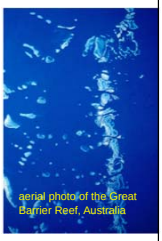
Coral Reef Ecology

I. Importance of Coral Reefs
II. Distribution
III. Reef Structure/Zonation
IV. Key Taxa
V. Coral Biology
VI. Productivity & Diversity
VII. Biotic Interactions
VIII. Abiotic Disturbance
IX. The Future of Coral Reefs

I. Importance of Coral Reefs

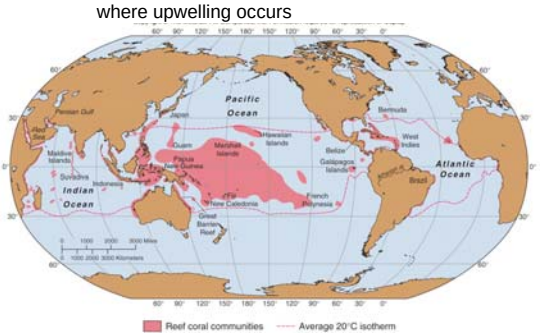
- largest biologically formed structures in world
  (e.g., Great Barrier Reef is 2000 km long & 150 km wide)
- greatest taxonomic diversity of all marine habitats
  (~1 million species)
- remove ~700 billion kg of CO_2/yr
- but cover only 0.71% of area of planet

Provide
- food (e.g., feed 1 billion people in Asia)
- income (fisheries & tourism)
- cultural value
- esthetic value
- pharmaceuticals
- protection from waves/erosion



II. Distribution

- worldwide in tropical seas
- lower abundance on western margin continents, where upwelling occurs



Pattern of Diversity

- diversity highest in Indo-Pacific

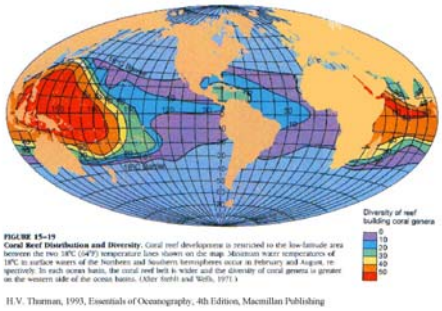
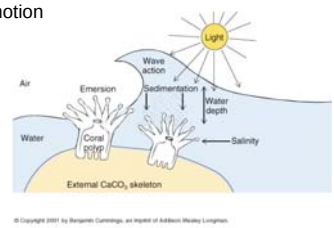


FIGURE 15–19
Coral Reef Distribution and Diversity. Coral reef development is restricted to the low-latitude area between the two 18°C (64°F) temperature lines shown on the map. Minimum water temperatures of 18°C in surface waters of the Northern and Southern hemispheres occur in February and August, respectively. In each ocean basin, the coral reef belt is wider and the diversity of coral genera is greater on the western side of the ocean basins. (After Stehli and Wells, 1971.)

H.V. Thurman, 1993, Essentials of Oceanography, 4th Edition, Macmillan Publishing

Conditions for coral reef growth

- warm water: 18-40 ºC
- shallow with light (at least 1% surface intensity <70m depth)
- salinity: fully marine
- low sediment
- limited emersion: <1hr
- moderate water motion

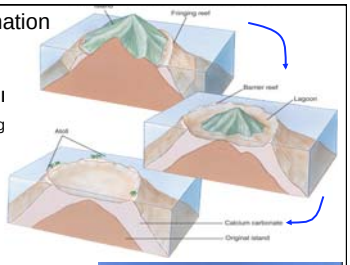


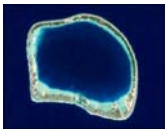
III. Reef Structure/Zonation

Reef Formation:

fringing ⇒ barrier ⇒ atoll

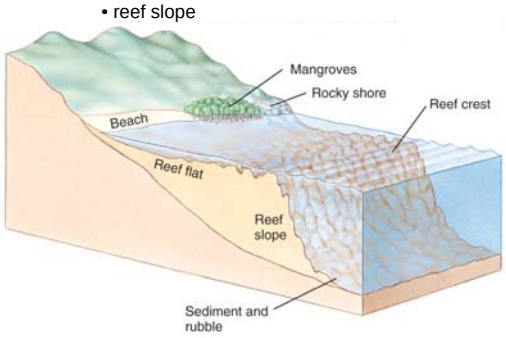
(process results from rising sea level + subsidence of underlying land)



