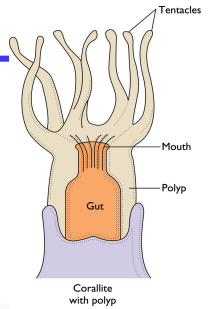
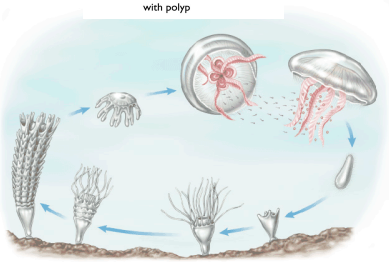
What is Coral?

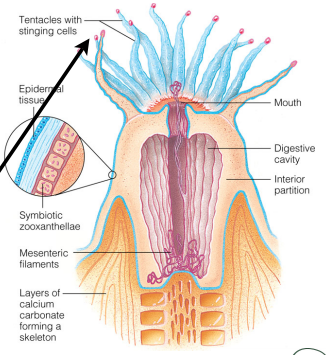
- Phylum Cnidaria
  - Similar to sea anemone
  - Radial symmetry
    - Circular body plan
    - No left & right sides
  - Ring of tentacles around mouth
  - Alternation of sedentary & free-living life-cycle stages
    - Medusae (jellyfish)

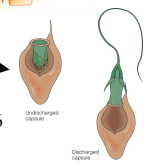




What is Coral?

- Cylindrical “polyp” body
  - Has lost free-swimming stage of life cycle
  - No circulatory, respiratory, excretory systems
  - Waste eliminated via mouth
- Toxic “stingers” on tentacles = cnidoblasts
- Thin layer of tissue over external calcareous base

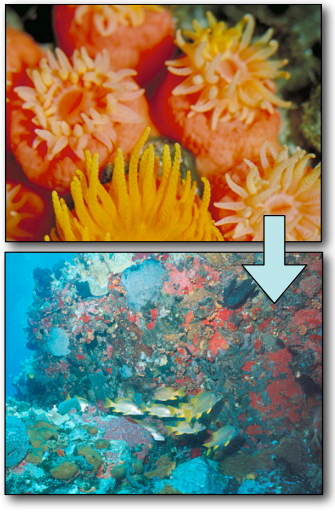




Garrison Figs 15.4 & 15.6 pp. 358 & 360

What Builds Coral Reefs?

- Secrete external calcium carbonate skeleton
  - Common skeleton of colony builds structure
  - Particular species build solid reefs
- Grow in large colonies
  - Colony shape is shape of skeleton
    - Individual organisms are tiny
  - Slow — about 1/2 inch/year
    - 4 m - 20 m per 1000 years



What Builds Coral Reefs?

- Largest biologically created structures on Earth
  - Up to 1300 m thick
  - Up to 2000 km long
- Reef builds upward in successive layers
  - Living coral tissue is just a few millimeters thick on surface of reef

www.gbrmpa.gov.au/

What Builds Coral Reefs?

- Other species of stony corals
  - Brain, fan, elkhorn, etc. live on built reef
- Some reef-building by other organisms
  - Calcareous algae also deposit limestone
  - Help reinforce the reef
  - Some reefs mostly built by algae

Other Kinds of Coral

- Other corals live outside tropical reefs
  - Including in cold water
    - Cup corals in Puget Sound
- Deep-sea corals
  - Newly discovered off Washington coast
    - Soft & stony reef-building
  - Impacted by fishing nets
    - Essential fish habitat
    - New regulations to protect

www.noaanews.noaa.gov/stories2006/s2652.htm

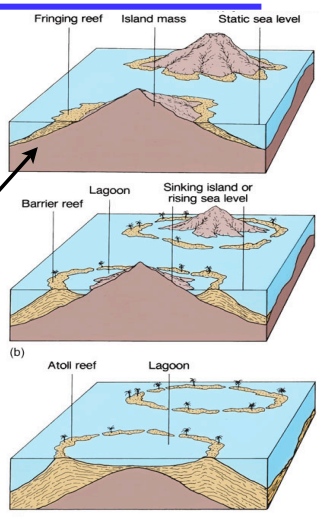
Deep-sea Corals

- Coral community on Gulf of Alaska seamount

www.oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html

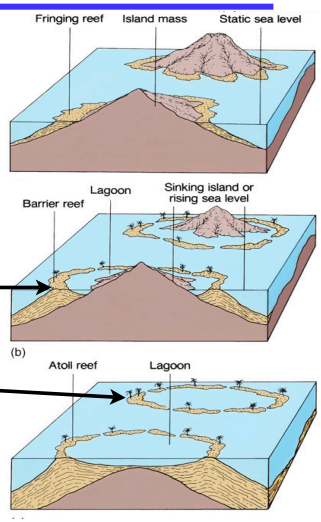
How do Coral Reefs Grow?

