
C19
C8a
C15d
Stylophora
Pocillopora
C5


Pacific
Caribbean
oceans separated
million years ago
1
2
3
4
5
6
D
C
B
A
?
-100 m
100 m
5

7 to 5 Mry ago

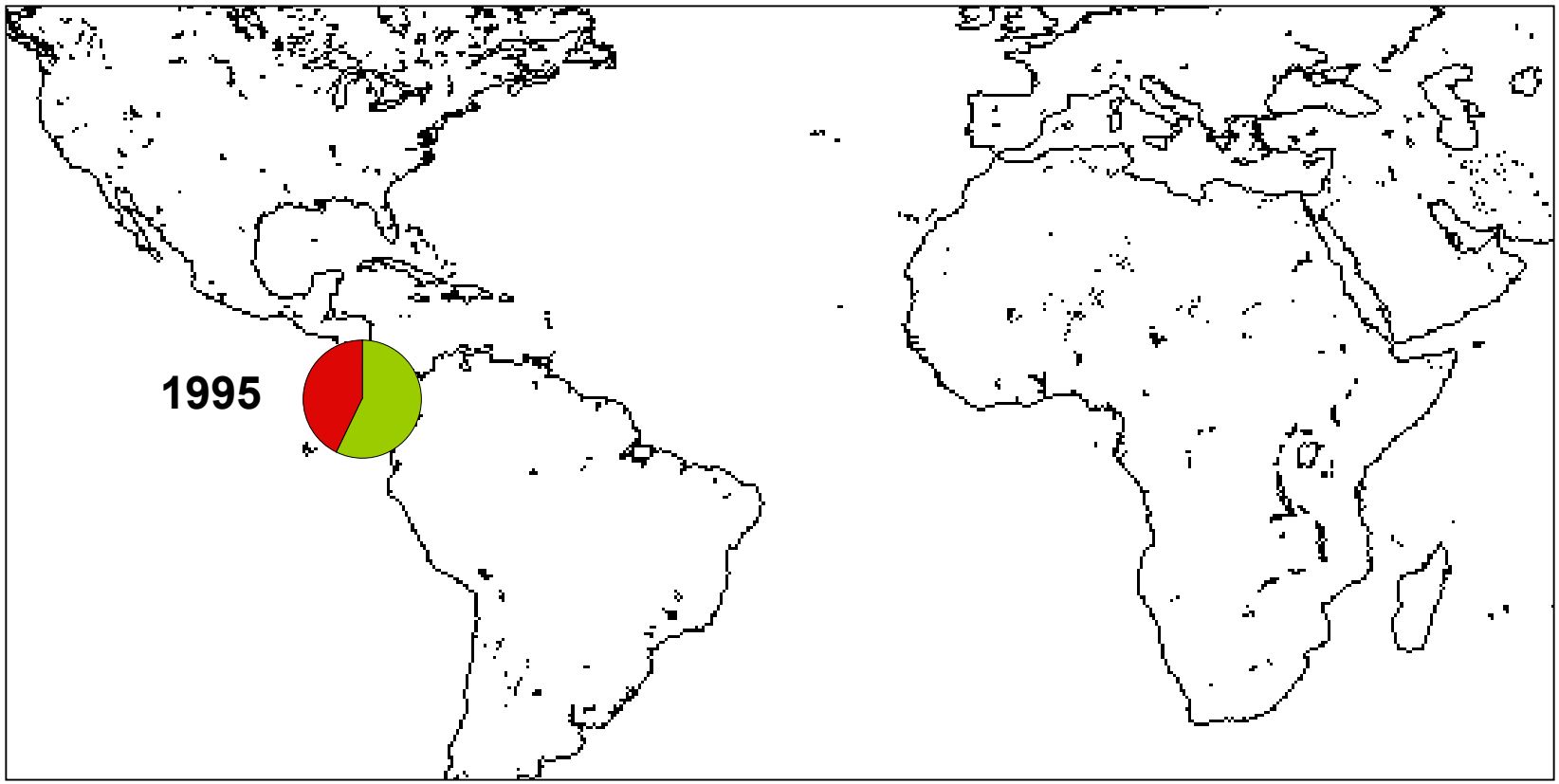
The patterns and processes of coral symbiont evolution:

The evolution of coral symbionts is punctuated…. undergoing rapid changes to form symbioses with select generalists.