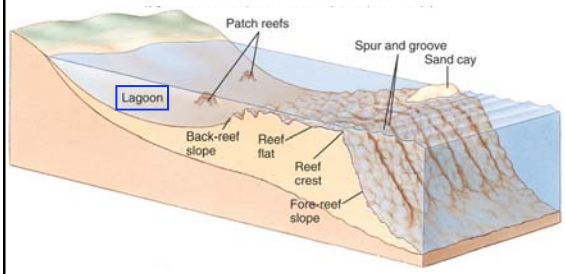


Reef Zones

- reef flat
- reef crest
- reef slope



Barrier reefs have **lagoons**



IV. Key Taxa

- **Hard Corals**
  - **stony corals**
  - **stony hydrozoans (fire coral)**
- **Sessile Invertebrates**
- **Macroalgae**
- **Mobile Invertebrates**
- **Fishes**

Hard corals

stony corals (order Scleractinia)

stony hydrozoans (class Hyrdozoa)

Sessile Invertebrates

ascidians

soft corals

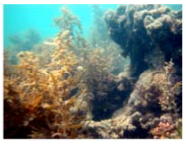
sponges

gorgonians

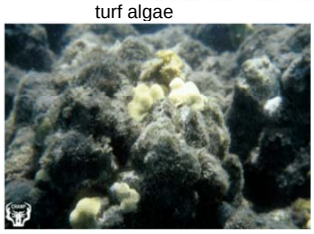
hydroids

Algae

macroalgae



turf algae

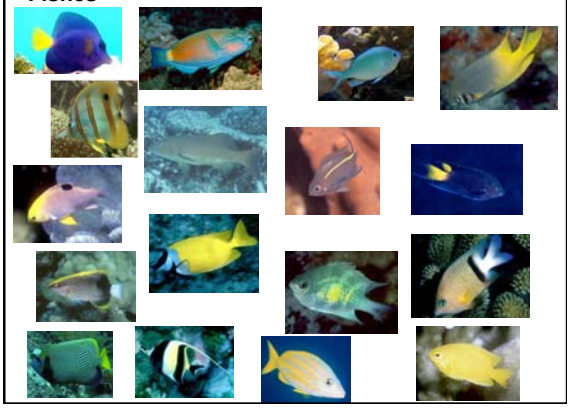


coralline algae

Mobile Invertebrates

- echinoderms
- crustaceans
- polychaetes
- molluscs

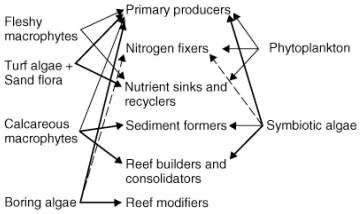
Fishes



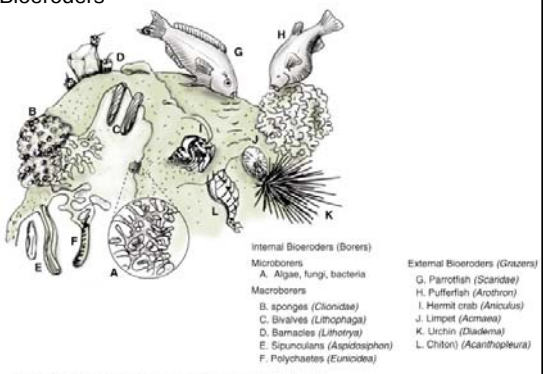
Functional groups on reefs

- Primary producers
- Herbivores
  - bioeroders – remove coral skeletons
  - scrapers – remove algae and sediments
  - grazers – remove macroalgae
- Planktivores
  - fishes & invertebrates, including corals
- Predators
  - piscivores, corallivores, invert eaters

Primary Producers



Bioeroders



V. Coral Biology

1. Coral Phylogeny
2. Coral Morphology
3. Life Cycle
4. Sexual Reproduction
5. Asexual Reproduction
6. Coral-Algal Symbiosis

Corals are cnidarians (like sea anemones, jellies, etc.)

Phylum Cnidaria

Class Scyphozoa (jellies)

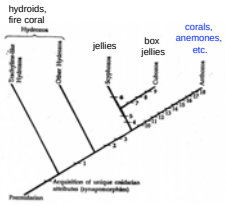
Class Cubozoa (box jellies)

Class Hydrozoa (hydroids, hydromedusae)
Order Milliporina (hydrocorals *Millipora spp.*)
Order Stylasterina (*Allopora, Stylaster*)

Class Anthozoa (sea anemones, sea pens, corals)

Subclass Octocorallia
Order Gorgonacea (sea fans, sea whips)
Order Alcyonacea (soft corals)

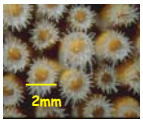
Subclass Zoantharia (sea anemones and 'true' corals)
Order Actinaria (sea anemones)
Order Zooanthidea (zooanthids)
Order Corallimorpha (coralimorphs)
Order Scleractinia (stony corals)
35 Indo-Pac Families, ca. 350 spp (incl Red Se
12 Caribbean Families, ca 60 spp.

