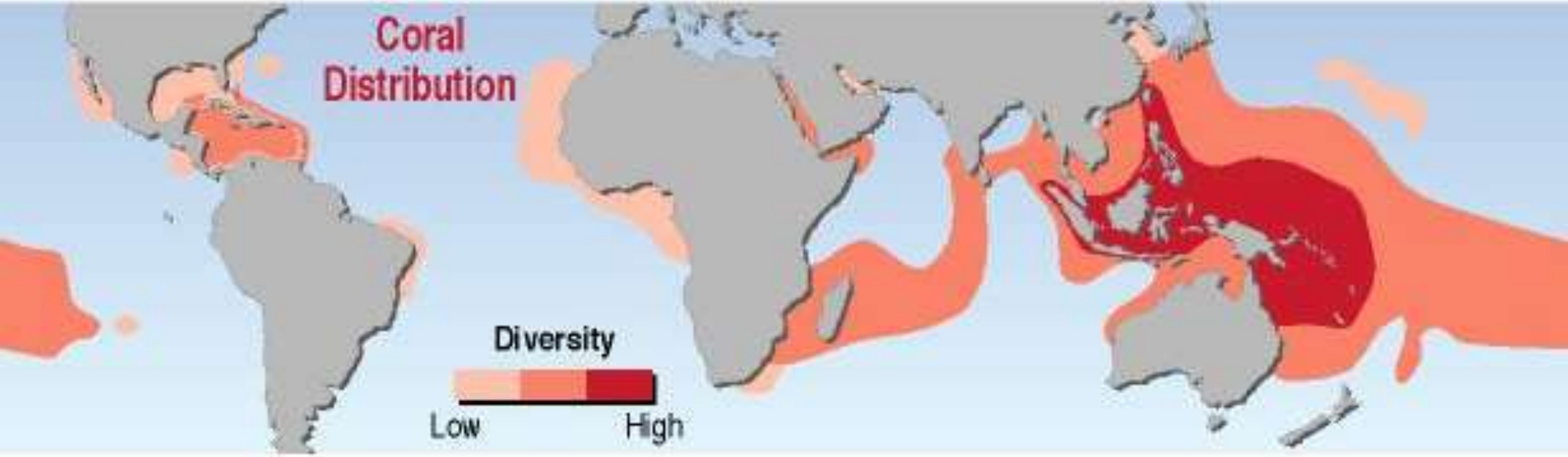
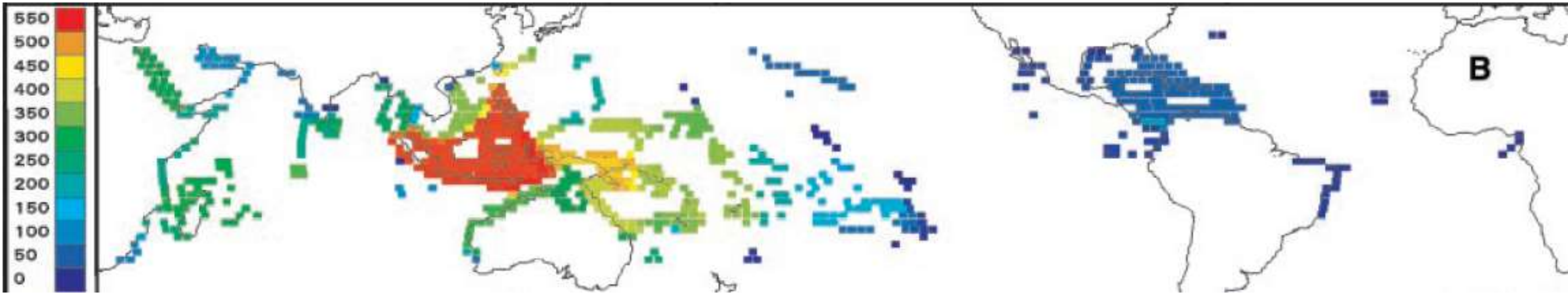



Coral reefs


Global patterns of coral species diversity





No. of coral species

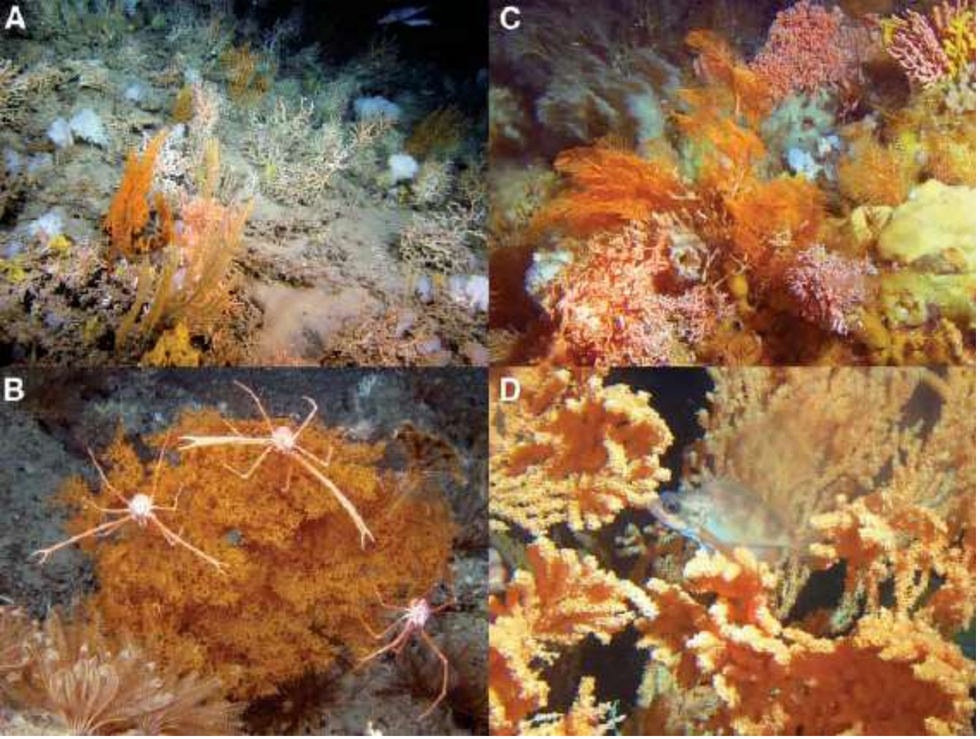
Roberts et al. 2002

Conditions required by coral reefs:

- high water temperature (>14 ^{o}C)
- substrate available in euphotic zone
- low nutrient concentration
- HCO_3 available
- low turbidity and sedimentation

Corals in cold waters

sorry, no reef ecosystems



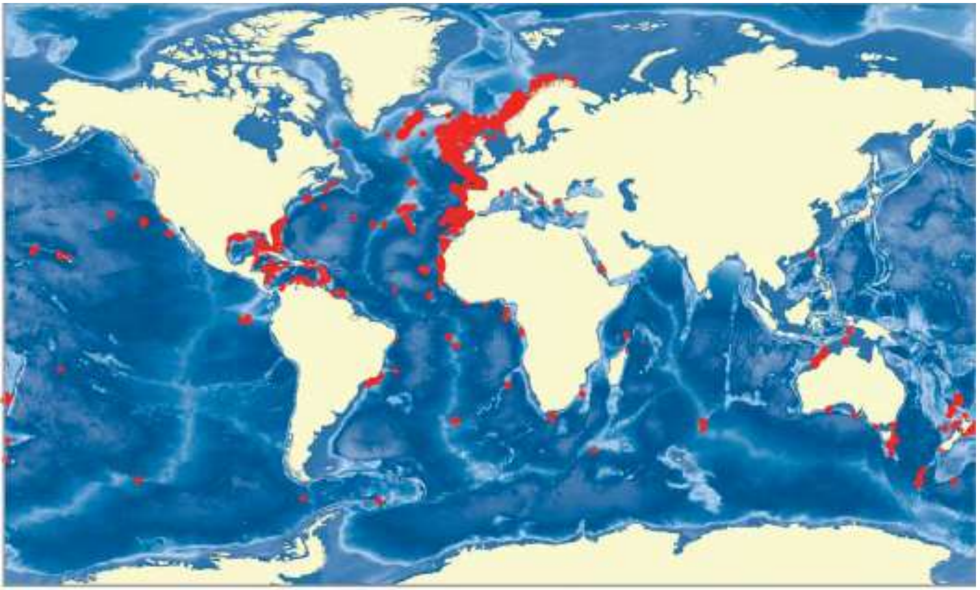


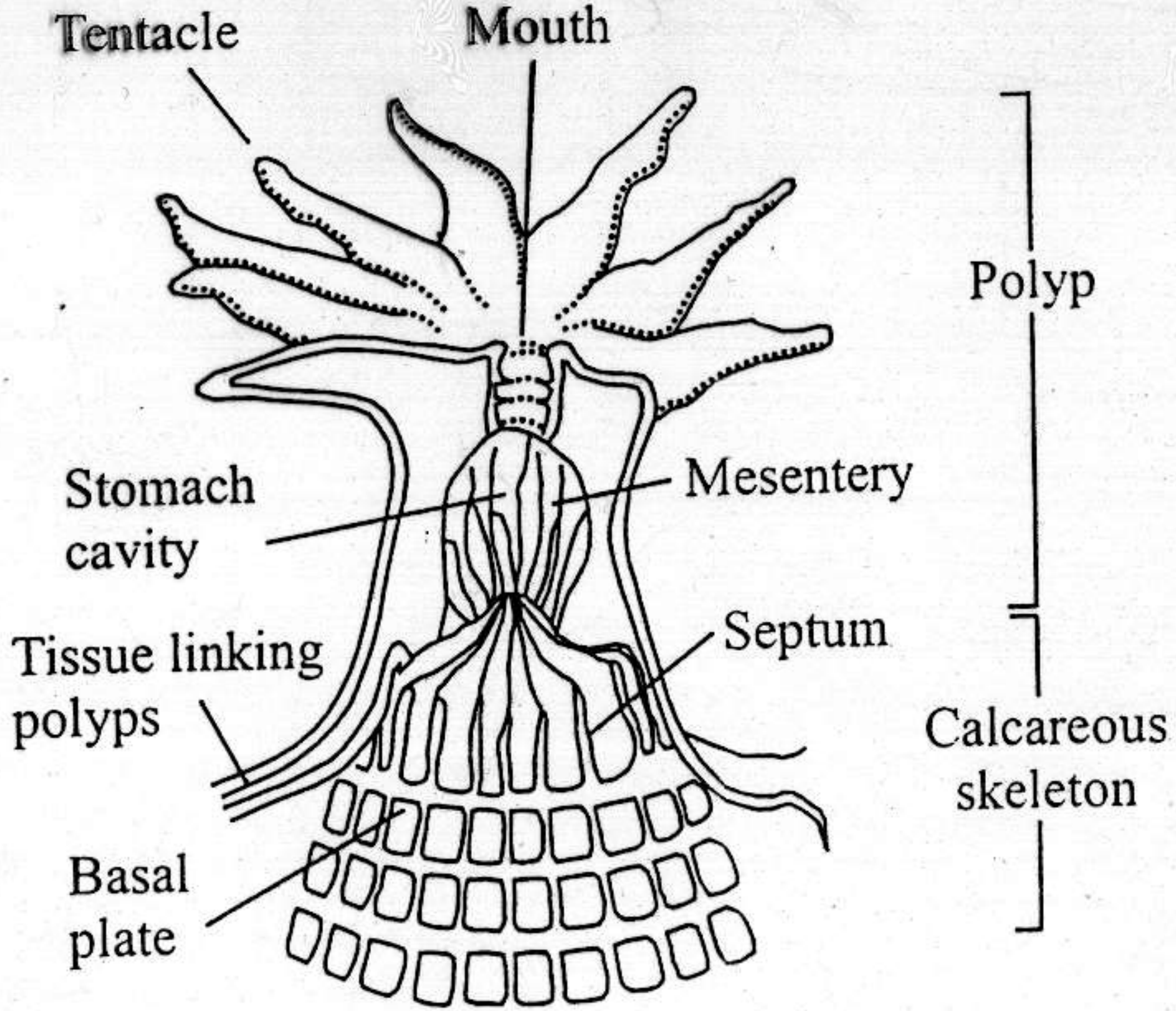
Fig. 2. Current global distribution of reef framework–forming cold-water corals [modified from (1)].

Fig. 1. Cold-water coral reef fauna. (A) Sloping flank of the Galway carbonate mound colonized by scleractinian and gorgonian corals and glass sponges. (B) Currently undescribed antipatharian coral (Leiopathes sp., pers. comm. D. Opresko) and associated anomuran crustaceans from the Twin Mounds, Porcupine Bank (NE Atlantic). [Images courtesy Alfred-Wegener-Institut für Polar und Meeresforschung and Institut Français de Recherche pour l'Exploitation de la Mer] (C) Diverse coral and sponge fauna recently discovered off the Aleutian Islands. [Image courtesy of A. Lindner, National Oceanic and Atmospheric Administration (NOAA) Fisheries] (D) Sharpchin rockfish (Sebastes sp.) among gorgonian corals (Primnoa sp.) in the Gulf of Alaska (N Pacific). [Image

Reefs of the Deep: The Biology and Geology of Cold-Water Coral Ecosystems

J. Murray Roberts,[1] Andrew J. Wheeler,[2] André Freiwald[3]

Large rivers are not coral-friendly



CORALS - ANTHOZOA: CALCIFICATION ORIGINATED SEVERAL TIMES

- **TABULATA: Cambrian - Triassic 500 - 200 My**
- **RUGOSA: Ordovician - Permian 450 - 250 My**
- **SCLERACTINIA: Triassic - Recent 200 - 0 My**