- Darwin first correctly theorized about reef succession
  - Proposed after voyage of *Beagle* 1831-1836
- Fringing Reef grows on shore
  - Island sinks (or sea level rises)
  - Coral growth keeps pace with change in relative sea level



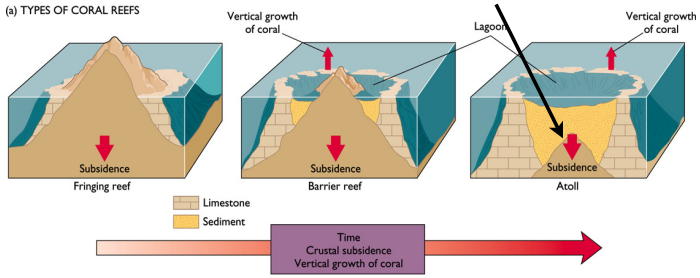
How do Coral Reefs Grow?

- Reef remains in original position as shoreline retreats
  - Coral continues to grow upward above original shoreline
  - Barrier reef
    - Lagoon between reef & shore
  - Atoll
    - Island submerges & only reef & lagoon remain



How do Coral Reefs Grow?

- Darwin's theory not proven until 1960
  - Plate tectonics explained why islands sink as they drift away from mid-ocean ridge
  - Drilling confirmed presence of volcanic basalt beneath limestone & sediments from atoll lagoon

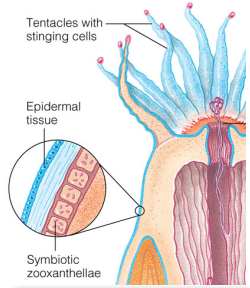


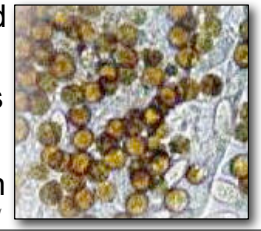
How Do Coral Animals Feed?

- Ambush predators on zooplankton
  - Do not pump water or swim
    - Not filter-feeders
  - Typically feed at night when zooplankton rise to surface
- Supplies <50% of their nutritional needs
  - Protein, as for Venus fly trap

How Do Coral Animals Feed?

- Symbiosis= "Life together"
- Mutualism
  - Both partners gain from symbiosis
- Nutritional mutualism in corals
  - Internal "zooxanthellae" 1-celled algae
  - Coral use carbohydrates produced by photosynthesis
  - Algae use coral waste as nutrients
  - Majority of coral's nutrition
  - Consume CO_2, aid CO_3 deposition

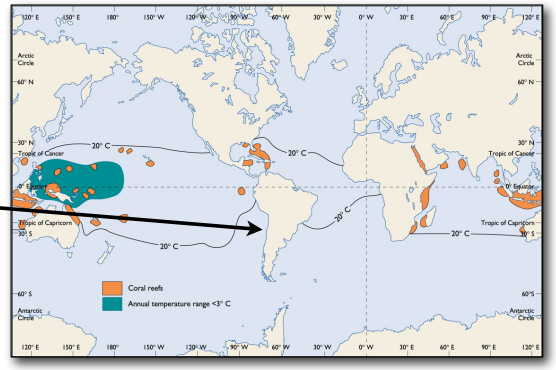




www.gbrmpa.gov.au/corp_site/info_services/science/bleaching/

Environmental Needs of Coral

- Reef-builders require at least 20˚ C minimum temperature
  - Prefer 23–29˚ C & <3˚ C annual variation
- Restricted to tropical latitudes
  - 30˚ N - 30˚ S
  - Upwelling (E. boundary current) limits