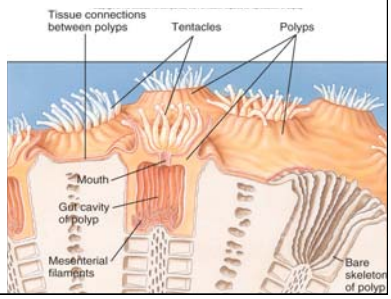


Coral Morphology: hermatypic (reef building) corals

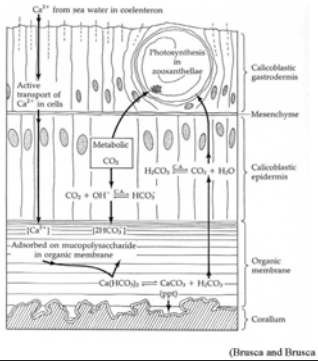
Slime covered rocks?

- thin layer of tissue on top of an inorganic skeleton ($CaCO_3$)



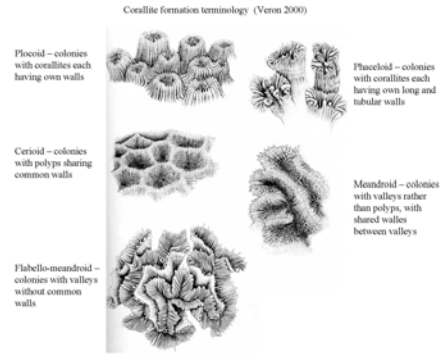


Hermatypic corals build $CaCO_3$ skeletons from CO_2 and calcium in sea water

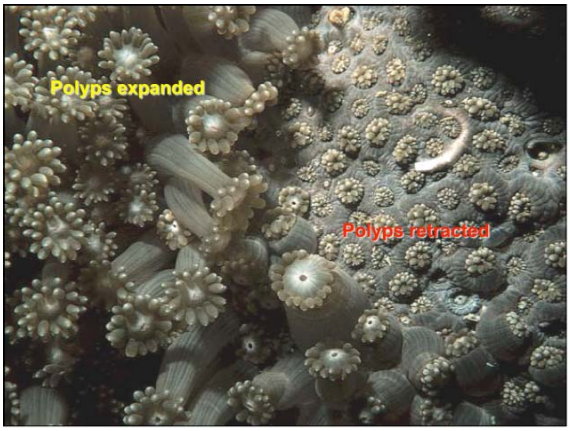


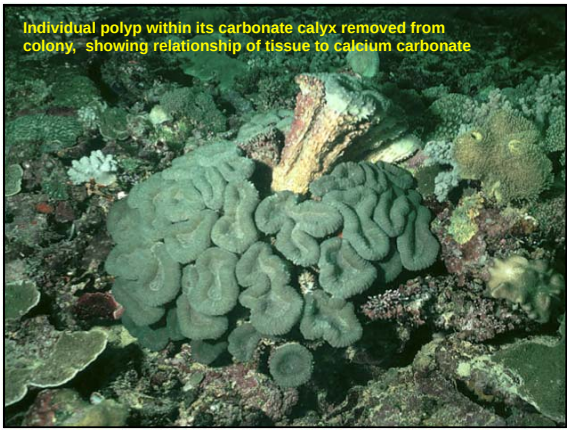
(Brusca and Brusca 1990)

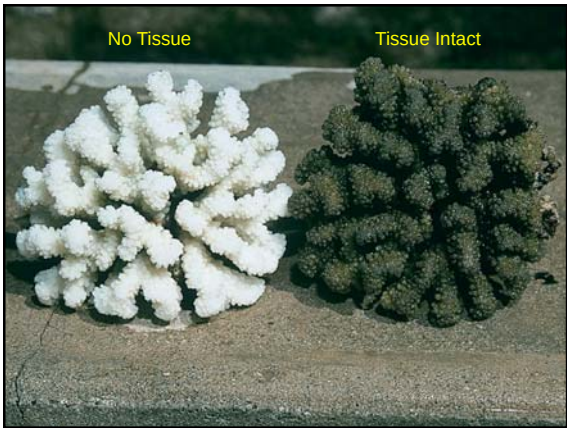
Coral Morphology - corallite structure is variable