Growth forms of corals

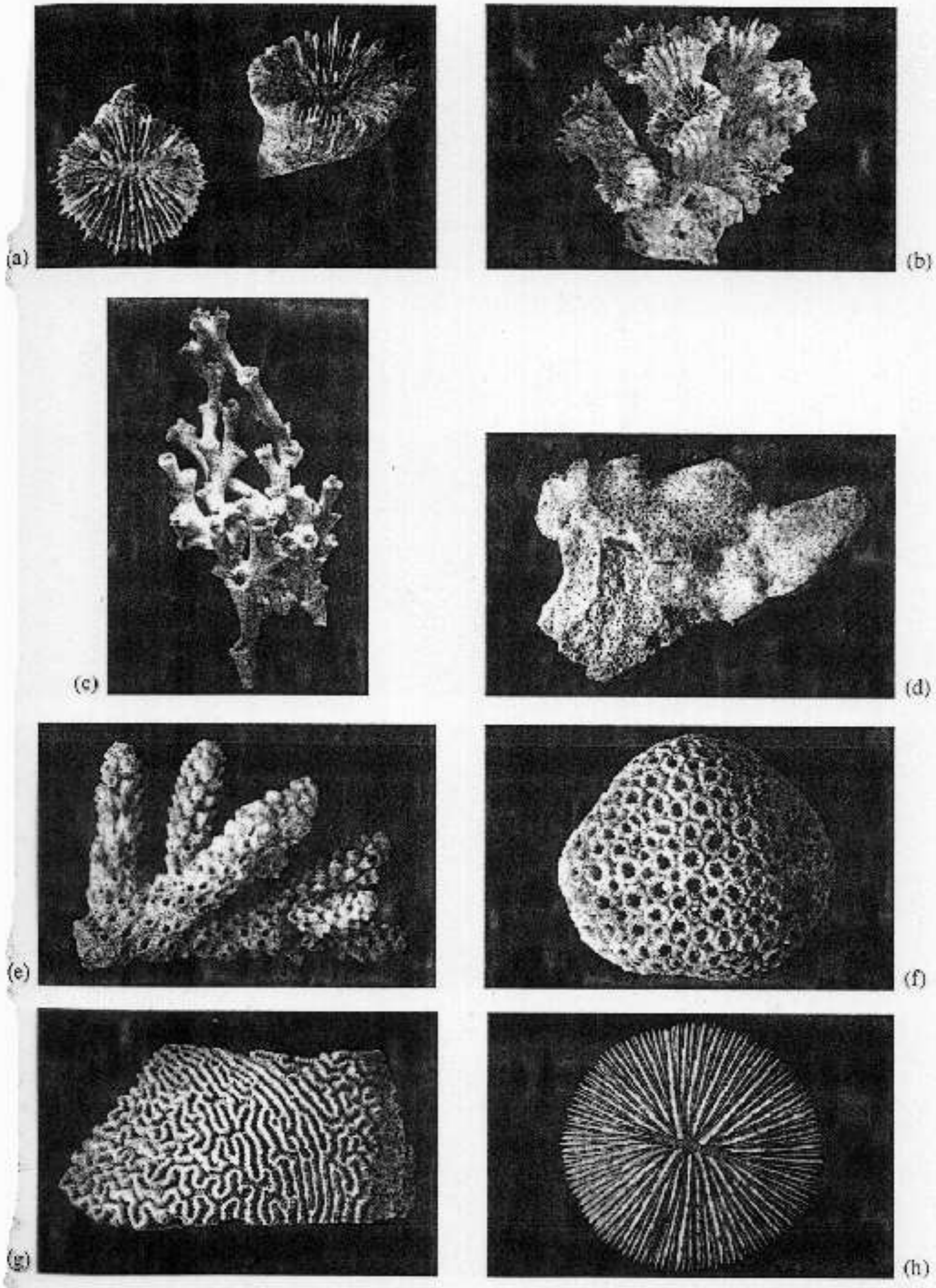


Fig. 6.23 Growth forms in corals: (a) solitary/aclonal; (b) pseudocolonial, phaceloid; (c) uniserial erect; (d) multiserial encrusting; (e) multiserial erect; (f) multiserial massive; (g) multiserial massive—meandroid; (h) solitary/clonal (the free-living *Fungia*).

Coral ecology

- The polyps form a skeleton made of calcium carbonate
- They are colonial
- Live symbiotically with photosynthetic dinoflagellates

BIODIDAC, ©P. Crawford, UPEI

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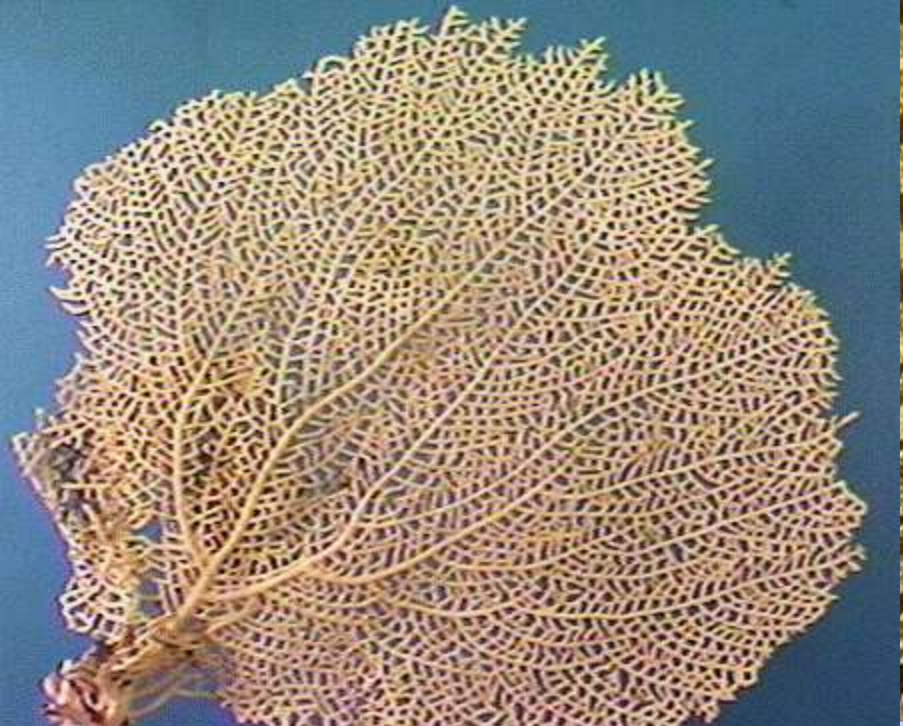

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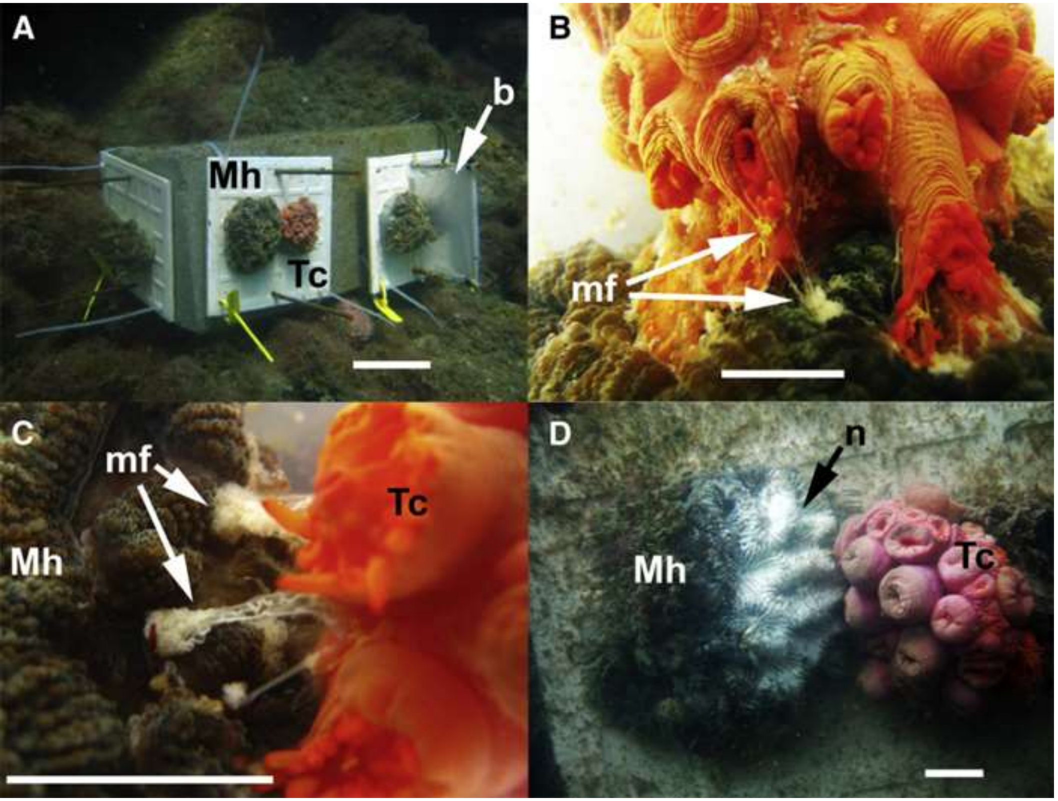
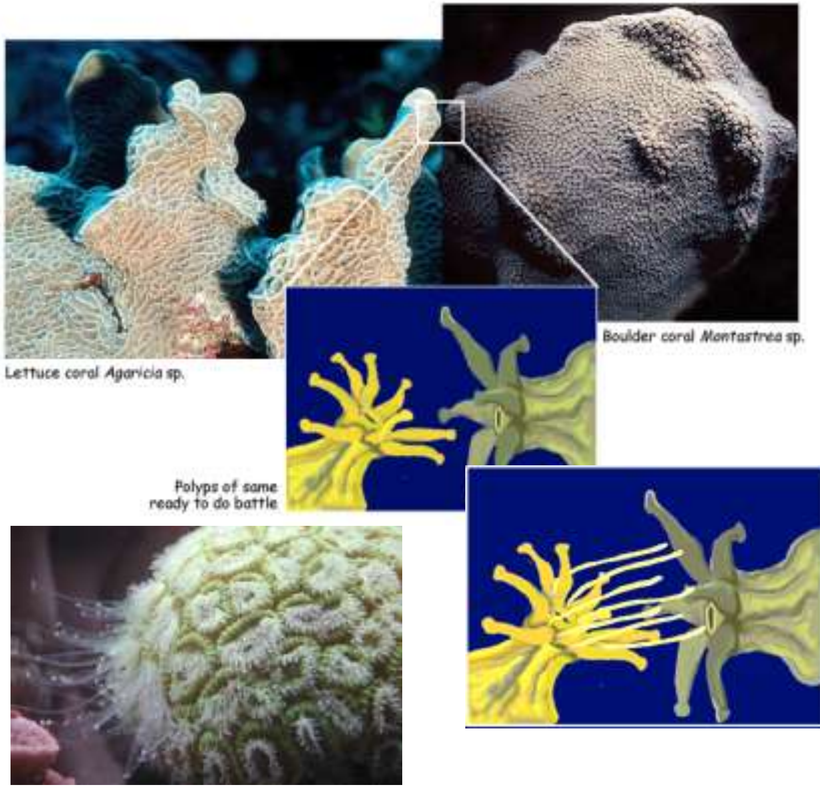
Coral reefs and rainforests:
intense competition for space and light

Coral competition and aggression:
mesenterial filaments, or longer-range sweeper tentacles (often developed in response to a competitor), and short-range allelopathic chemical attack

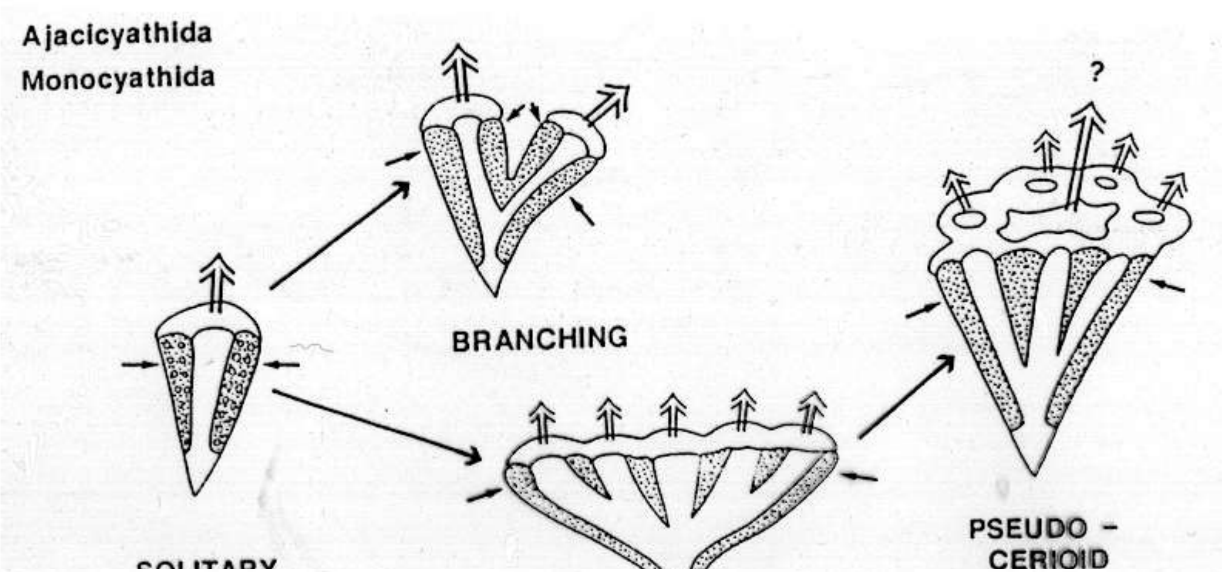


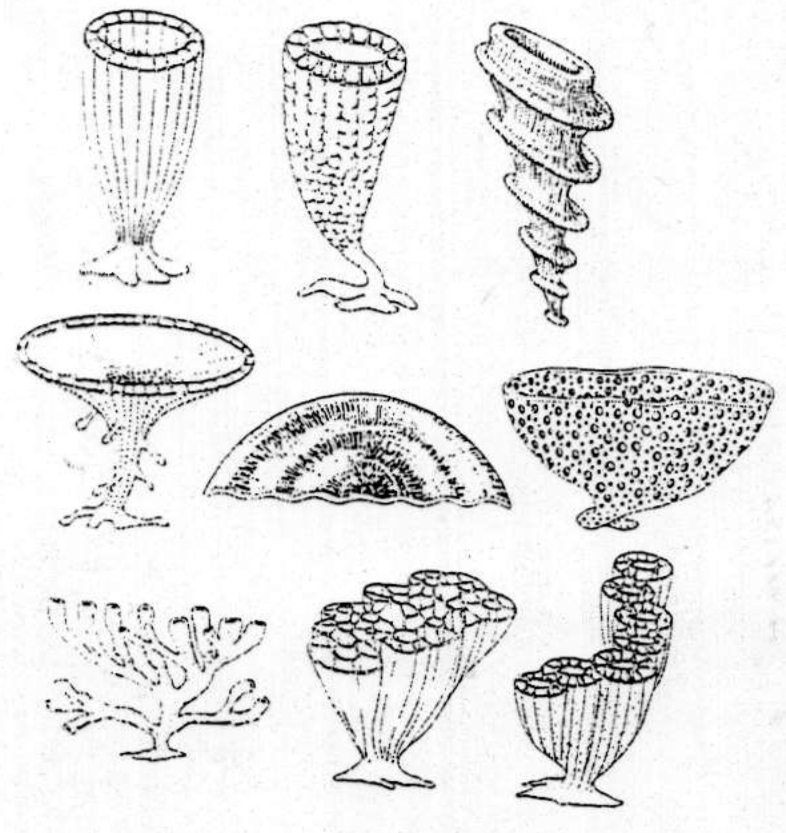
A. Experiment with native coral Mussismilia hispida and invasive Tubastraea coccinea. B mesenterial filaments produced by both native corals, C detail of mesenterial filaments, D necrosed area on native coral