Under relative stability or "equilibrium," the host internal environment becomes a major axis of niche diversification and leads to the adaptive radiation of specialized symbiont lines (e.g. co-evolution, symbiont competition, etc…)

Is there evidence for the rise and spread of a successful generalist?

Shifts in symbiont community structure on reefs worldwide following 1997-98 mass bleaching

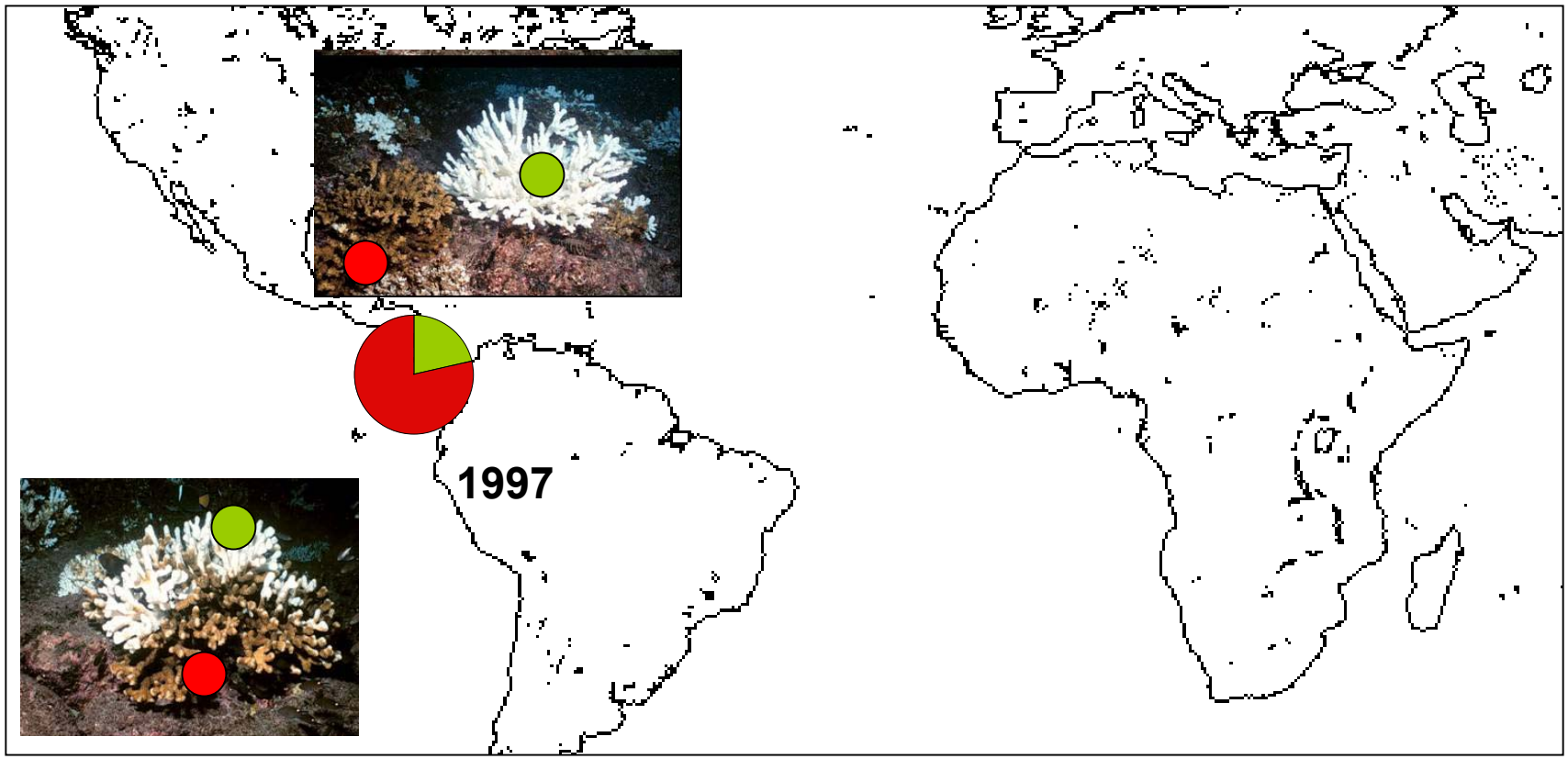


Symbiodinium C

Symbiodinium D

Far eastern Pacific: prior to 1997-98 El Nino

Non-naïve reefs already contained significant amounts of *Symbiodinium* in clade D following 1982-83 El Nino