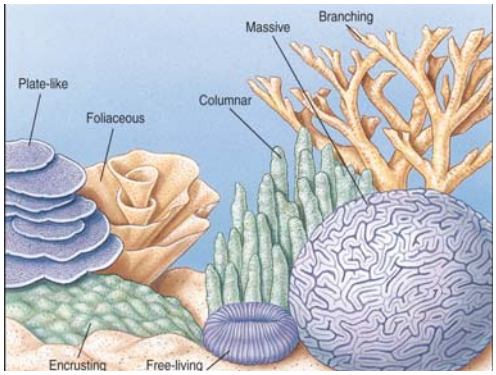
corallite structure



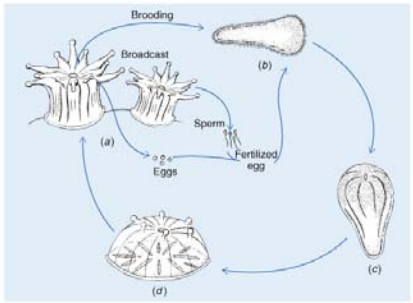




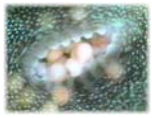
Coral Morphology - colony structure varies



Life cycle

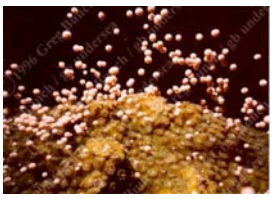
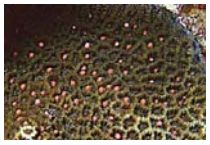


Sexual Reproduction




Sexual Reproduction



Sexual Reproduction

Asexual Reproduction

- **Fragmentation**: portions of a colony break off, then reattach to the substrate and continue to grow

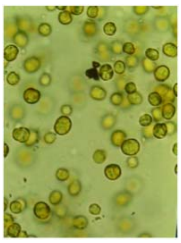
Coral-Algal Symbiosis

- **Corals & Zooxanthellae**

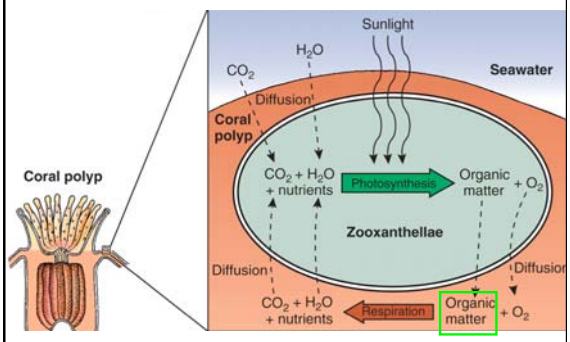
Zooxanthellae…

- unicellular dinoflagellate algae
- use photosynthesis to fix carbon
- some of the fixed carbon is passed to the host (coral)

Zooxanthellae



Molecules move between coral tissue & zooxanthellae



VI. Productivity & Diversity

- extremely **high productivity**
- extremely **high diversity**

VI. Productivity & Diversity

High Productivity

- (especially considering surrounding waters are oligotrophic)

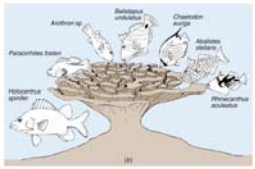
Production (kg Carbon per m^2 per year)	
Average Oceanic areas	**0.1 kg**
Rainforest	**2 kg**
Kelp forest	**2 kg**
Coral Reef	**1.5-5 kg**

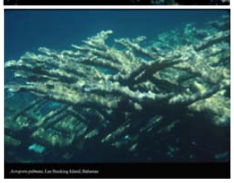
- high productivity possible because of tight recycling of nutrients, photosynthetic fixation of carbon (by corals and algae) and nitrogen (by blue-green algae)

High Diversity

- similar species diversity per unit area to tropical rain forests
- highest diversity on earth of higher level taxa (Phyla)
- sustained by high productivity & structural complexity

Physical structure (cracks and crevices) provides refuge from predators



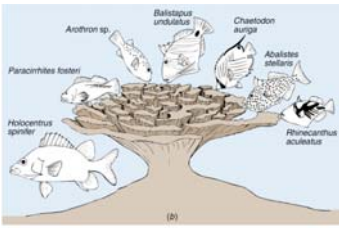


VII. Biotic Interactions

- facilitation
- mutualism
- competition
- herbivory
- predation
- disease

Facilitation

- common on coral reefs
- e.g., corals provide food and refuge for most coral-reef organisms