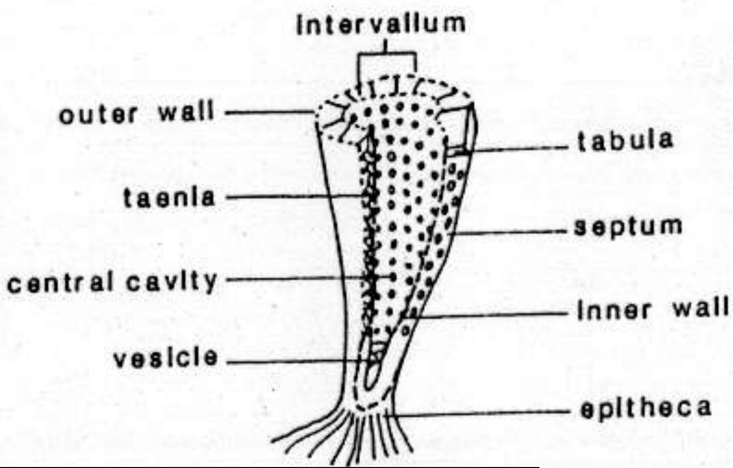


T. Carefoot, http://www.virtualcoralreefdive.com/ Dos Santos et al. J. Exp. Marine Biol. Ecol. 449 (2013) 69–76

Porifera:
also reef builders

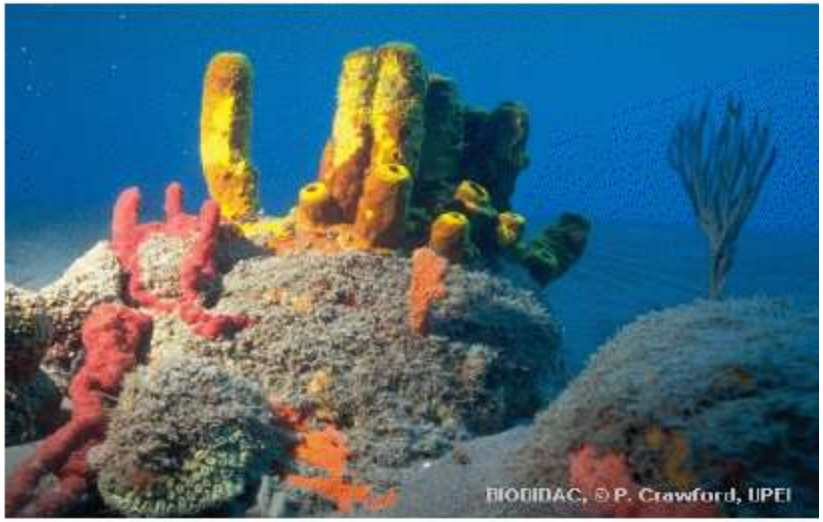


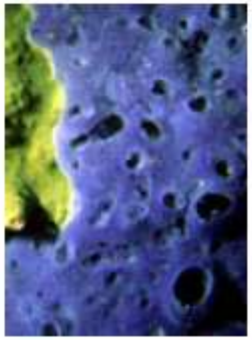




Porifera – variable morphology


© D. Giberson, UPEI


BIODIDAC, © P. Crawford, UPEI

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Porifera: the ability to form calcareous skeleton evolved several times

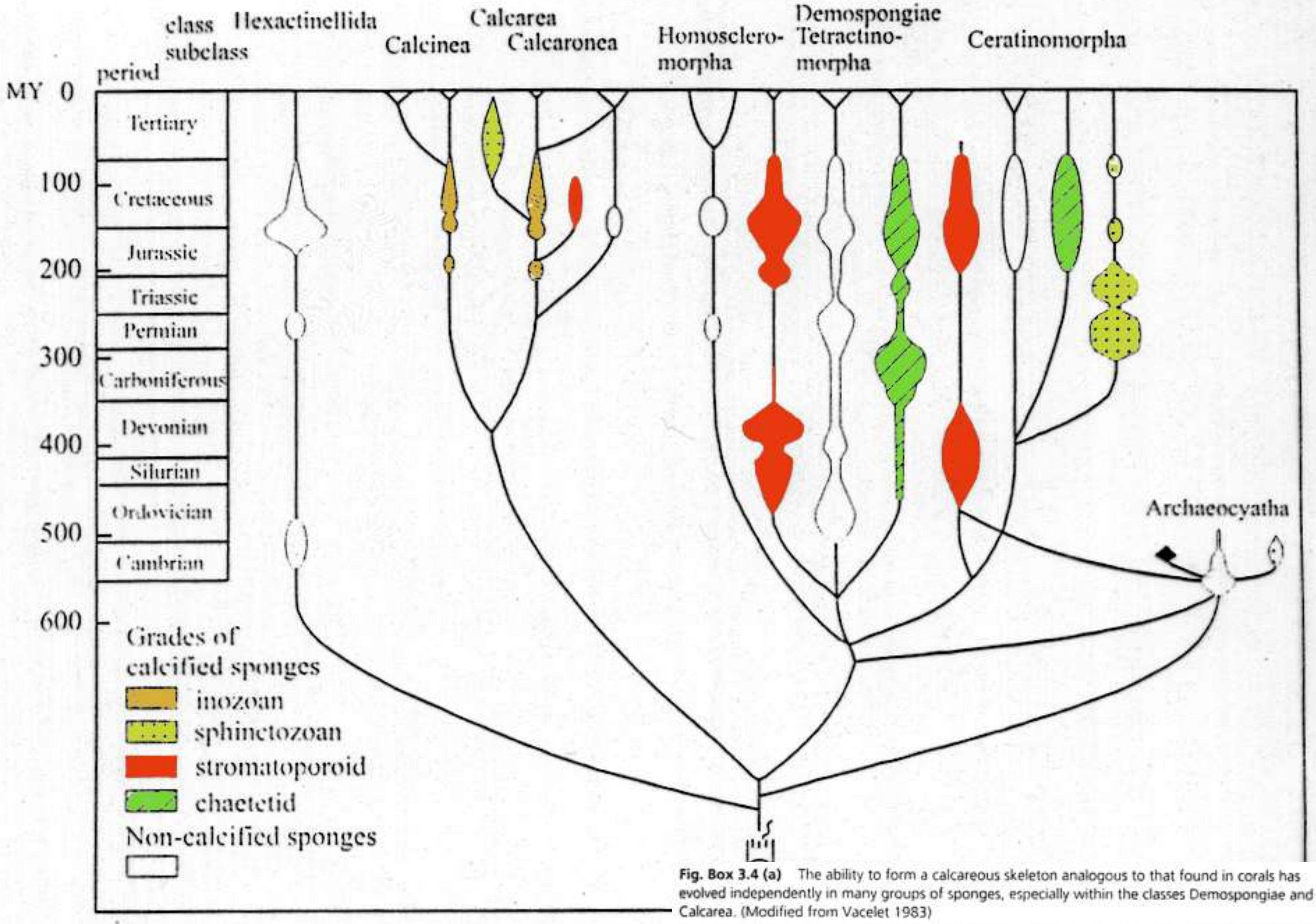
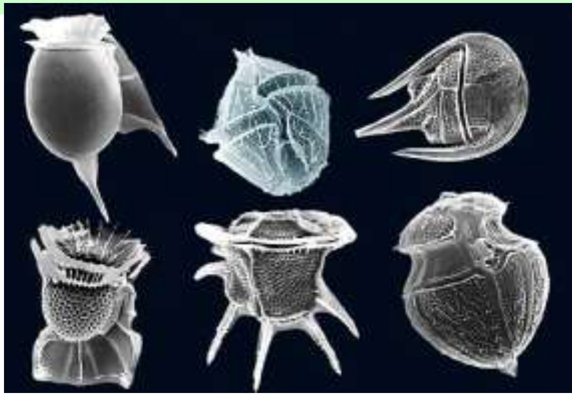


Fig. Box 3.4 (a) The ability to form a calcareous skeleton analogous to that found in corals has evolved independently in many groups of sponges, especially within the classes Demospongiae and Calcarea. (Modified from Vacelet 1983)

Association with photosynthetic algae is common in reef animals



Dinoflagelates are associated with:

Foraminifera

Radiolaria

Porifera

Anthozoa: corals

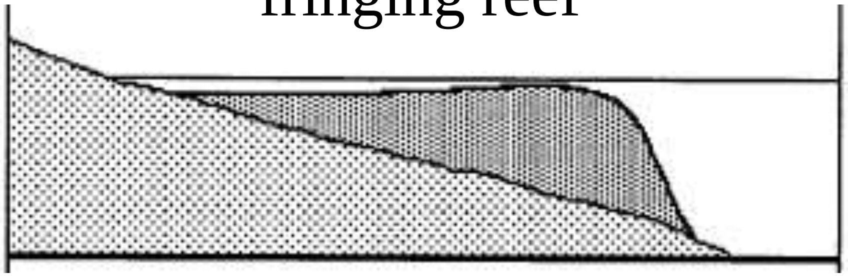
Anthozoa: anemones

Turbellaria

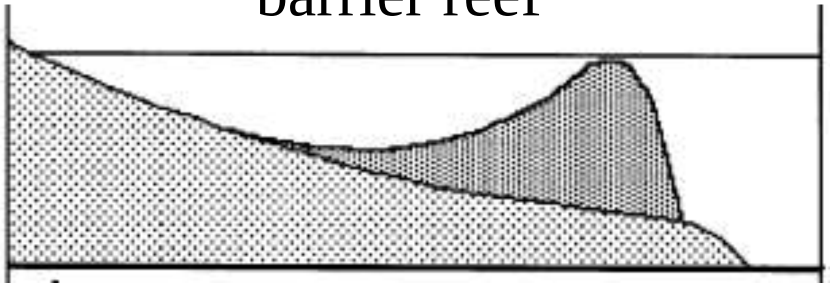
Mollusca

Main stages in reef development

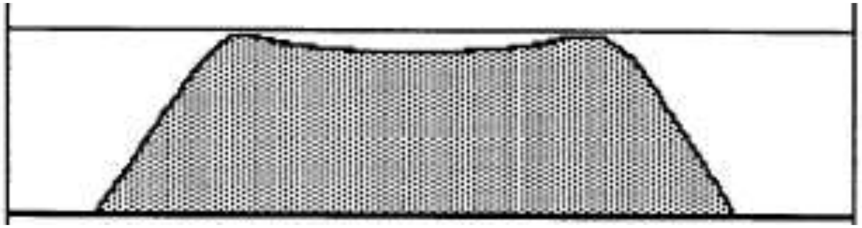
fringing reef

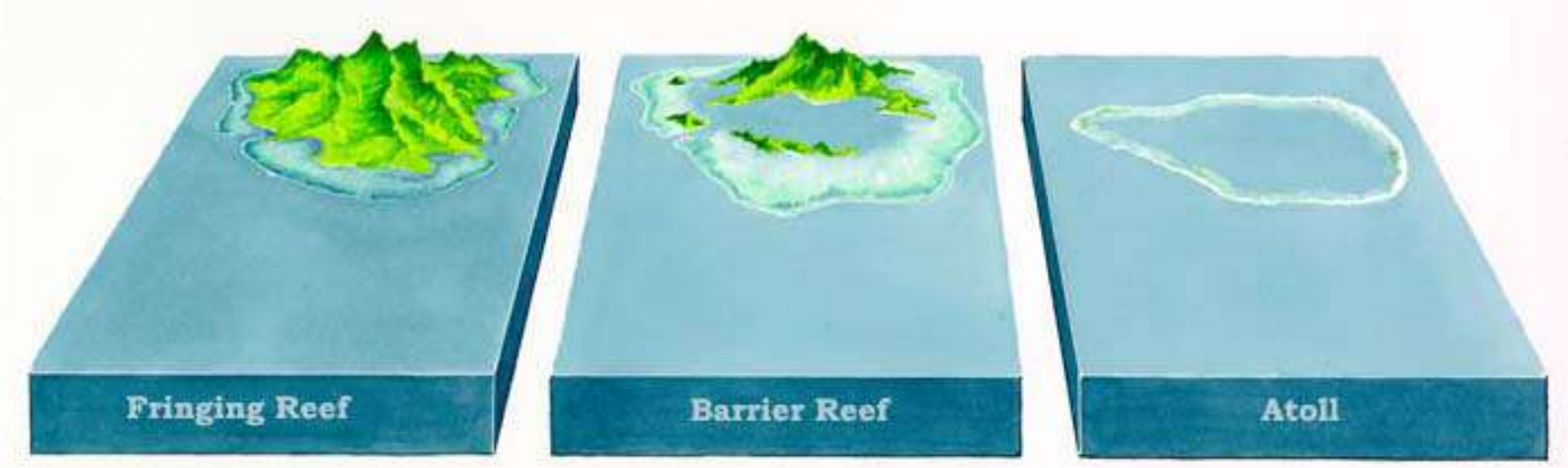


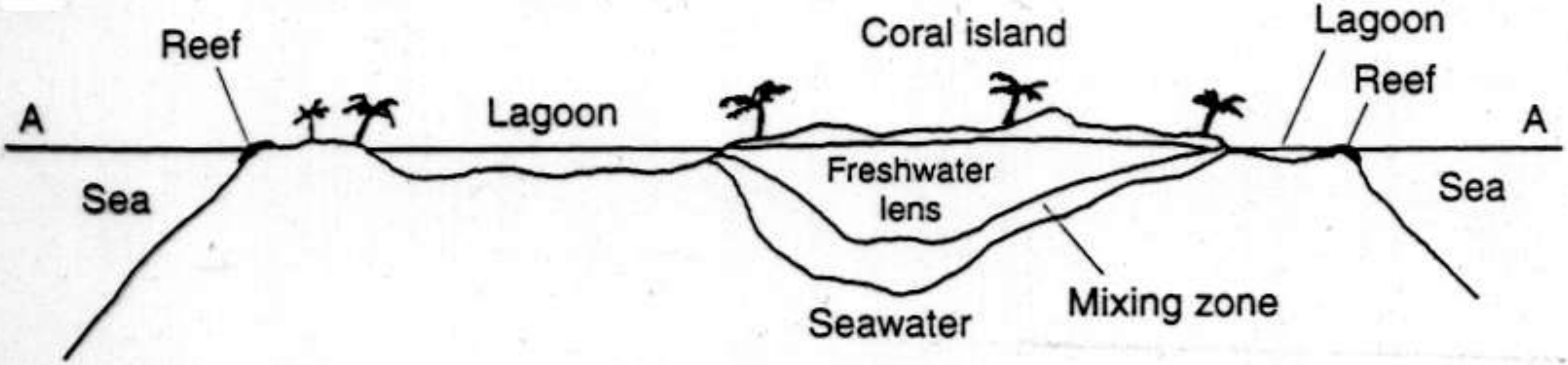
barrier reef

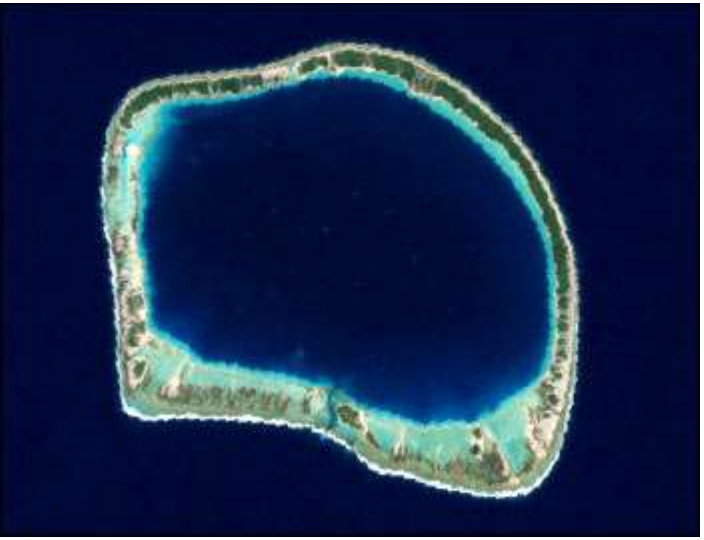


atoll







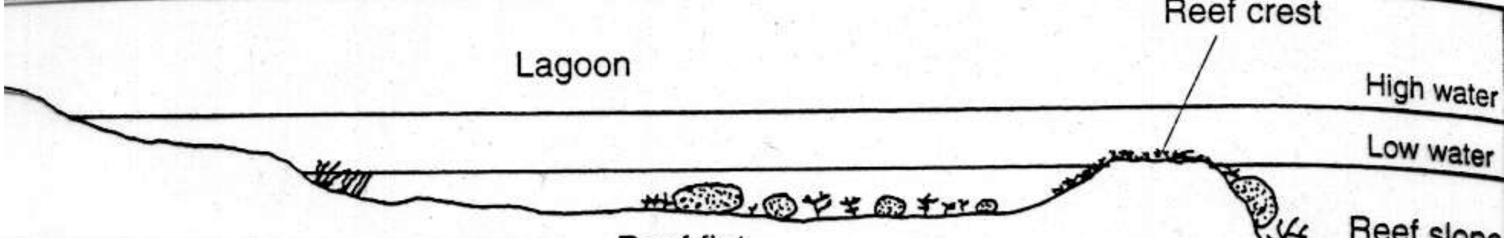


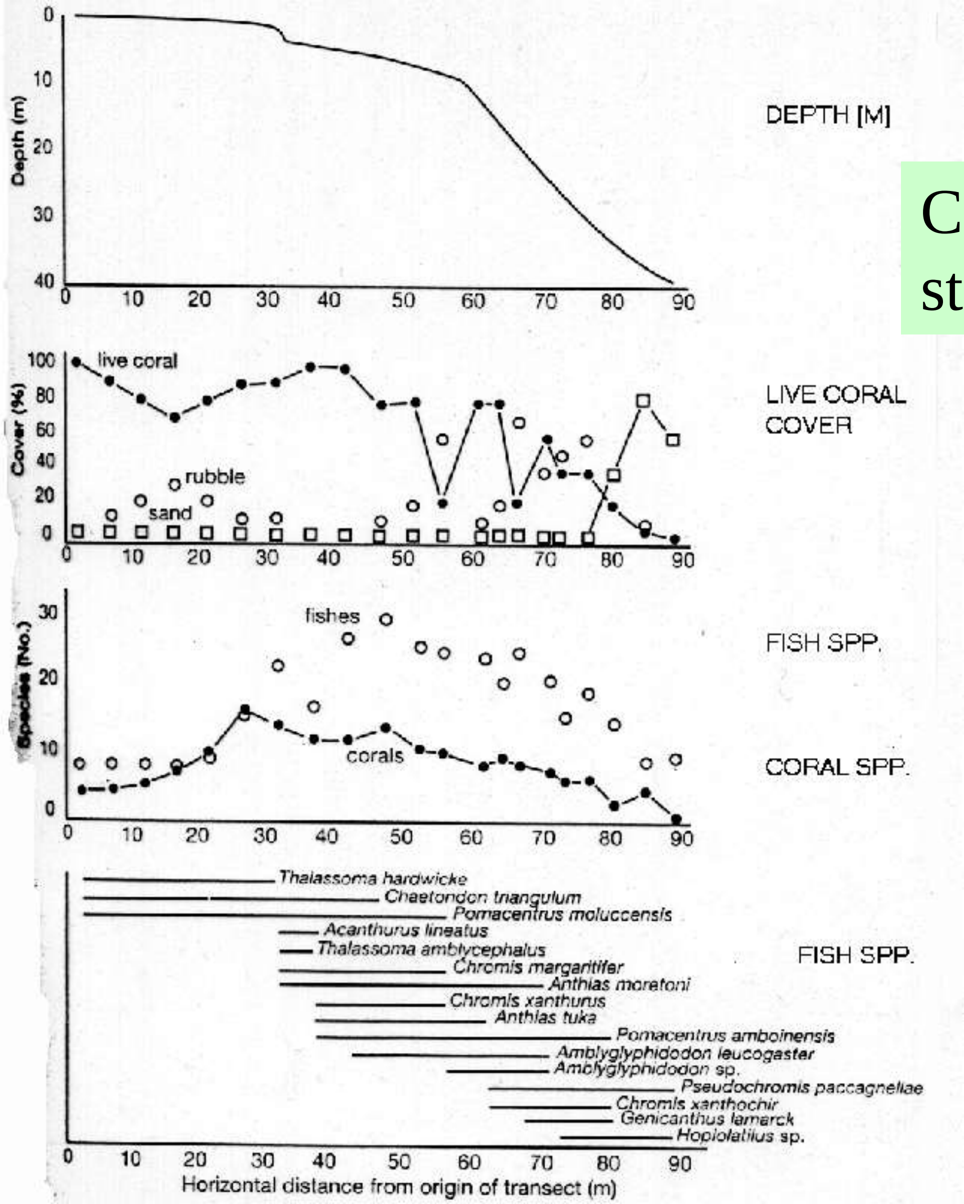
Moorea Island, Polynesia – fringing reef

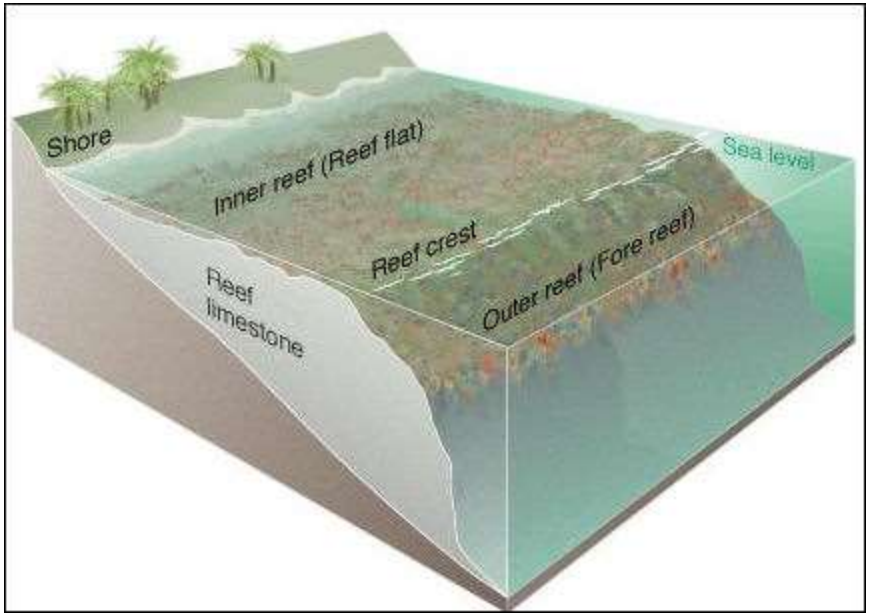
Madang lagoon (New Guinea): coral barrier next to mainland

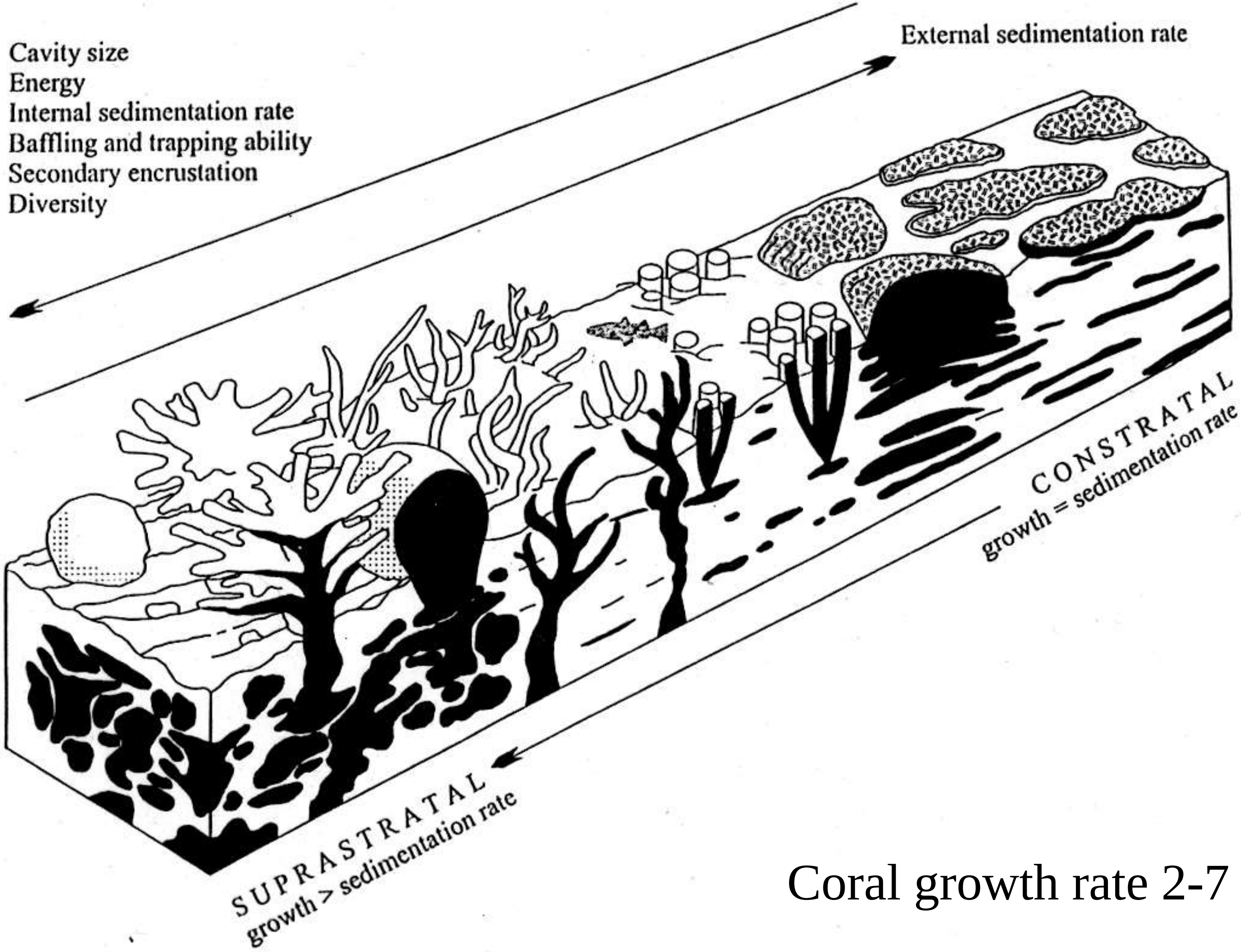
700 spp. of fishes, 800 spp. of nudibranchs, etc.

Coral reefs:
stratification with water depth





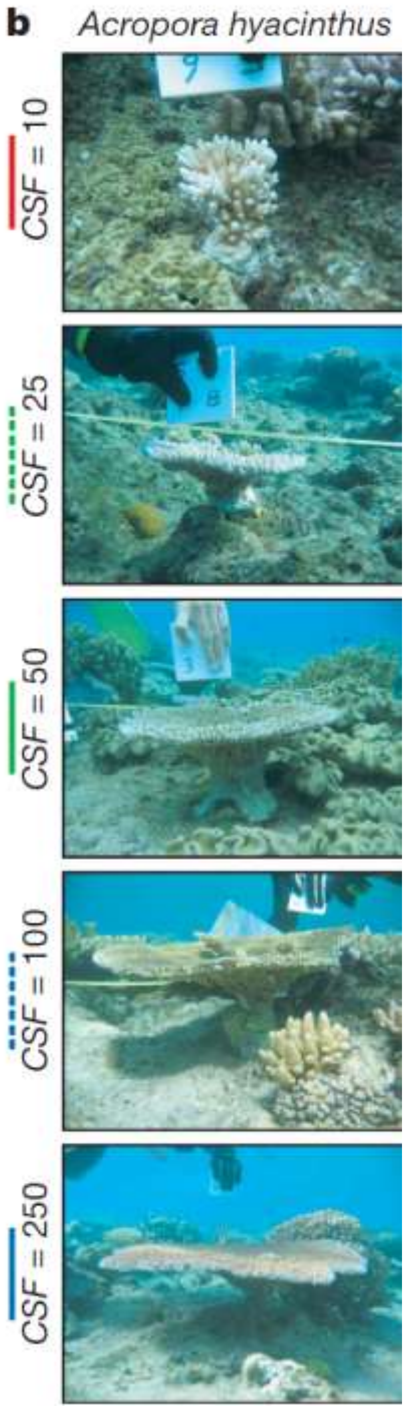


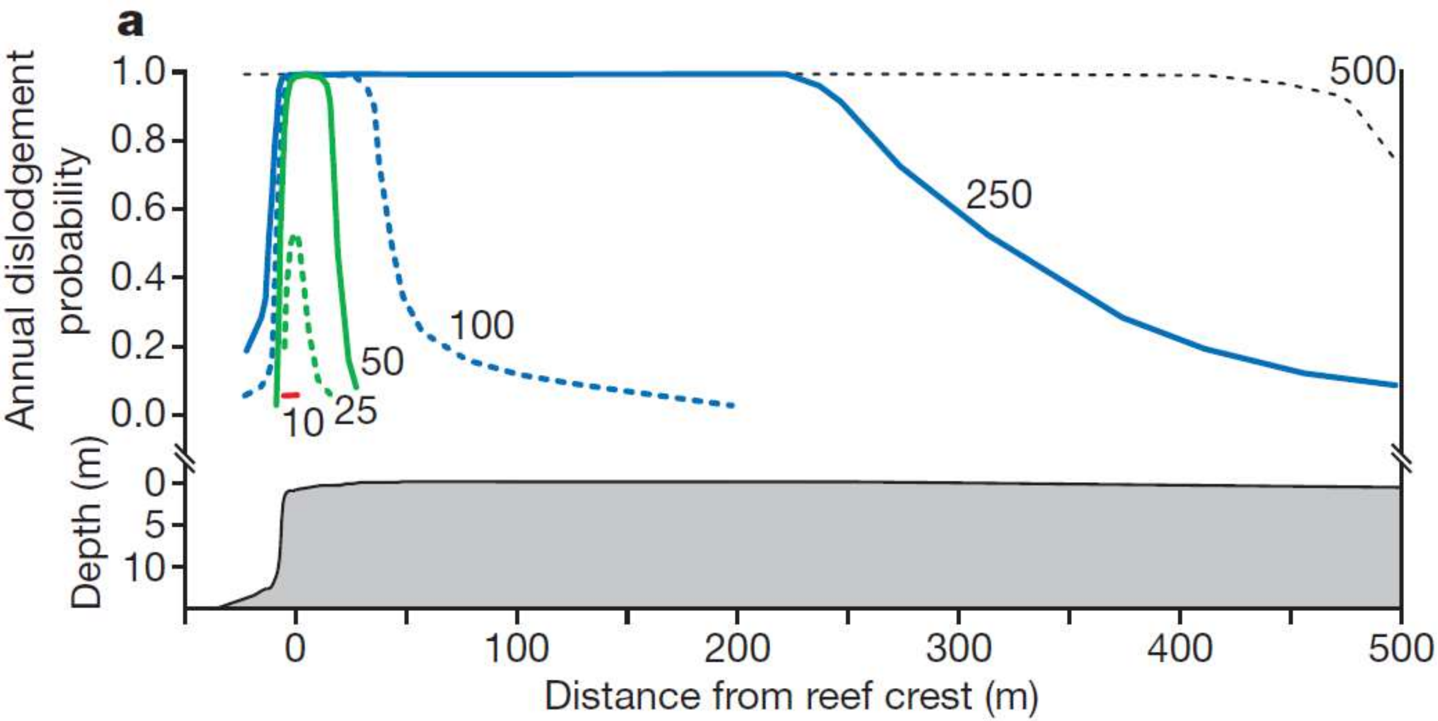


Coral growth rate 2-7 mm/yr

Fig. 6.7 Generalized environmental preferences and ecological consequences of constratal and suprastratal growth.