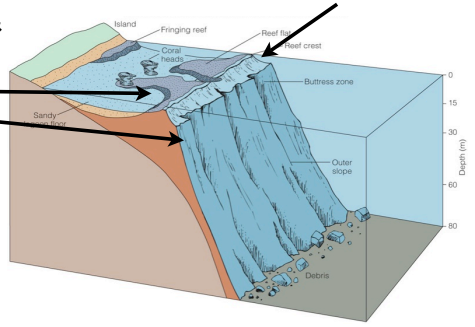


Environmental Needs of Coral

- Reef-building corals depend on clear water
  - Water is low in nutrients & phytoplankton
  - Light available for photosynthesis by zooxanthellae
    - Consume CO_2, make it easier to deposit carbonate
- Tropical surface waters warm & highly stratified
  - Organic matter sinks out of the surface
  - Nutrients trapped in deep water
  - Production very dependent on recycling of animal wastes
  - And on symbioses

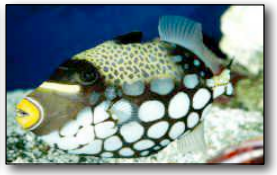
Environmental Needs of Coral

- Reefs grow best in areas of high wave energy
  - Other species not as resistant to force of waves
    - Reefs broken down by waves almost as fast as they grow
    - Solid, rounded corals grow in shallows of outer reef crest
    - More delicate fan & tube corals grow in lagoon and at greater depths
  - Advantage in competition for plankton prey
  - Protect shore from large waves



Interactions with Other Species

- Depend on some other species to prevent algae overgrowth — “housecleaners”
  - Sea urchin *Diadema* in Caribbean
  - Fish with scraping teeth eat both coral & overgrowing algae
    - Parrotfish, triggerfish, surgeonfish



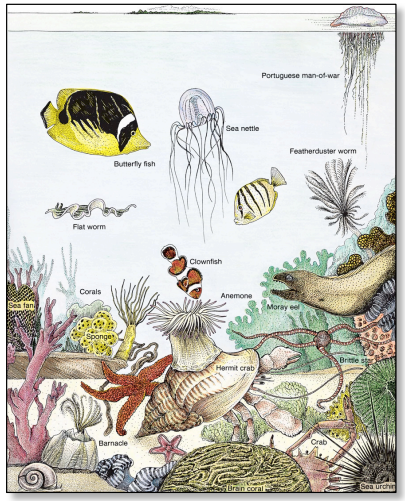
 greatescapetravel.com/album/parrotfish.jpg

Benefits of Coral Reefs

- Fish species supported directly or (usually) indirectly by the reef
  - Reef physically shelters juvenile & adult fish
  - Coral is base of food chain for harvestable species
- Absorb wave energy for islands
  - Reduce storm damage & coastal erosion
- Source of building materials
  - Coral rock for construction on small sandy islands
- Source of medications
- Tourism

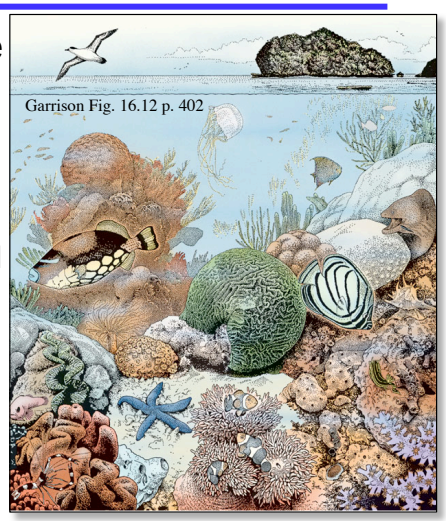
Coral Reef Biodiversity

- 2% of ocean area, 25% of marine species
  - Scarce resources foster diversification
    - Mutations that result in using resources in original ways are rewarded with survival
- Diversity promotes ecological stability
  - Stress less likely to affect whole community



Benefits of Coral Reefs

- Most diverse marine ecosystem
  - Except possibly deep-sea floor?
  - Varied habitat
  - Compared to tropical rain forests
    - Rain forests also nutrient-poor
  - Both threatened by human exploitation

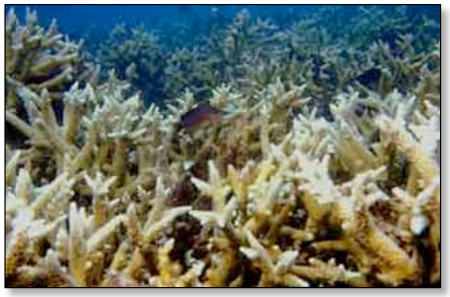


Threats to Corals (Overview)