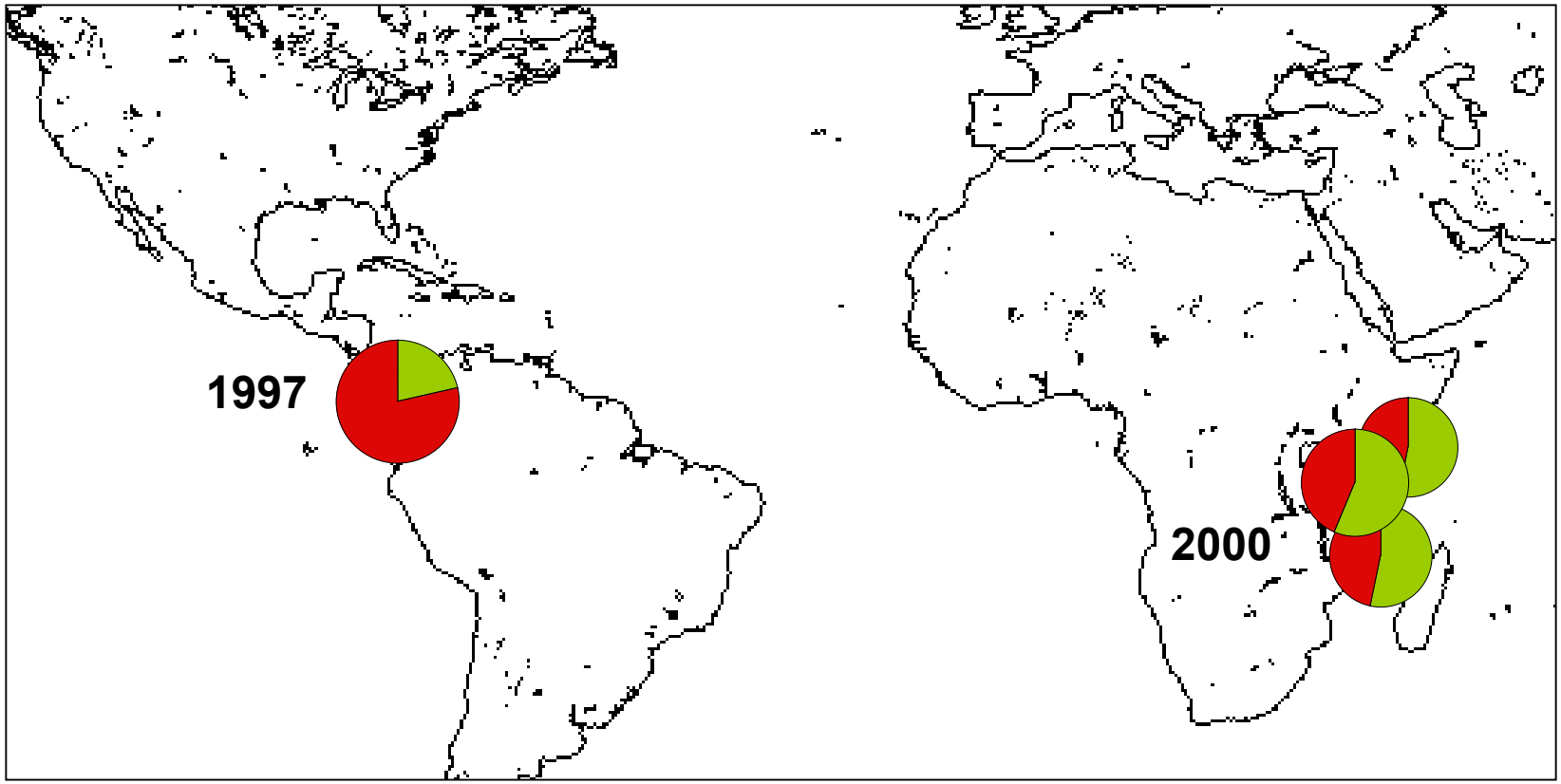


Symbiodinium C

Symbiodinium D

Far eastern Pacific: during 1997-98 El Nino

During 1997-98 El Nino, corals containing high temperature resistant *Symbiodinium* in clade *D* became even more common