Mechanical resistance of coral morphologies

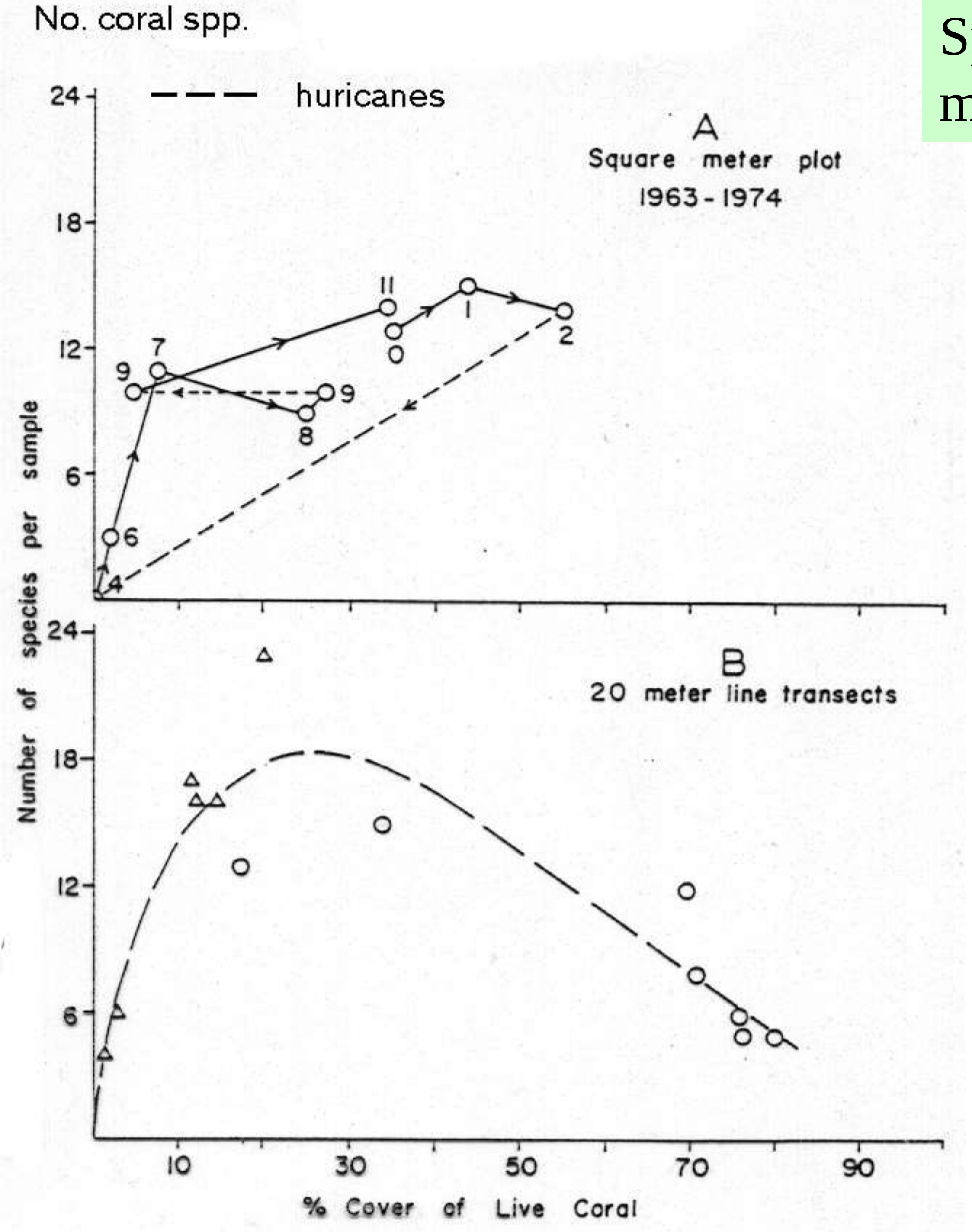




Annual probabilities of colony dislodgement as a function of distance from the reef crest for six coral morphologies (CSF is a shape factor)

Madin & Connolly 2006, Nature 444: 477

Species diversity of reefs: medium-disturbance hypothesis



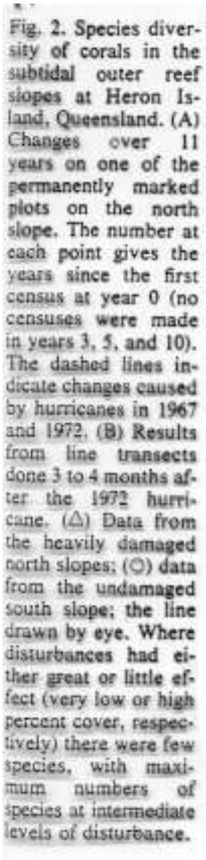
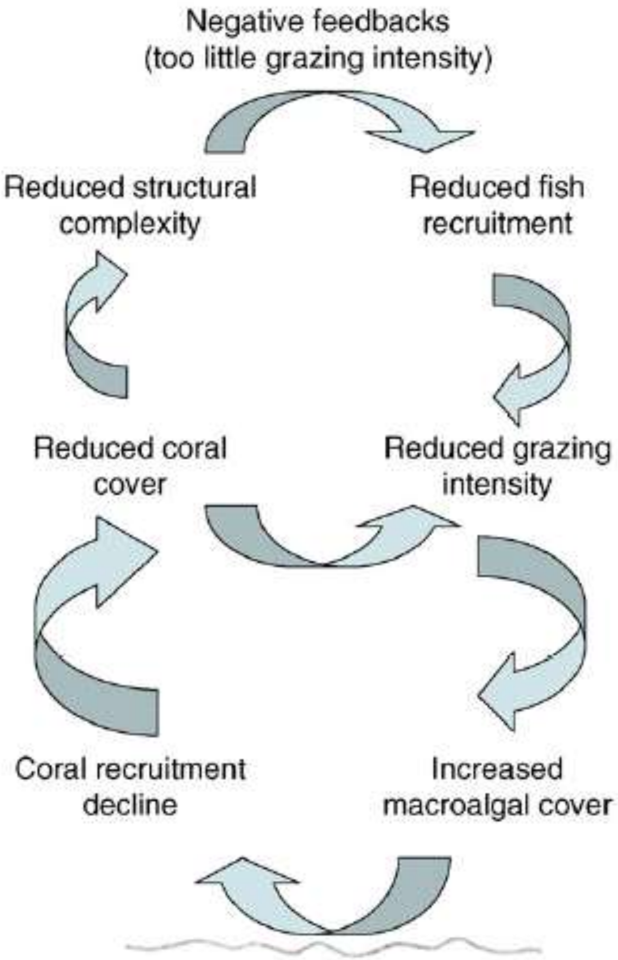


Fig. 2. Species diversity of corals in the subtidal outer reef slopes at Heron Island, Queensland. (A) Changes over 11 years on one of the permanently marked plots on the north slope. The number at each point gives the years since the first census at year 0 (no censuses were made in years 3, 5, and 10). The dashed lines indicate changes caused by hurricanes in 1967 and 1972. (B) Results from line transects done 3 to 4 months after the 1972 hurricane. (△) Data from the heavily damaged north slopes; (○) data from the undamaged south slope; the line drawn by eye. Where disturbances had either great or little effect (very low or high percent cover, respectively) there were few species, with maximum numbers of species at intermediate levels of disturbance.

Coral reefs require grazing of algal biomass



Negative feedbacks
(too little grazing intensity)

Reduced structural complexity

Reduced fish recruitment

Reduced coral cover

Reduced grazing intensity

Coral recruitment decline

Increased macroalgal cover

Mumby & Steneck 2008, TREE 23: 555

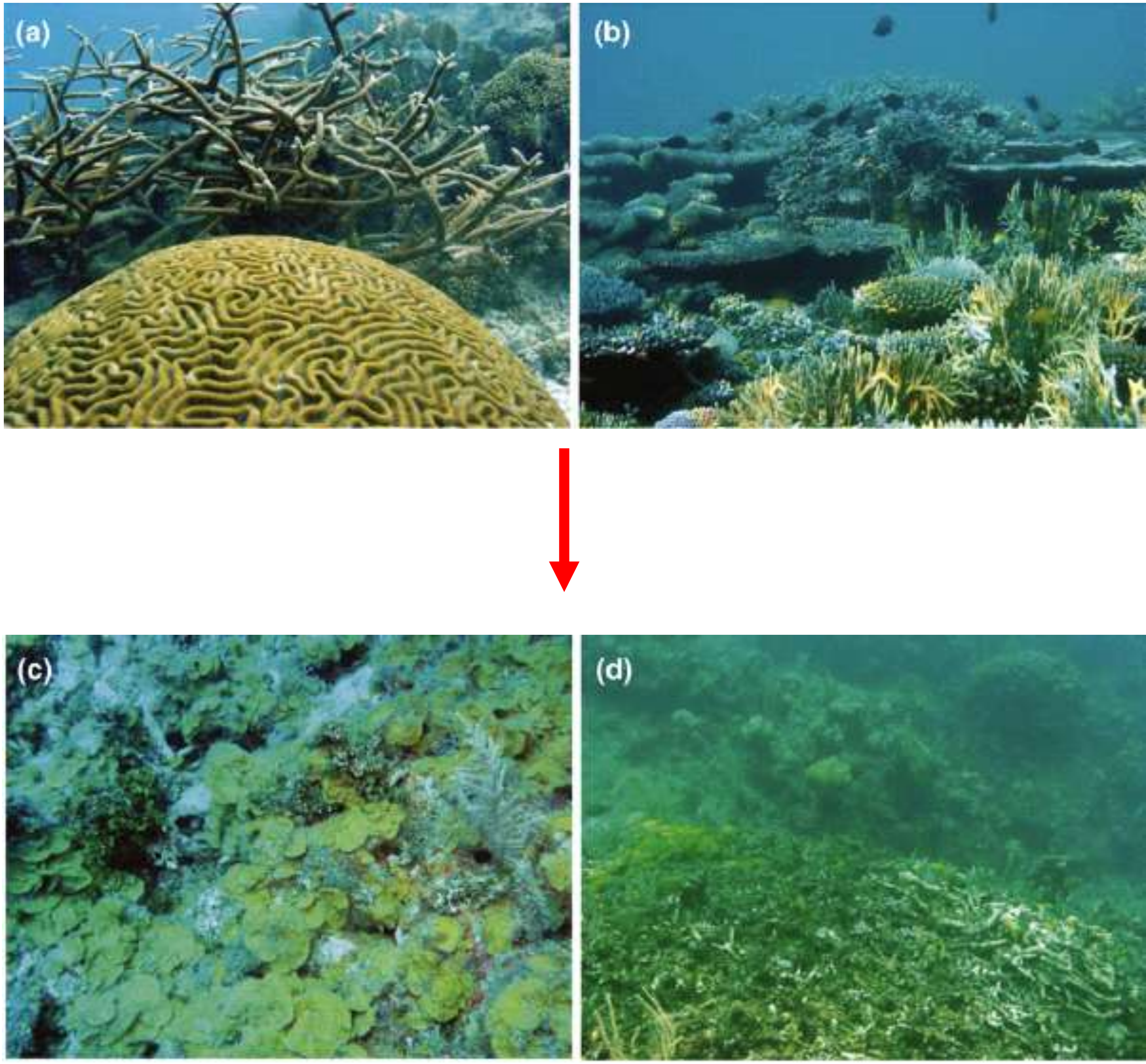


Figure 1. The changing fortunes of coral reefs. Healthy coral reefs in (a) the Caribbean and (b) the Pacific characterised by great structural complexity from branching and table acroporid corals. (c) Rising macroalgal cover, such as *Lobophora variegata*, limits the settlement space available to coral recruits and their subsequent survival and (d) causes prolific algal blooms with low coral cover. (Photos from the Caribbean.)

Variable coral morphology

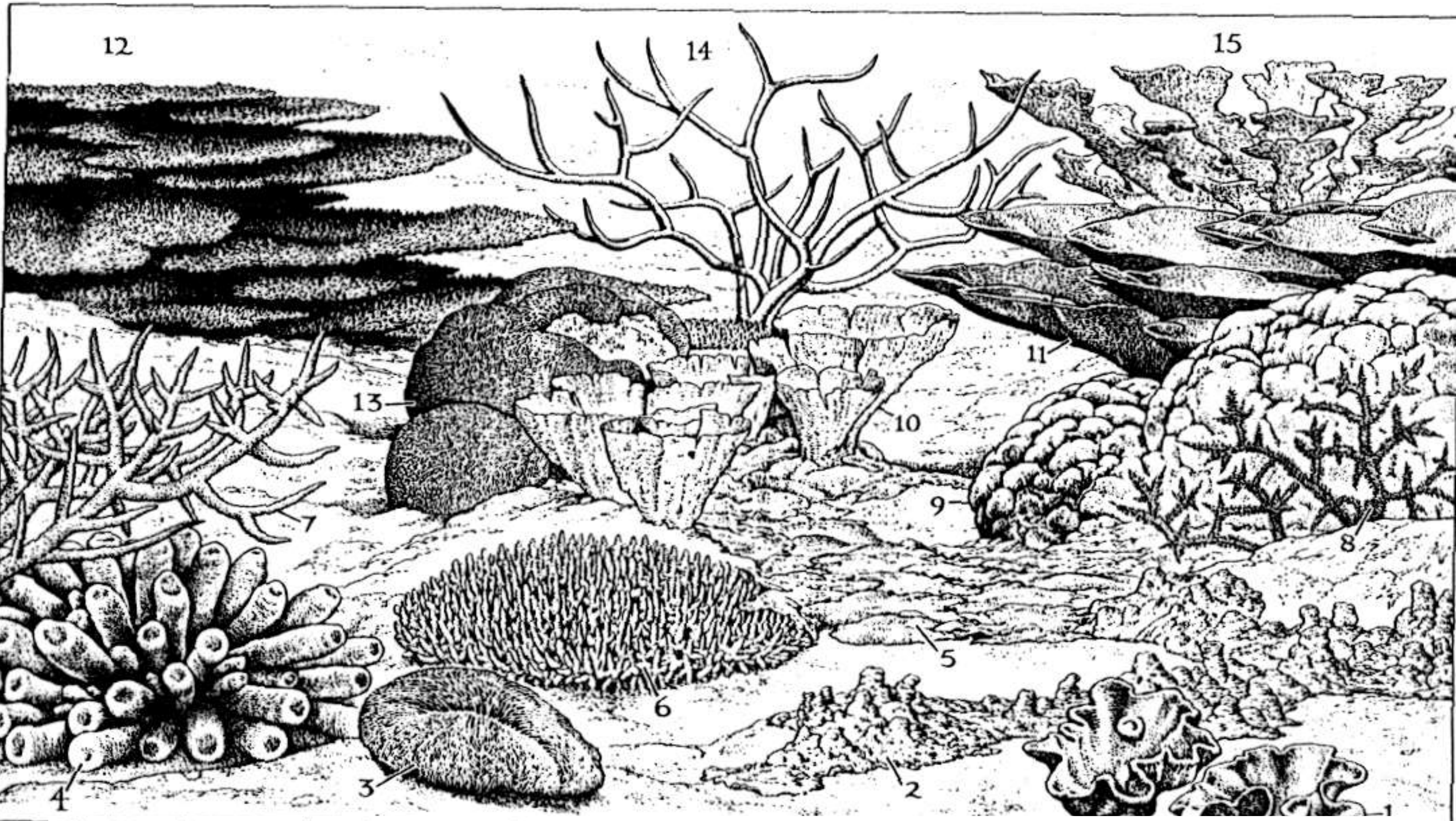


Fig. 6.2 The variety of coral morphology found on modern reefs showing the flexibility of multiserial growth. 1: Cup-shaped soft coral; 2: columnar; 3: free-living; 4: digitate; 5: encrusting; 6: corymbose; 7: caespitose; 8: bottlebrush; 9: massive; 10: foliaceous (cup-shaped); 11: foliaceous (forming a whorl); 12: tables and plates; 13: massive; 14: arborescent (staghorn); 15; arborescent (elkhorn). (Modified from Veron 1986; copyright, John Sibbick.)