Mutualism

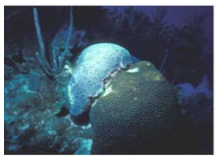



Competition

Limited resources:

- space (e.g., competition among corals)
- light (e.g., competition among corals & algae)
- food (e.g., competition among fishes)
- shelter (e.g., competition among fishes)

Competition for space: corals vs. corals


sweeper tentacles

Competition for space: corals vs. macroalgae

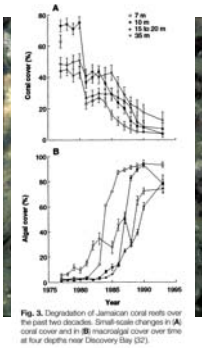
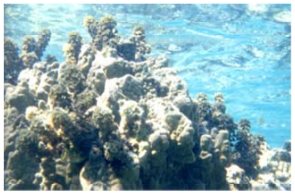


Fig. 3. Degradation of Jamaican coral reefs over the past two decades. Small-scale changes in (A) coral cover and in (B) macroalgal cover over time at four depths near Discovery Bay (32).

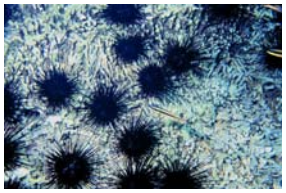
Hughes 1994

- macroalgae have faster growth rates than corals
- macroalgae respond more rapidly to nutrient addition



Herbivory

- keeps macroalgae from outcompeting corals

Predation

- on corals
- on other organisms

"wall of mouths" removes plankton

sea star *Acanthaster:* coral predator

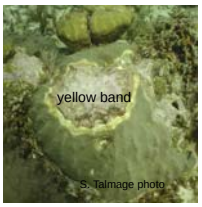
Disease

- coral diseases
- *Diadema* mass mortality

Diadema before mass mortality:
95-99% died

Coral Diseases

- occur in hard and soft corals
- most pathogens are not known
- temperature may contribute (e.g., by increasing bacterial growth)



VIII. Abiotic Disturbance

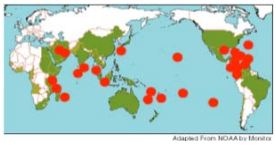
- **storms** (water motion)
- **water temperature**
- **sedimentation**

Storms: hurricanes and cyclones

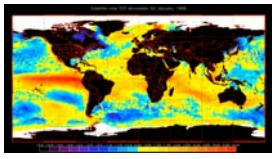
Water Temperature & Coral Bleaching

- **bleaching** occurs when corals expel their symbiotic algae (zooxanthellae)
- triggered by stress, mainly too **warm water**
- stress causes mutualism breaks down
- coral die if the stress is extreme or prolonged (coral starves)

Water Temperature & Coral Bleaching



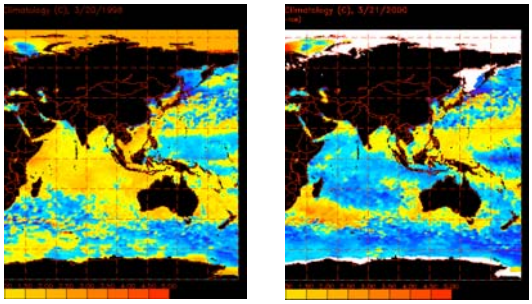
Red dots show areas with most severe coral bleaching (1997-1998 event)



NOAA sea surface temperature anomalies for January 1998

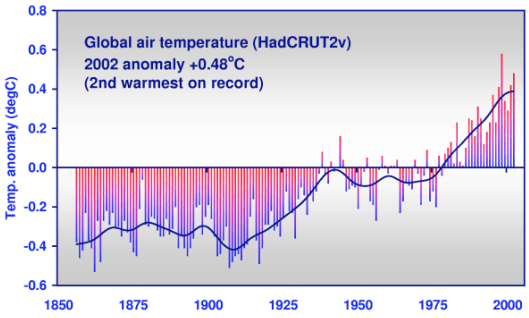
Water Temperature & Coral Bleaching

warm year | "normal" year



March 20, 1998 www.noaa.gov March 21, 2000

Global Air Temperature Anomaly



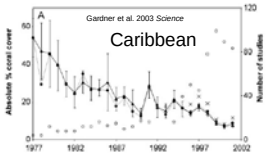
Sedimentation

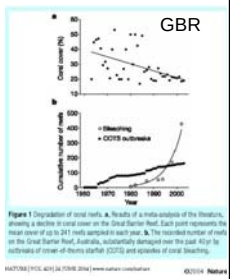
- smothers corals
- reduces water clarity