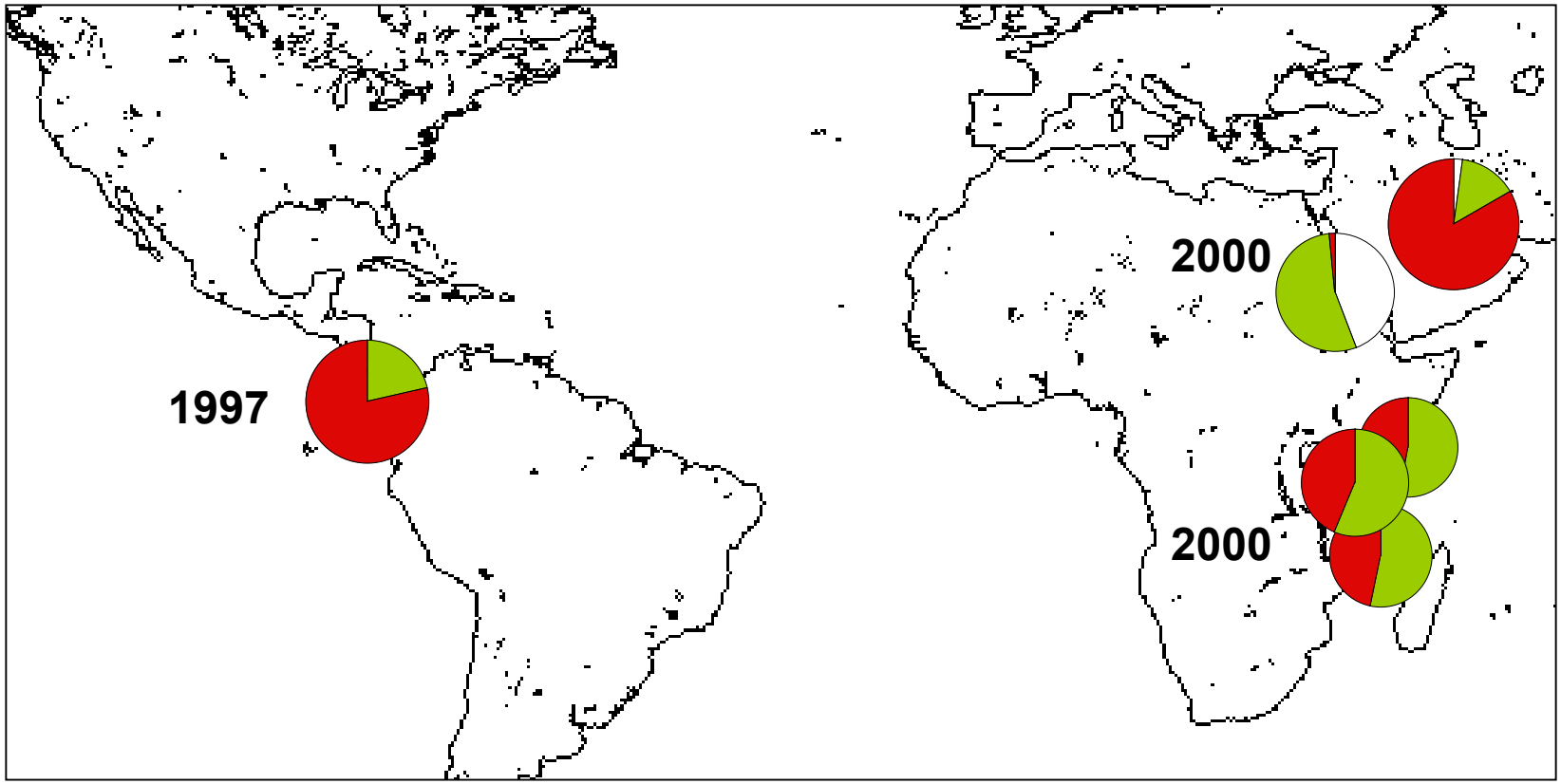


Symbiodinium C

Symbiodinium D

Kenya

During 1997-98 El Nino, reefs suffered ~60% mortality. By 2000 these reefs also contained significant *Symbiodinium D*