An Indo-Pacific coral reef

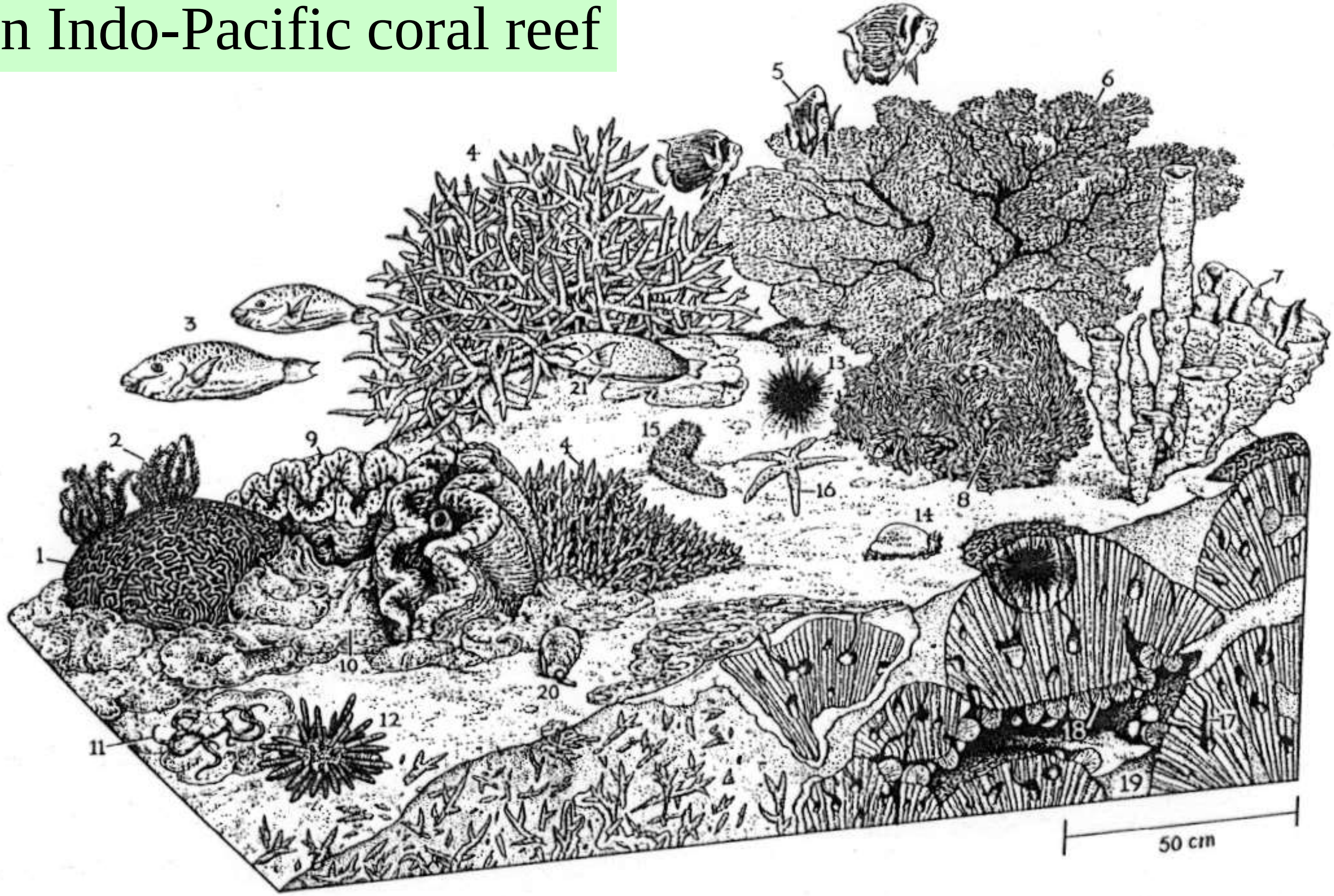


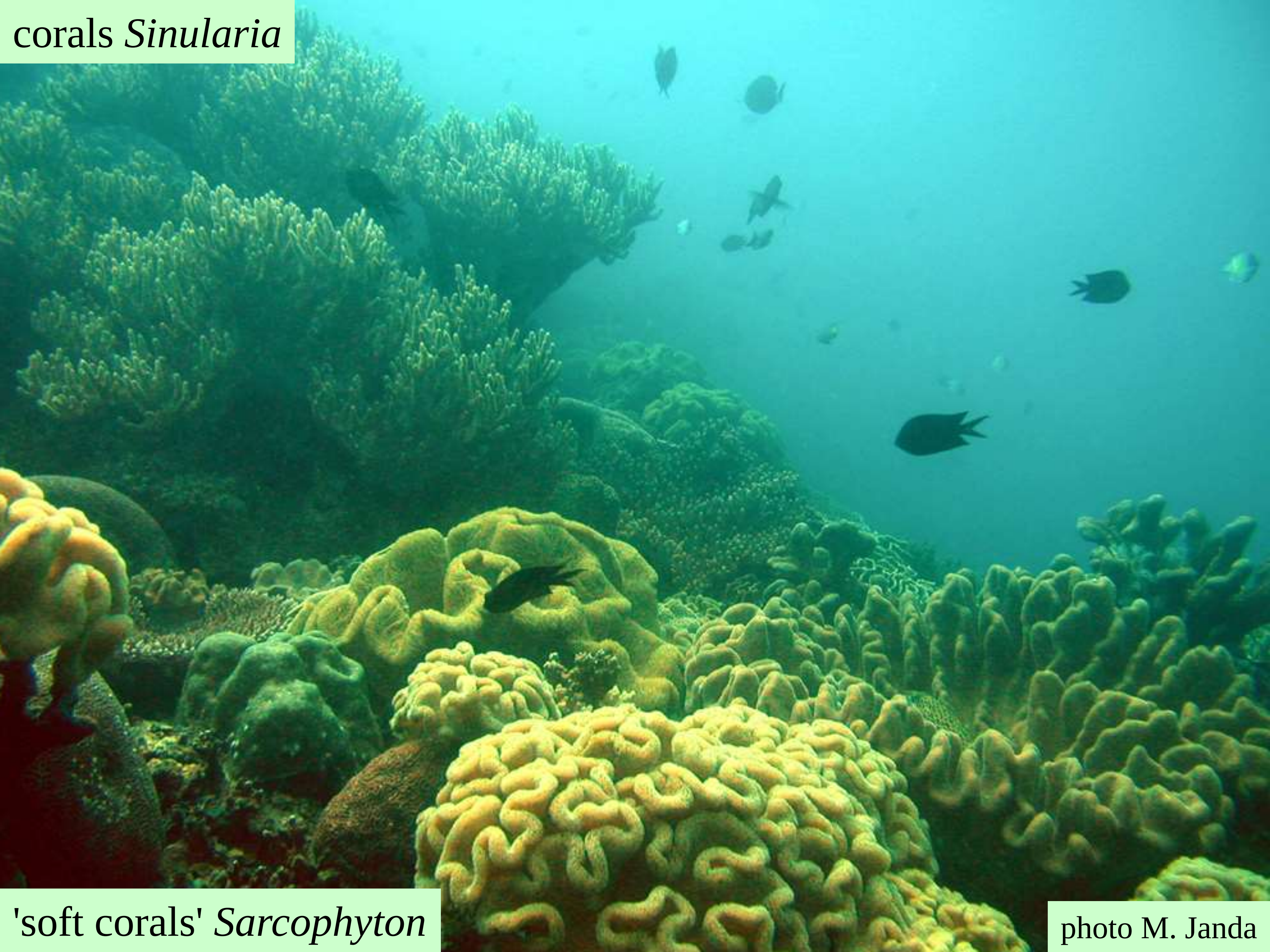
Fig. 3.35 Reconstruction of an Indo-Pacific coral reef. 1: Brain coral (*Leptoria phrygia*); 2: feather star (*Comanthus bennetti*); 3: Parrotfish (*Scarus* sp.); 4: Staghorn coral (*Acropora* sp.); 5: Emperor Angelfish (*Pomacanthus imperator*); 6: Gorgonian; 7: vase sponge (*Callyspongia* sp.); 8: anemone with clown fish; 9: giant clam (*Tridacna gigas*); 10: encrusting corals (*Montipora* and *Hydnophora*); 11: brittle star (*Ophiarachella gorgonia*); 12 and 13: sea urchins; 14: cowrie; 15: sea cucumber (*Thelenota ananus*); 16: sea star; 17: boring bivalve (*Lithophaga*); 18: cement botryoids; 19: internal sediment; 20: cone shell (*Conus textile*); 21: wrasse (*Coris gaimard*.) (Copyright, John Sibbick.)

hard corals

photo M. Janda

'black corals' r. *Cirripathes*

photo M. Janda



corals *Sinularia*

'soft corals' *Sarcophyton*

photo M. Janda

Turbinaria? soft corals

photo M. Janda

sponges

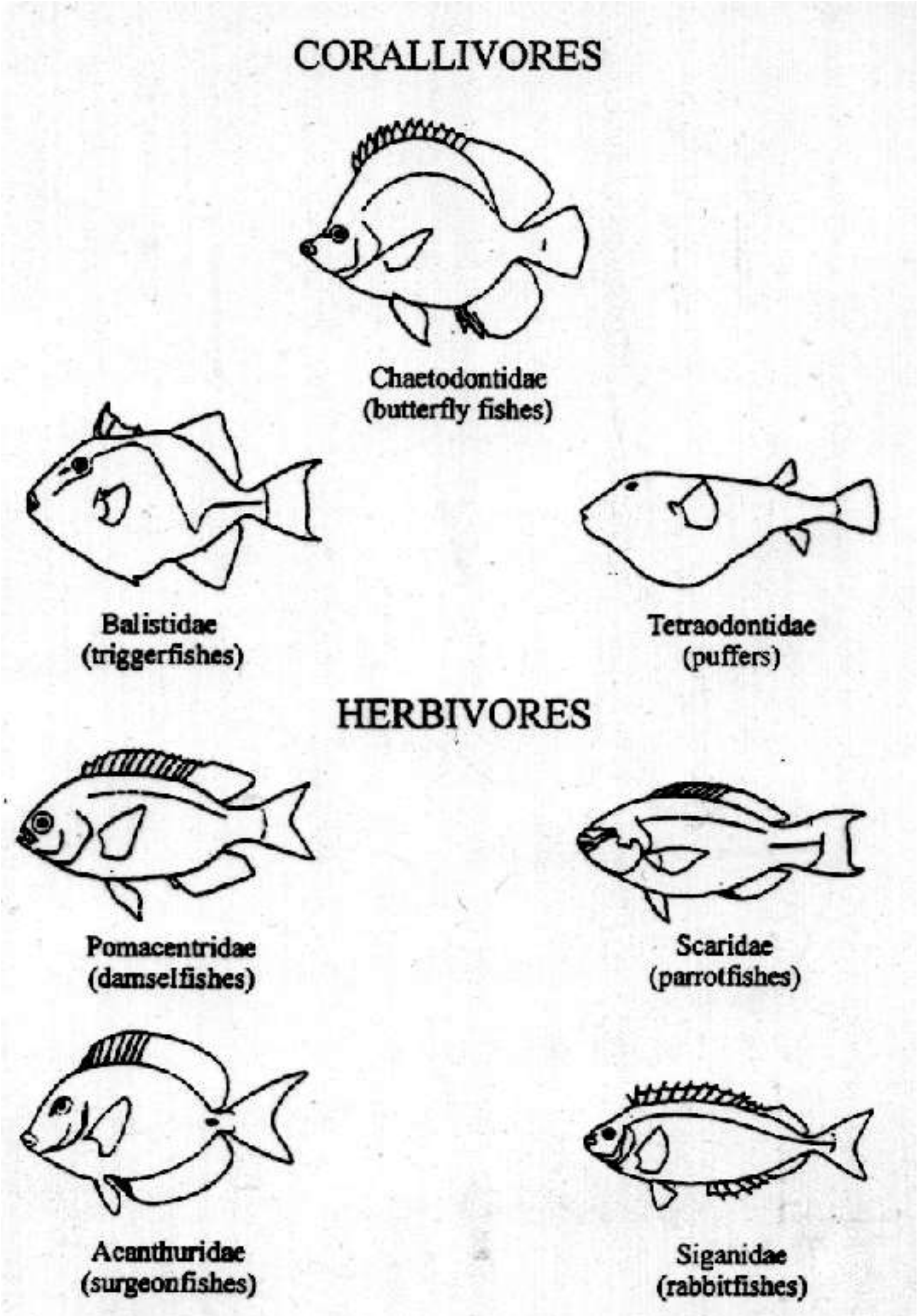
photo M. Janda

Joseph Dougherty

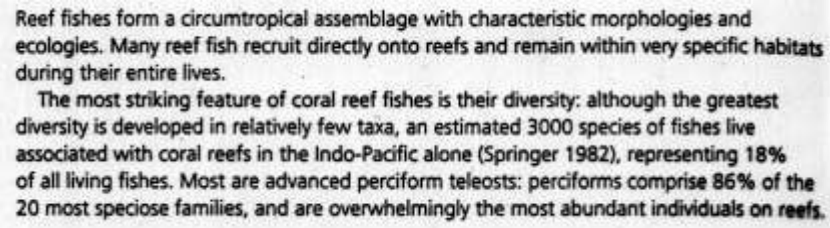
Copyright Aaron Fink, 2003

Reef fishes:

Indo-Pacific alone has some 3,000 species, i.e. 18% of all fish species



7.1 Main families of larger bodied modern reef fishes. (Redrawn from Nelson 1984.)



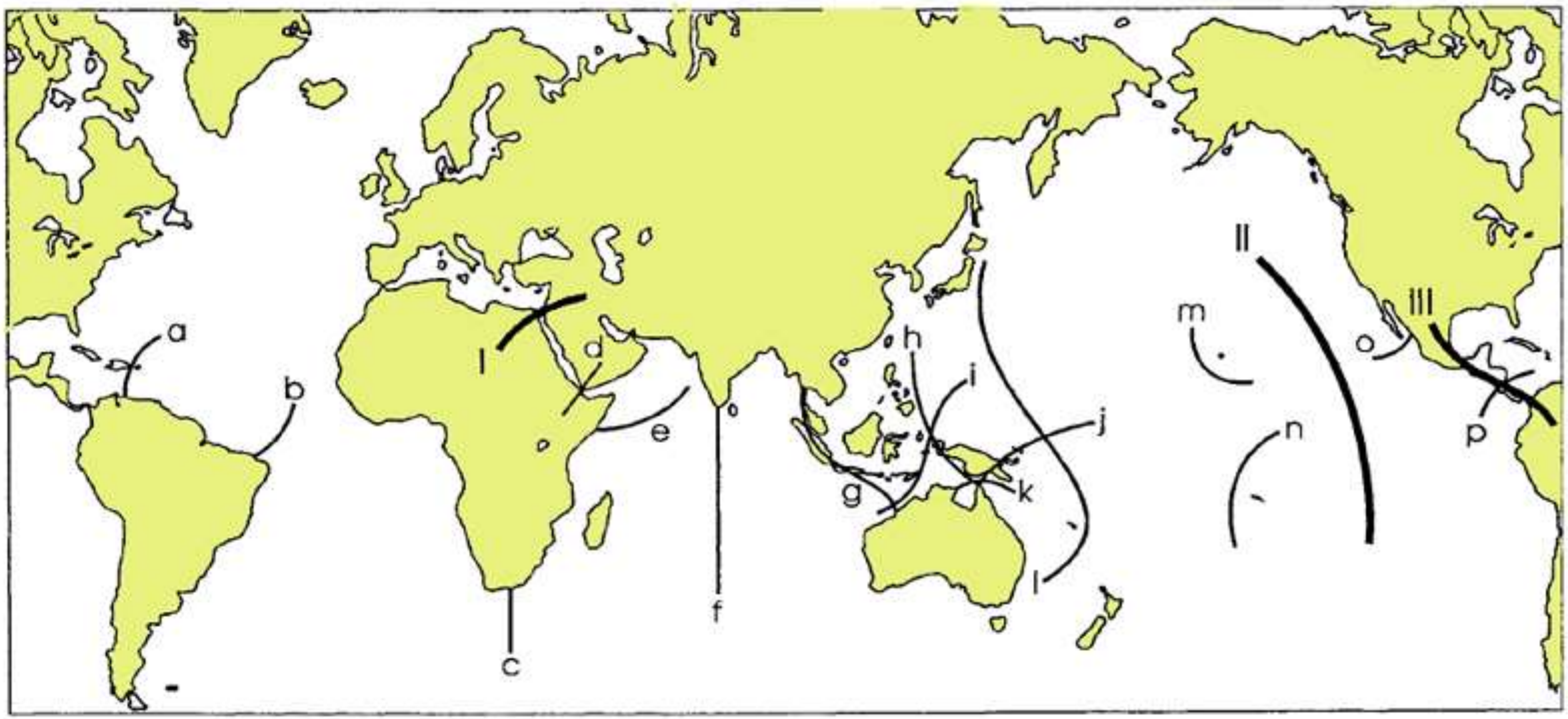
Reef fishes form a circumtropical assemblage with characteristic morphologies and ecologies. Many reef fish recruit directly onto reefs and remain within very specific habitats during their entire lives.

The most striking feature of coral reef fishes is their diversity: although the greatest diversity is developed in relatively few taxa, an estimated 3000 species of fishes live associated with coral reefs in the Indo-Pacific alone (Springer 1982), representing 18% of all living fishes. Most are advanced perciform teleosts: perciforms comprise 86% of the 20 most speciose families, and are overwhelmingly the most abundant individuals on reefs.

Coral reefs: 25% of total marine biodiversity

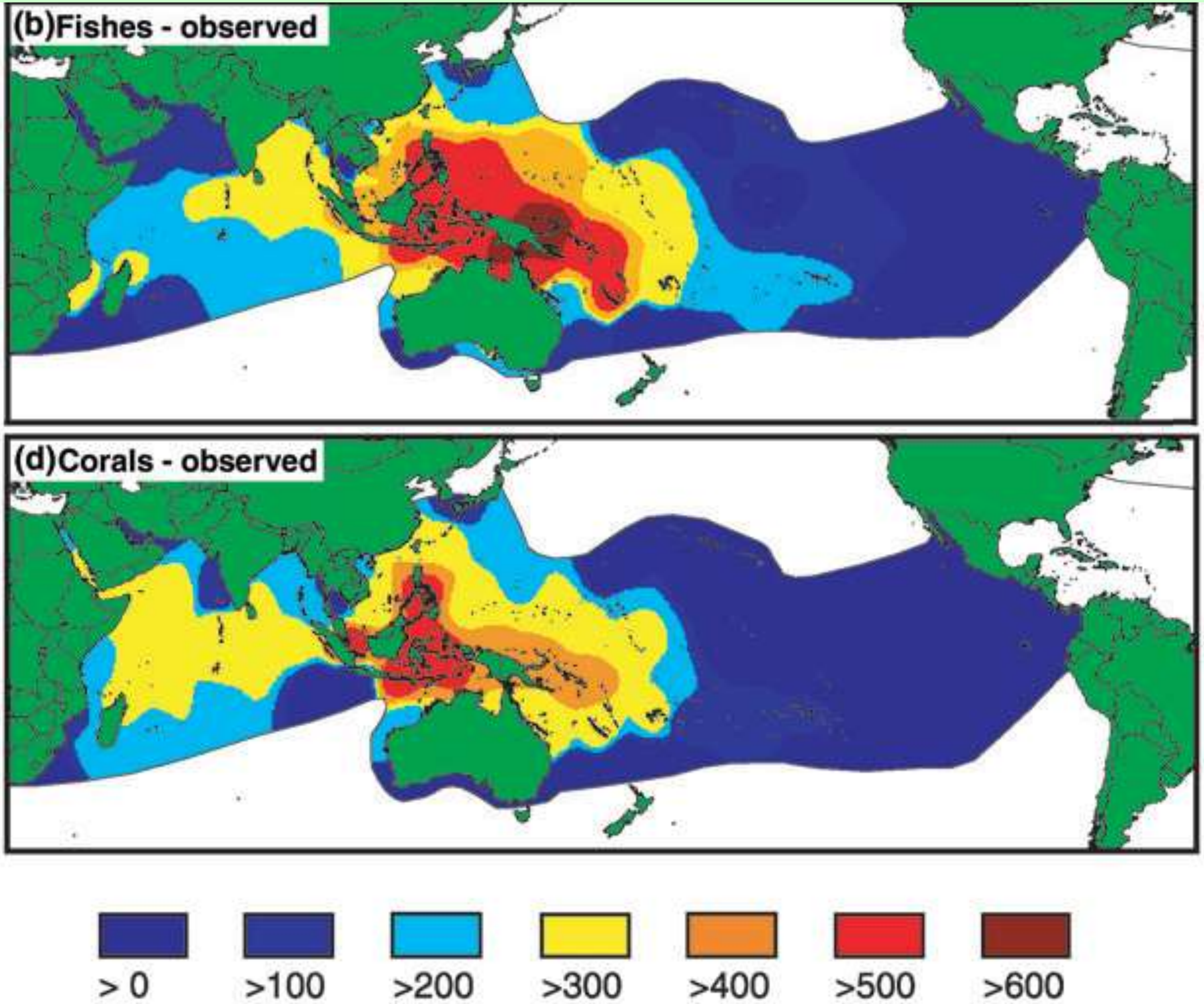
photo M. Janda

Faunal boundaries proposed for reef fish taxa



Blum, 1989

Coral Triangle: epicenter of marine biodiversity, >2700 species of shore fishes and 600 species of corals



Bellwood et al (2005). Ecology Letters 8: 643–651.

Coral triangle – global species diversity hotspot

Center of Accumulation model: speciation in peripheral locations with subsequent dispersal into the Coral Triangle. The long history of the Pacific archipelagos, isolation in peripheral habitats, and current and wind patterns that favor dispersal towards the Coral Triangle have been suggested as a mechanism.

Center of Overlap model: overlap of distinct faunas from the Pacific and Indian Oceans, the isolating mechanism being the Indo-Pacific Barrier, which separates the Pacific and Indian Oceans during low sea-level stands

Center of Speciation model: diversity hotspots such as Coral Triangle are exporters of species, driven by the fracture of populations that result from geologic complexity and habitat heterogeneity coupled with intense competition.

Bowen et al. TREE 2013, 28: 359

Reef fish biodiversity: Indonesian & Philippine Region (IPR) as the major center of evolution

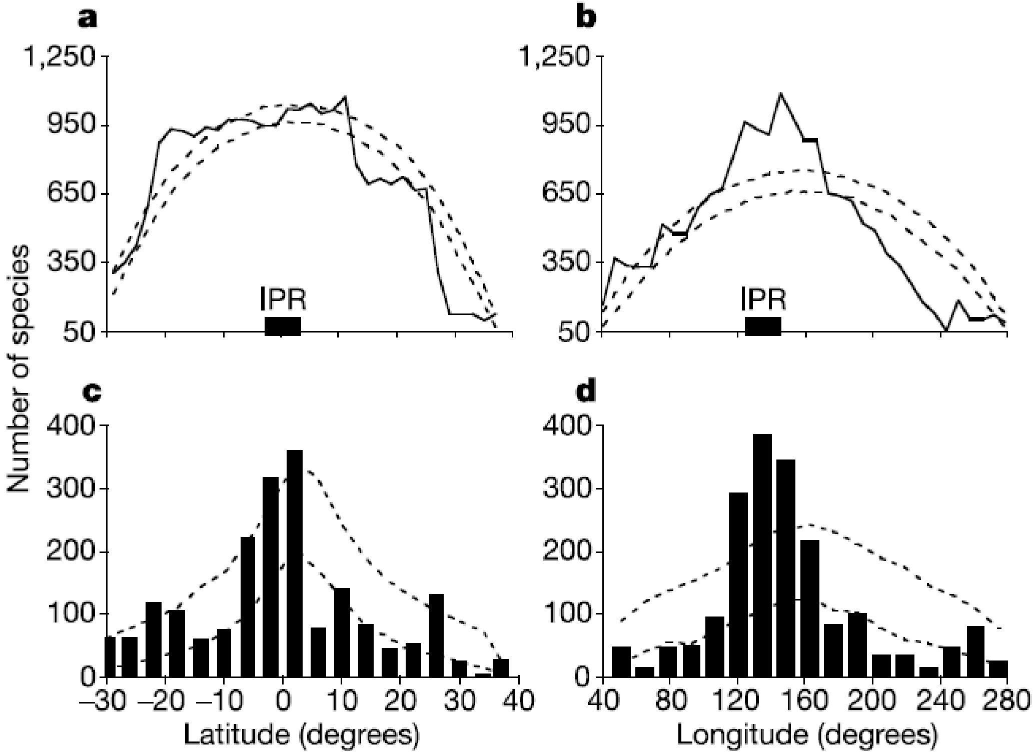
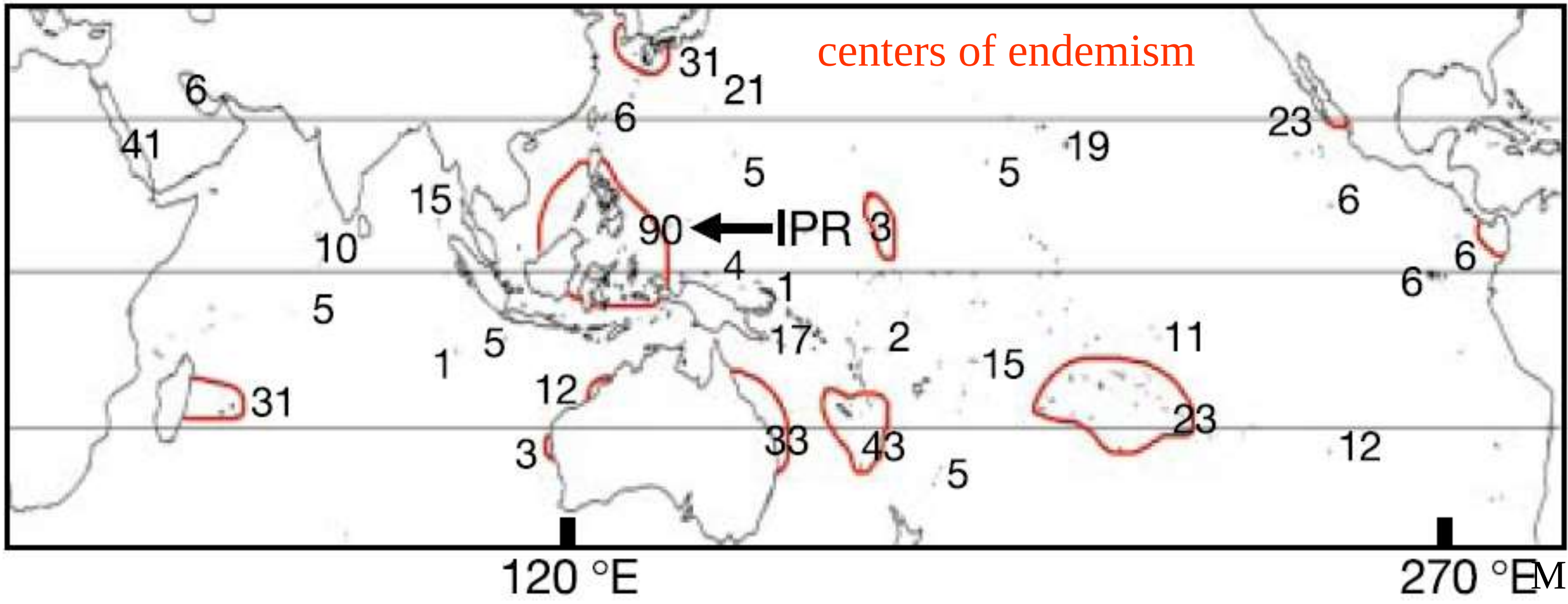


Figure 1 Geographical patterns in reef fish biodiversity in the Indian and Pacific oceans. IPR, Indonesian and Philippine region. Latitudinal (**a**) and longitudinal (**b**) clines (solid lines) were defined as the number of species whose geographical ranges included a point in latitude or longitude, respectively. Distributions of mid-latitudinal (**c**) and mid-longitudinal (**d**) ranges (filled bars) are also shown. The effects of geographic constraints on such patterns (the mid-domain effect[10]) were tested by running a null model in which the ranges (for **a** and **b**) and mid-ranges (for **c** and **d**) were randomly allocated between boundaries. These boundaries were the 'hard' limits imposed by the coasts of Africa and America in longitude and the 'soft' limits implied by the 37° N and 32° S latitude where tropical organisms show striking reductions in species richness[20]. Dotted lines correspond to the maximum and minimum values after running the model 1,000 times.