- Predators
  - Crown-of-thorns starfish
- Fishing
  - Dynamite & cyanide fishing
  - Overfish species that prevent overgrowth of algae
- Sedimentation
  - From logging & land development on shore
- Eutrophication
  - Excess fertilization
  - Nutrients from land agriculture & sewage

Threats to Corals (Overview)

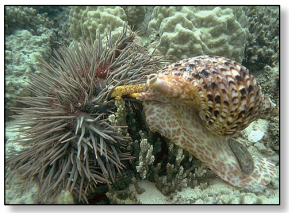
- Shipping & diving
  - Physical damage from collisions & anchors
  - Walking on reef
- Harvesting
  - Use of coral rock & sand as a building material
- Climate change
  - "Bleaching" = loss of symbiotic algae
  - Acidification



Staghorn coral

Crown-of-Thorns Starfish

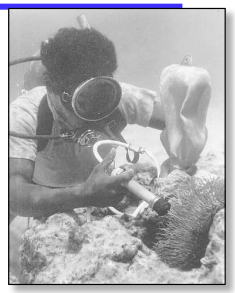
- Voracious predator on coral
  - Preyed on by Pacific triton snail
  - Large size
    - 7–21 arms up to 18" long
  - Long, sharp, toxic spines
  - High fecundity (12–60 million eggs per female)
- 1st documented population explosion 1950
  - Began south of Japan
  - Spread to GBR by 1963
  - Serious throughout W. Pacific by 1970's
  - Blamed on overharvesting of triton by collectors

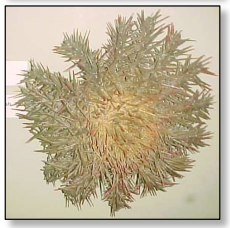


qldscienceteachers.tripod.com/photos/animals/echinoderms/crown_of_thorns_starfish.jpg

Crown-of-Thorns Starfish

- Attempts at population control
  - Injection with poison
  - Physical destruction
    - Can regenerate from a small piece of arm
    - Regrown arms make problem worse
- May be stimulated by rainfall
  - Nutrients run off land
  - Feed phytoplankton
  - Increase survival of starfish larvae
  - Adult population boom 3 years later





Crown-of-Thorns Starfish

- Evidence of long-term population cycles emerged 1970's
  - Decline in population since 1970's
  - Possible unidentified pathogen
- But no evidence of crown-of-thorns in fossil deposits
  - No reports by aborigines or early European explorers
- Still may be a modern human-caused phenomenon
  - Overfishing of prawns that prey on larval starfish?

Harmful Fishing Methods

- Dynamite used to stun or kill fish for easy capture
  - Kills coral polyps
  - Mortality of other fish species
  - Damage to reef structure

- Cyanide used to stun fish for live capture
  - For aquariums & restaurants
  - Very inefficient & wasteful
  - Kills 50% of fish, 40% more die in transport
  - Cyanide kills coral polyps

Harmful Fishing Methods

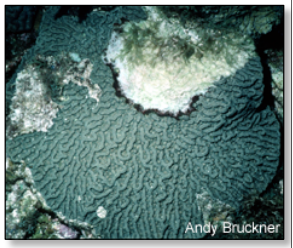
- Uncontrolled & unregulated harvest
  - Almost all Philippine & Indonesian reefs overfished
  - Divers pry apart reef to capture fish taking refuge
    - Aquarium species
  - Overfishing of herbivore fish
    - Allows overgrowth of algae
    - Out-compete corals for space
  - Overfishing of predatory fish
    - E.g., sharks barracuda
    - Allows overpopulation of herbivorous prey species
    - Disease strikes & wipes out herbivores, algae overgrow
  - Balance among species is critical

Land Runoff

- Sewage
  - Nutrients stimulate phytoplankton & attached algae
    - Overgrowth suffocates coral
  - Cloudy water inhibits zooxanthellae
- Sediment
  - From logging, land clearing, construction
  - Cloudy water inhibits zooxanthellae
  - Sediment clogs feeding apparatus