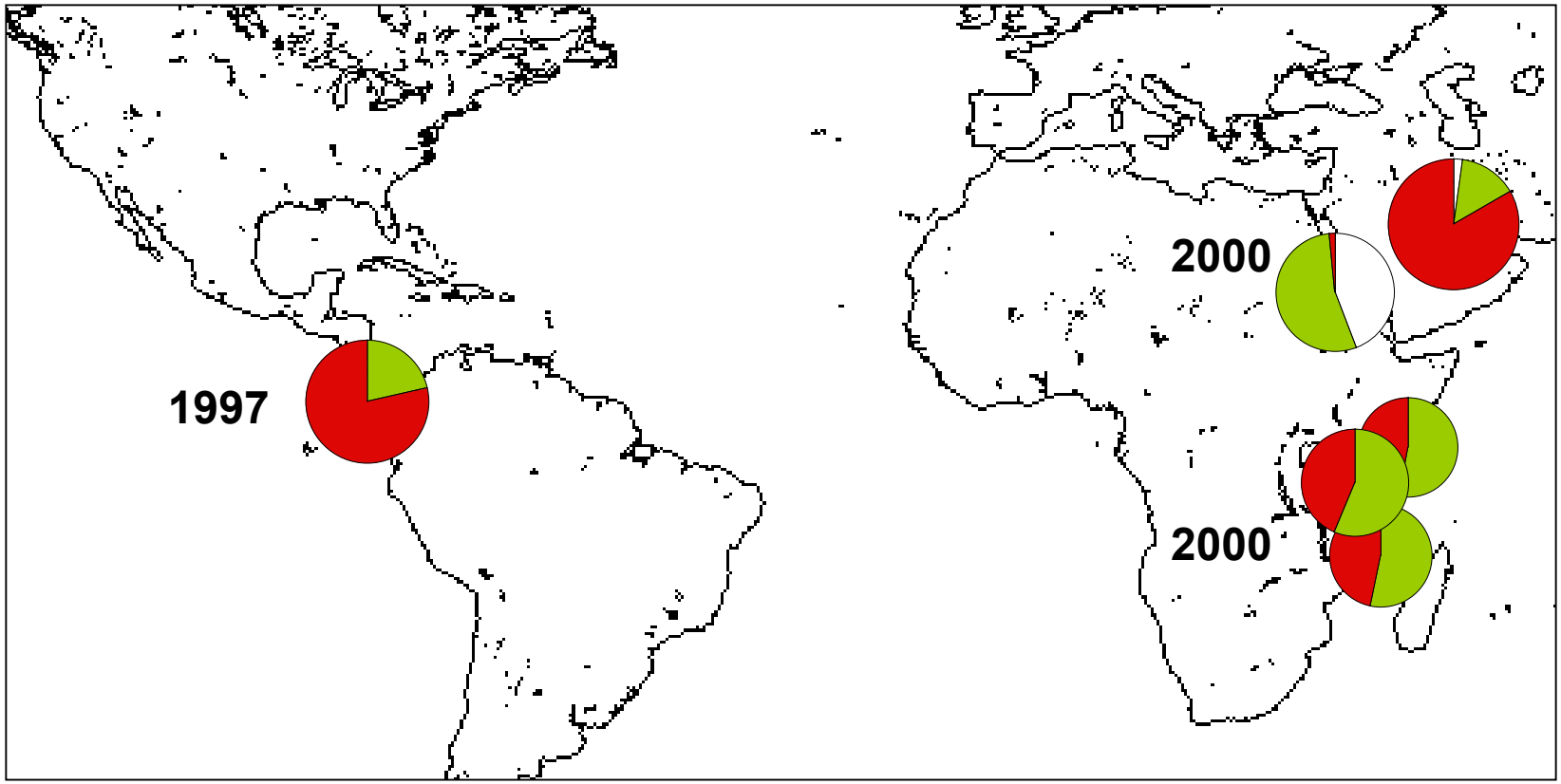
Symbiodinium A

Symbiodinium C

Symbiodinium D

Saudi Arabia

These extreme high temperature of the Persian Gulf (routinely >33^{o}C in summer) are dominated by *Symbiodinium* clade *D* in contrast to the central Red Sea (29^{o}C in summer), which have little or no clade *D*