IX. The Future of Coral Reefs

Declines in coral abundance (% cover)

- **80% decline on Caribbean reefs over last few decades**
- **50% decline on Great Barrier Reef**
- **good news: much less in most of the Indo-Pacific**





Bellwood et al. 2004 *Nature*

Causes of decline of coral reefs

- climate change (e.g., global warming ⇒ bleaching)
- storms
- diseases
- predator outbreaks
- pollution, runoff, sedimentation (due to coastal development)
- changes in community structure (e.g., due to overfishing, including with dynamite and cyanide)
- ship groundings & anchor damage

Result

⇒ phase shift (coral ⇒ macroalgal dominated reefs)

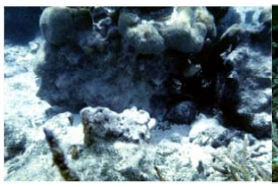
Phase shift: corals ⇒ macroalgae

Jamaican reefs – intensively studied since 1950s

- **Overfishing: 1960's – reduced fish biomass by 80% - herbivorous fishes**
- **Hurricane Allen: 1980 – destroyed lots of large shallow-water corals**
- **Urchin disease: 1982 – reduced urchin population by 99%**
- **Bleaching – 1987, 1989, 1990**

- **coral cover 52% ⇒ 3%**
- **macroalgal cover 4% ⇒ 92%**

Pre 1983



abundant free space for coral settlement

Post 1983

little free space for coral settlement

Phase shift: is it reversible?

Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef

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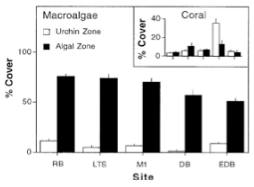
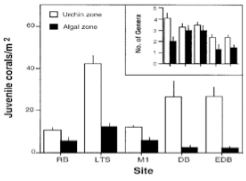
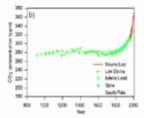
Macroalgal cover down



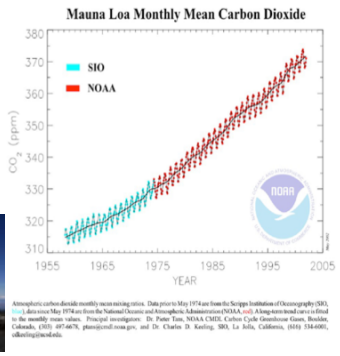
Coral recruitment up



Trends in Atmospheric CO_2

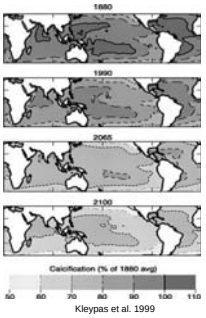


from: Niki Gruber, UCLA Institute of Geophysics and Planetary Physics



Ocean Acidification: increases in atmospheric CO_2 are predicted to acidify ocean and reduce rate of calcification -- which will **cause coral reefs to degrade**

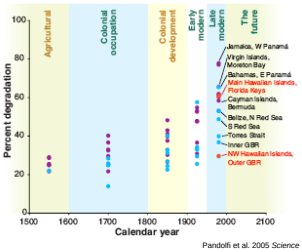
- **⇑ CO_2 lowers pH of ocean**
- **$CaCO_3$ dissolves or doesn't form properly**
- **$CaCO_3$ shells, casings, skeletons affected**



Kleypas et al. 1999

Predicted future of coral reefs

- Coral reefs may cease to exist in 20 years
  - (Jackson et al. 2001, Pandolfi et al. 2003, Hughes et al. 2003)
- Coral reefs will exist, but composition will change
  - (Loya et al. 2001, Tamelander 2002, Edmunds 2004)



Pandolfi et al. 2005 *Science*

Summary

- coral reefs are the largest biologically formed structures in the world
- highest taxonomic diversity in the world is found on coral reefs
- very high primary production due to tight recycling
- facilitation common – e.g., coral skeletons provide shelter
- corals contain symbionts (zooxanthellae) which photosynthesize
- coral reefs are in trouble (e.g., bleaching, diseases, macroalgal overgrowth)
- future of coral reefs is uncertain