Diseases

- Black-band disease (BBD)
  - 1st reported Belize & Bermuda 1970's
  - Now reported throughout Caribbean & Indo-Pacific
  - Cyanobacteria invade & kills zooxanthellae
  - Grow on organic compounds released after corals die
- Algae over grow once coral die
  - Kill 5% of Jamaica coral 1997
  - Spreading in direction of current
  - Humans appear to be source



www.nmfs.noaa.gov/habitat/ecosystem/disease.htm

Diseases

- White-band disease (WBD)
  - Emerged in Caribbean 1980's
  - Affected elkhorn & staghorn
  - A bacterial infection
  - "White plague" or "pox"
- Like BBD but spreads faster
  - Strikes corals weakened by other stresses
  - Humans apparently a source for many coral pathogens

Healthy Elkhorn

Diseased Elkhorn

www.flmnh.ufl.edu/fish/southflorida/coral/profiles.html

coastal.er.usgs.gov/navassa/scuba/nw2.html

Bleaching

- Stress causes zooxanthellae to be expelled
  - Surface temperature above optimal range of 25–29˚C the major cause
  - El Niño causes outbreaks
  - Also cold, sediment, toxins, salinity
- Exact reason & mechanism under study
  - What is advantage of losing algae?
  - Possible viral or bacterial infection?

www.gbrmpa.gov.au/corp_site/info_services/science/bleaching/

Bleaching

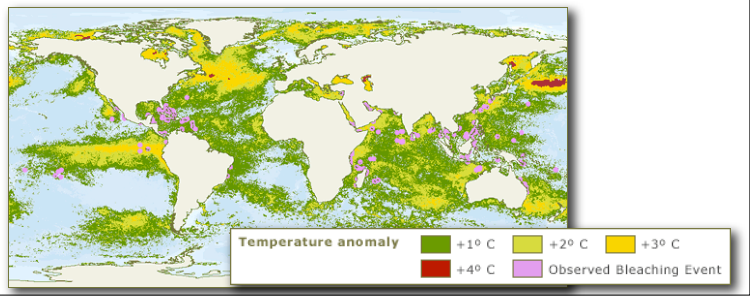
- Deprives coral of major nutrition source
  - Can survive & recover from bleaching episodes
  - But sustained or repeated bleaching kills reef
- First noticed 1980's
  - Severe 1982-83 El Niño raised temperatures
  - E. Pacific, W. Atlantic & Caribbean
- Bleaching warnings almost every year now
  - Great Barrier reef could be 95% dead by 2050?

http://news.mongabay.com/2005/1117-corals.html

Bleaching

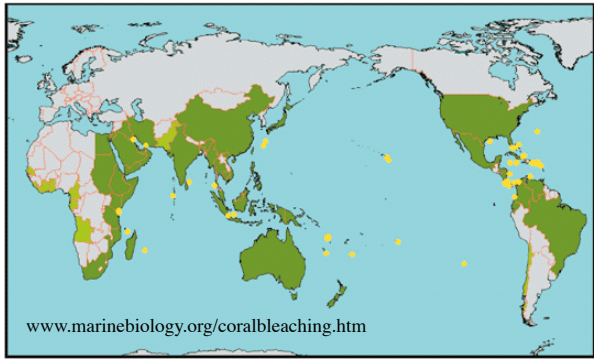
- 1997-98 Niño caused further bleaching
  - Estimated 16% loss worldwide from that event
  - Expected to spread under global warming
  - Growth of reefs may be slower than sea level rise

http://earthtrends.wri.org/text/coastal-marine/map-207.html



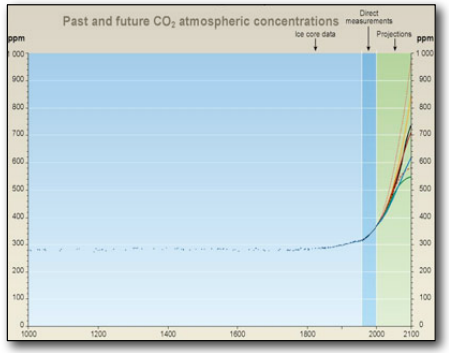
Bleaching

- Sites of major coral reef bleaching events during the past 15 years.
  - Yellow spots indicate major bleaching events
  - In every tropical area of every ocean