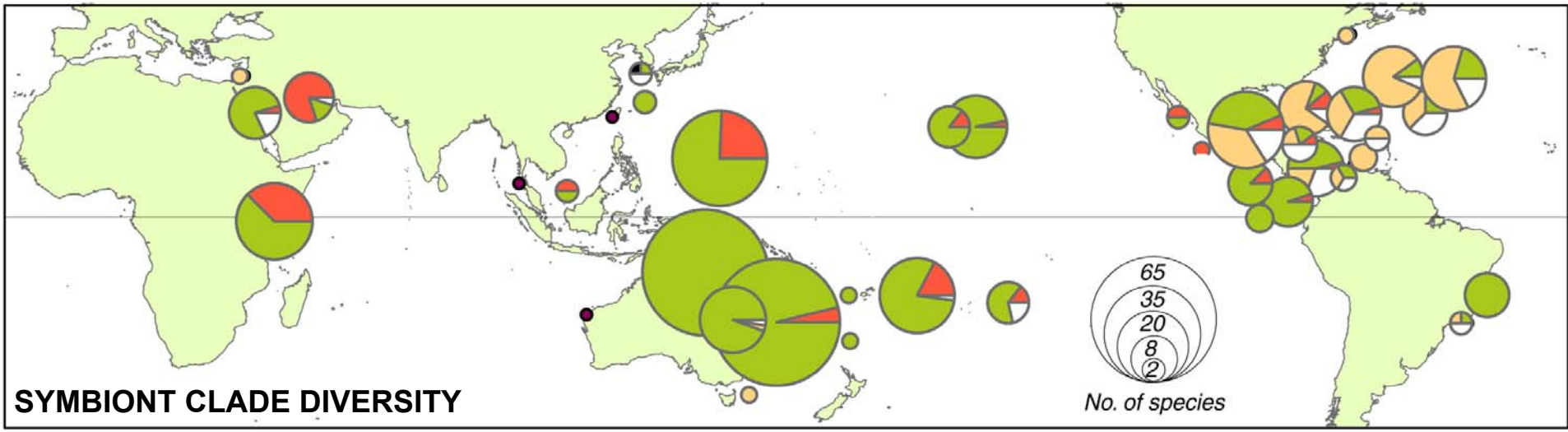
Symbiont community structure of scleractinian corals from bleached or recovering reefs:

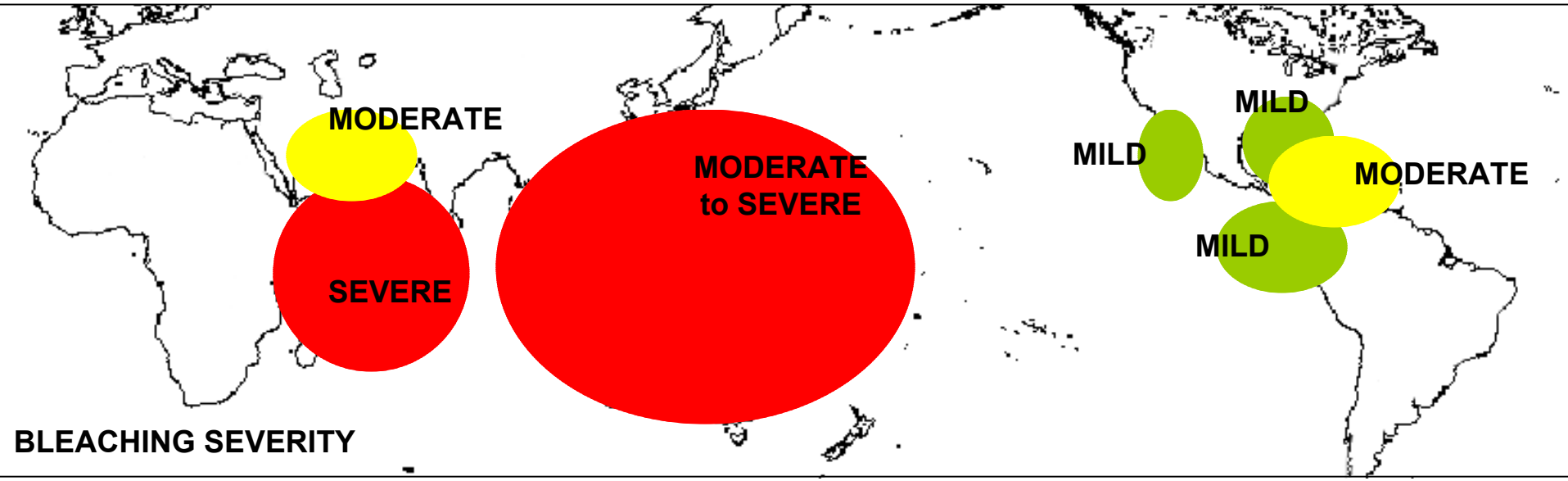
(1) Differs from that of the same reefs prior to bleaching

(2) More closely resembles the community structure of reefs found at higher temperatures

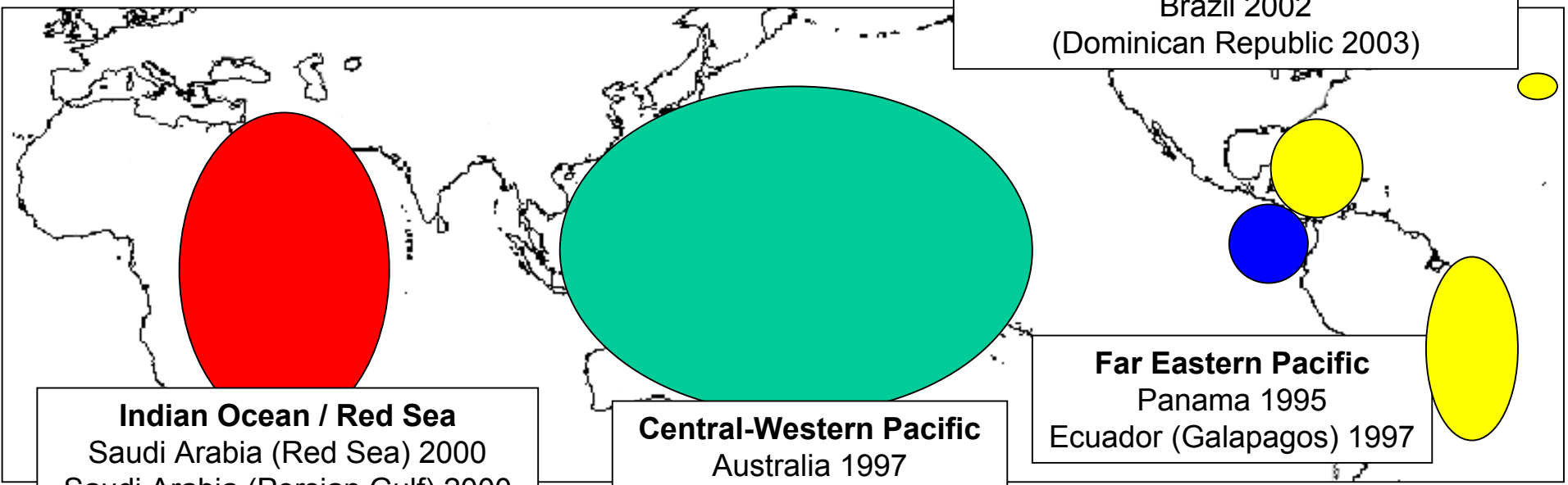
(Has a higher bleaching threshold as a result)

Correlating symbiont diversity with bleaching: a regional scale approach





Monitoring global patterns of *Symbiodinium* community change to understand bleaching resistance and resilience



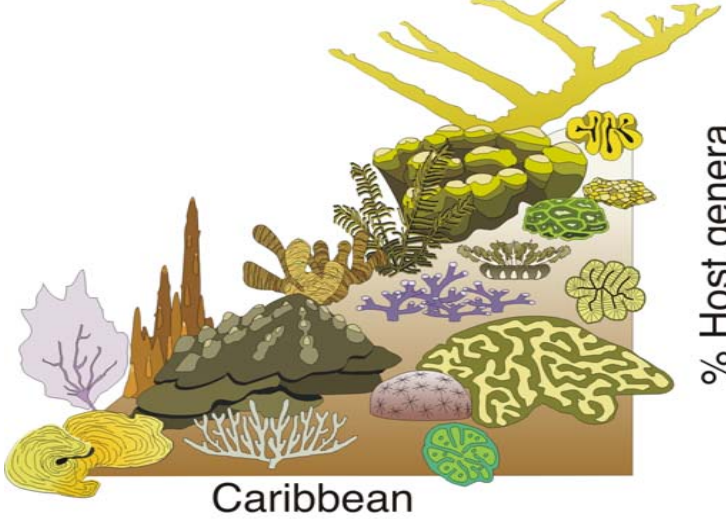
Western Atlantic (Caribbean)
Panama 1995
Bahamas (Lee Stocking Island) 1995
Florida Keys, USA 1999
Bermuda 2001
Belize 2001
Brazil 2002
(Dominican Republic 2003)

Indian Ocean / Red Sea
Saudi Arabia (Red Sea) 2000
Saudi Arabia (Persian Gulf) 2000
Kenya 2001
Madagascar 2001
Mauritius 2002
Zanzibar 2002
Israel 2003

Central-Western Pacific
Australia 1997
Hawaii 2003
(Japan 2003)
(Papua New Guinea 2003)
(Indonesia 2003)