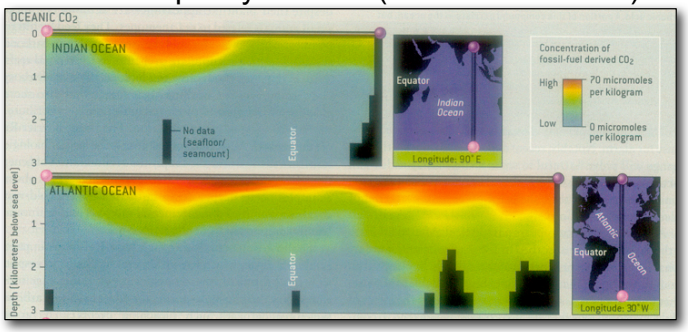
Acidification (Kolbert)

- Atmospheric CO_2 rising from human sources
  - Fossil fuel combustion & deforestation
  - Pre-industrial about 250 parts/million (ppm)
  - Today 380 ppm (~50% increase in ~150 years)
  - Predicted to reach 500 ppm by mid-century
    - Predict 3.5 - 7˚ F temperature increase by 2100



Acidification (Kolbert, Doney)

- About 50% of atmospheric CO_2 dissolves in ocean surface water
  - ~ 2 billion tons/year
  - Has lowered pH by 0.1 unit (30% less alkaline)



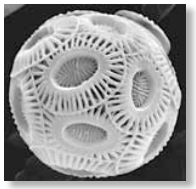
Effects of Acidification (Kolbert)

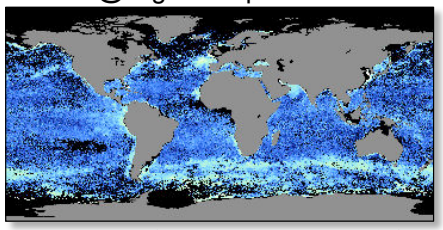
- Lower pH makes carbonate less available
  - Buffering response to increased carbonic acid
  - Carbonate shells & skeletons are more difficult to construct
    - Also dissolve more easily
- Surface pH predicted to drop 0.2 more units by 2100
  - More at high latitudes
  - Earliest impacts on planktonic organisms with $CaCO_3$ shells
    - Pteropods

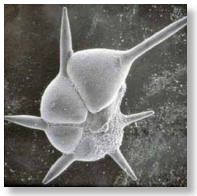
www.noaanews.noaa.gov/stories2006/s2606.htm

Effects of Acidification (Kolbert)

- Impacts on plankton with $CaCO_3$ shells
  - Coccolithophorids (phytoplankton)
  - Foraminifera zooplankton
  - $CaCO_3$ shells, now widespread at ocean surface, likely to decline
    - Rare @ high CO_2 period 55 million years ago







http://disc.gsfc.nasa.gov/oceancolor/scifocus/oceanColor/calcite.shtml

Acidification & Corals (Kolbert)

- Coral growth rate limited by availability of CO_3
  - Adding carbonate makes corals grow faster
  - Lower pH makes carbonate less available
    - Corals grow slower
- "Saturation level" of carbonate is decreasing
  - Ideally 4-5, now few places above 4
  - None above 3.5 by 2060, none above 3 by 2100
- In nature, reefs may shrink
  - Can't lay down $CaCO_3$ fast enough to offset consumption by fish & wave erosion
  - May occur by 2075?

Damage Estimates (Ellis)

- #1 35 million acres of reefs destroyed
  - 70% of reefs will be dead in "our lifetimes" if current trends continue
  - 75% of reefs thought to be deteriorating because of environmental stress
  - Only 5–10% of Indonesian & Philippine reefs in pristine condition
- #2 2000 assertion that 27% of reefs already destroyed
  - 14% more to die by 2010, 18% more by 2030

Damage Estimates (Ellis)

- #3 10% of reefs already dead (2003)
  - Another 20-30% to die by 2005?
  - 37% coral death off Florida since 1996
  - Higher for some species such as Elkhorn coral
  - Some reefs off Key West suffer 98% mortality
  - Blamed on "white pox" caused by sewage bacteria

Overall Risk to Coral Reefs

- Risk is greatest near human population centers
  - Source: Reefs at Risk: A map-based indicator of potential threats to the world's coral reefs. Dirk Bryant, Lauretta Burke, John McManus, and Mark Spalding. 1998. reefsatrisk.wri.org