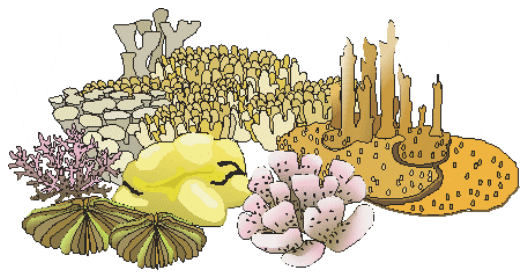
Far Eastern Pacific
Panama 1995
Ecuador (Galapagos) 1997

(Country, date of first WCS survey)

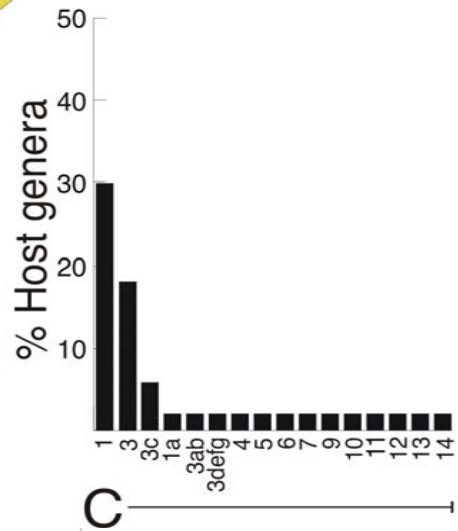


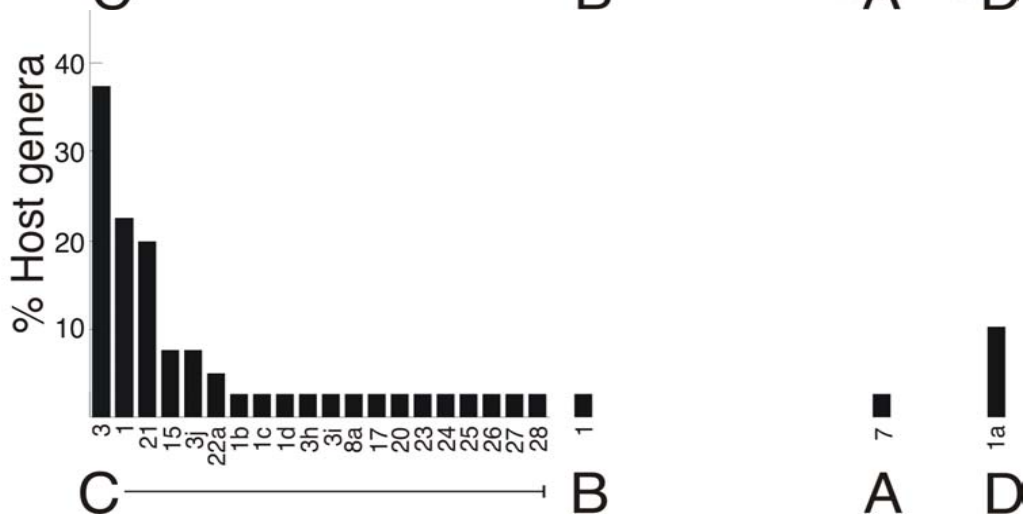
Caribbean

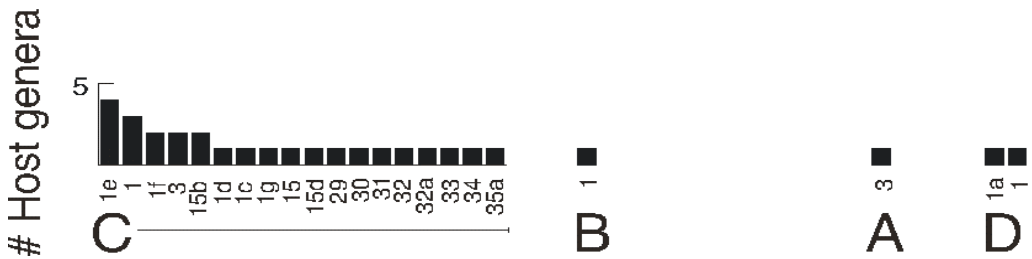
Great Barrier Reef



Hawaii







Shifts in symbiont community structure may mean that bleaching thresholds change over time.

Must take account of *regional symbiont diversity*, which is dependent on:

Evolutionary history/paleoclimates
Coral species composition
Biogeography
Recent bleaching history
Time between bleaching events

These may be important factors in determining long-term response to climate change

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