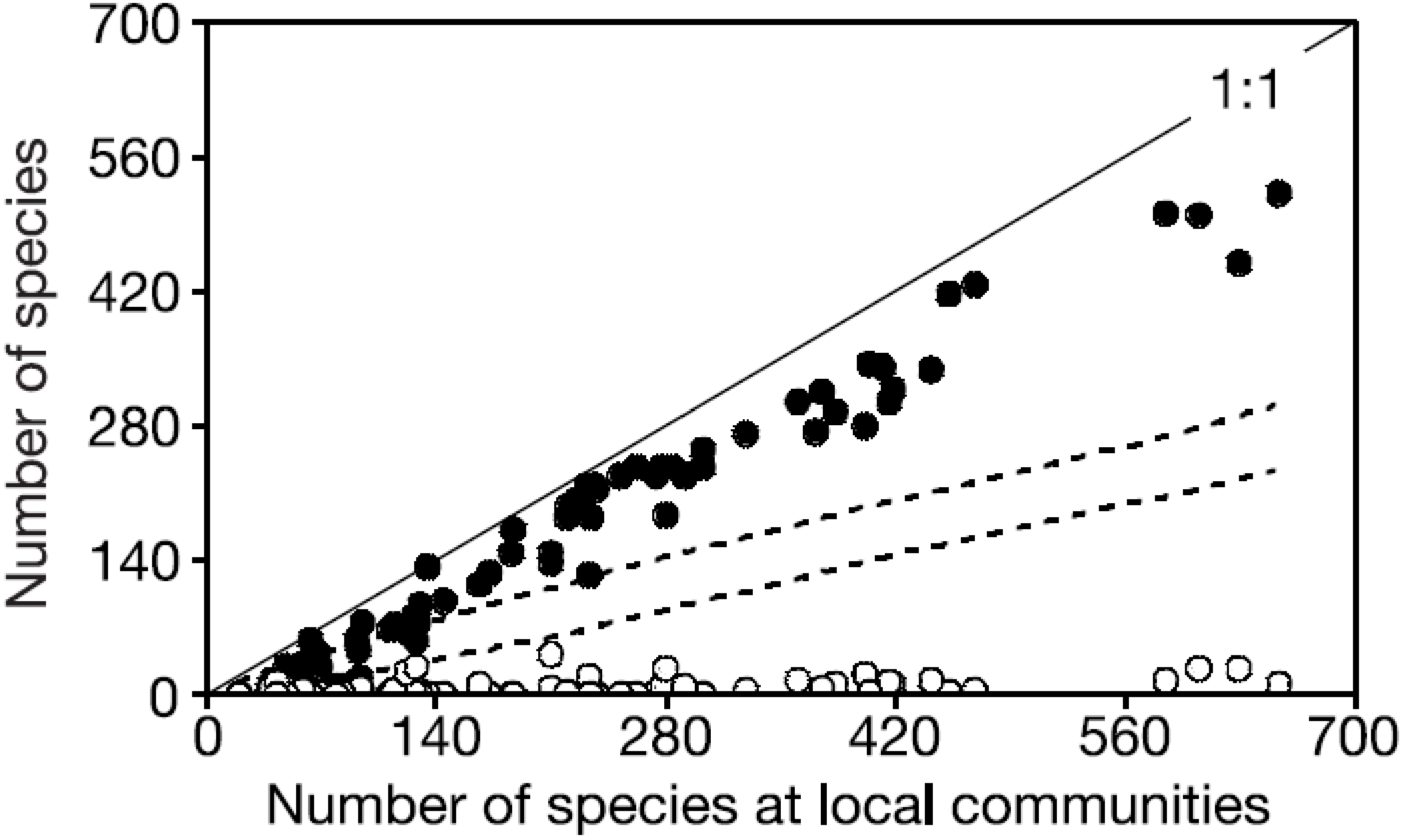
Figure 2 Geographical pattern of reef fish endemism in the Indian and Pacific oceans. Endemic species were defined as those species restricted to a single location in the



centers of endemism

Mora et al. 2003

Species from the Indonesian & Philippine Region (IPR) dominate reef fish communities in the Indian and Pacific oceans



● IPR species
○ endemic species

Figure 4 Contribution of IPR and endemic species to local reef fish assemblages in the Indian and Pacific oceans. Filled circles, IPR species; open circles, endemic species. We assessed the extent to which the number of IPR species at local communities is due to chance by determining the number of IPR species in communities (of the same size as observed) randomly generated from the total species pool (species selected with equal probability and without replacement). The upper and lower limits of the number of IPR species in 1,000 iterations for each community are shown as broken lines.

Species richness

corals

reef fishes

Endemic species (range $<10^5$ km^2)

★ no endemic sp.

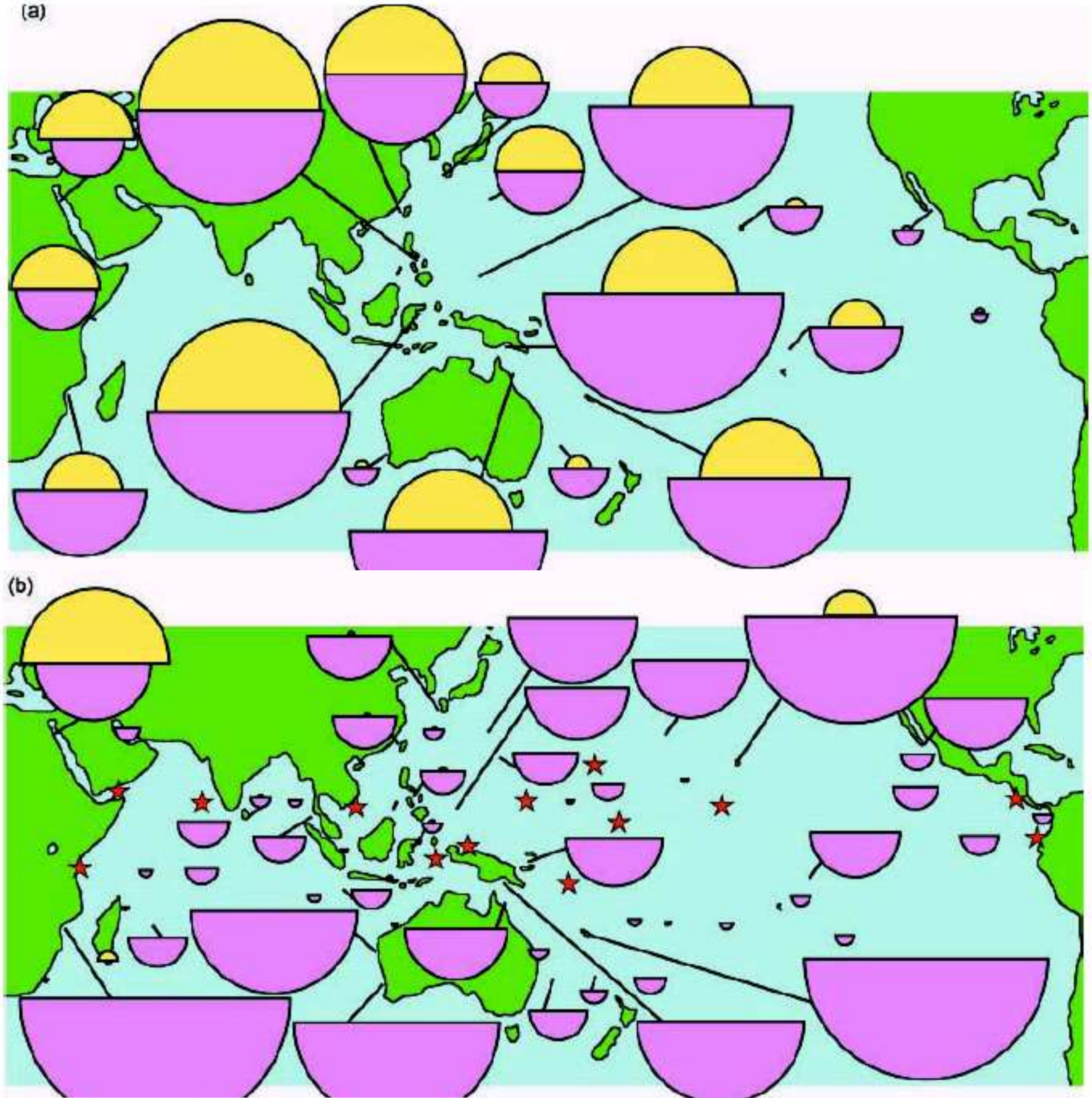


Figure 1 Map of the Indo-Pacific showing variation in (a) the species richness and (b) the number of endemic species (species with ranges of $<3 \times 10^5$ km^2) of reef-building corals (top yellow semicircle) and tropical reef fishes (bottom pink semicircle). Locations indicated by red stars have no endemics in either major taxon. The radius of each semicircle is linearly proportional to the number of species, scaled equally for corals and fishes. The largest semicircle represents 744 fish species in (a) and 42 fish endemics in (b).

Hughes et al. 2002

Distribution of geographic ranges of corals and fishes in Indo-Pacific

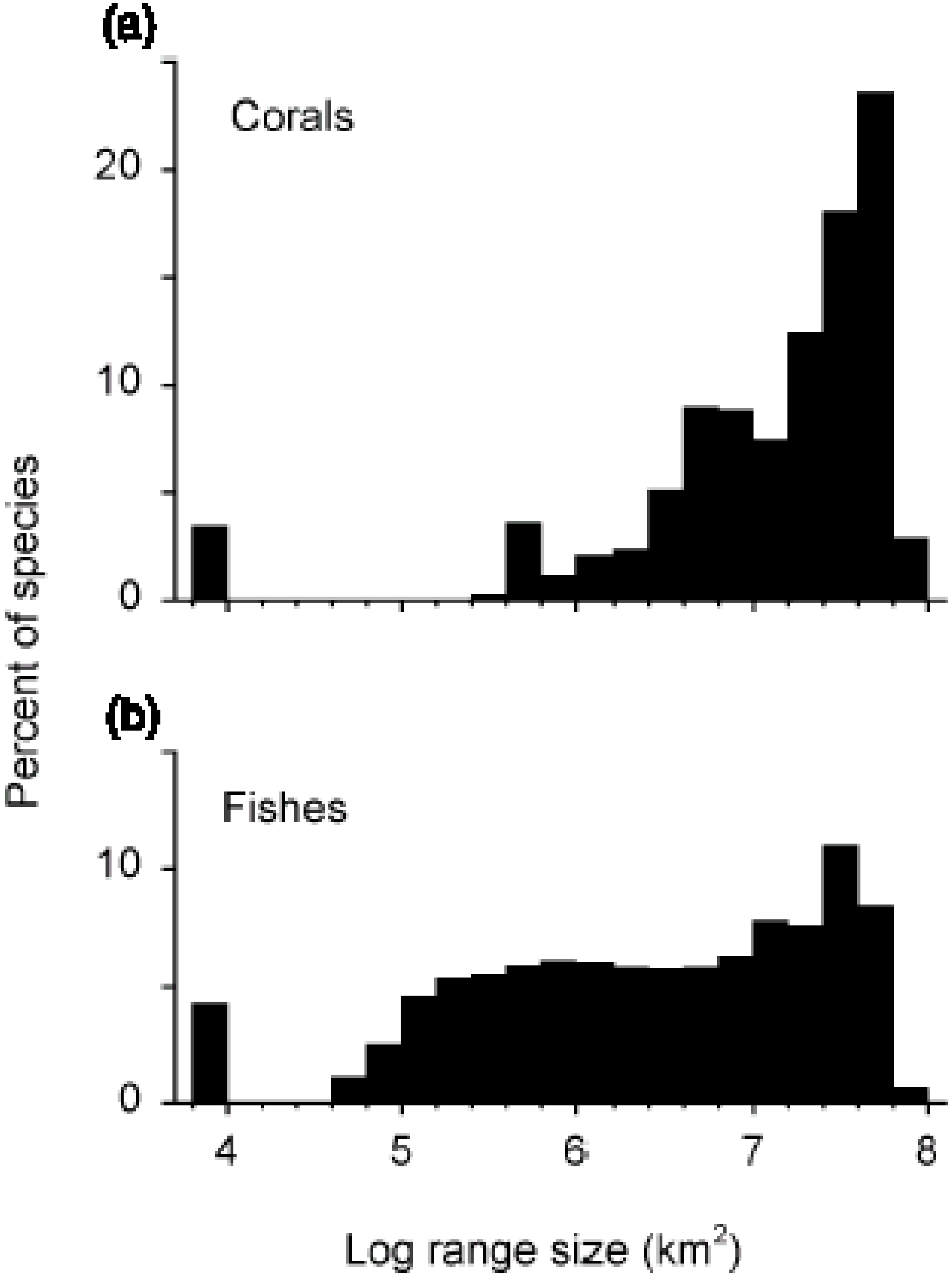
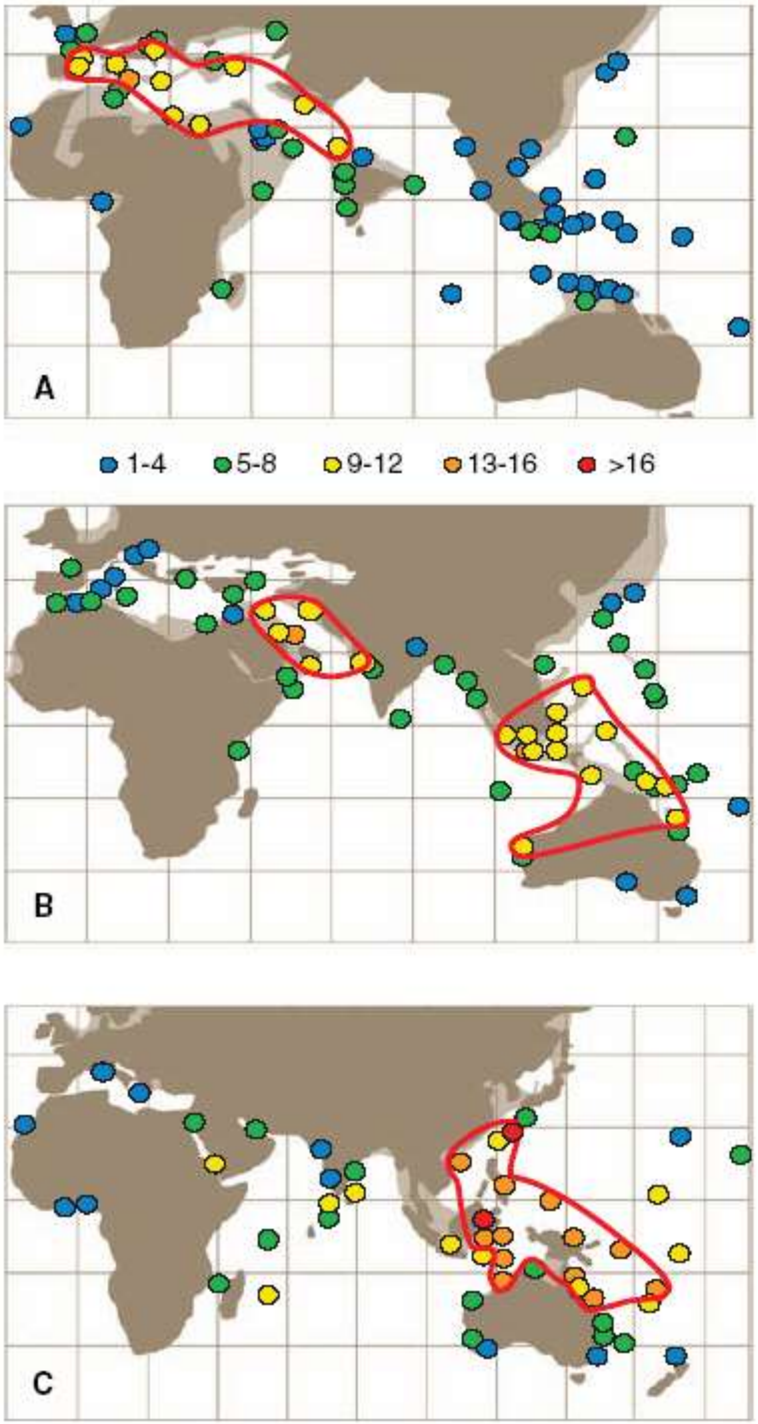


Figure 3 Frequency distribution of the geographical ranges of reef-building corals and tropical reef fishes in the Indo-Pacific Oceans. Ranges are expressed as km^2 (logarithmic scale).

Hughes et al. 2002

Marine biodiversity hotspots: moving over past 50 million years



Foraminifera hotspots:
A: 39-42 mil. years before present
B: 16-23 mil. years before present
C: at present

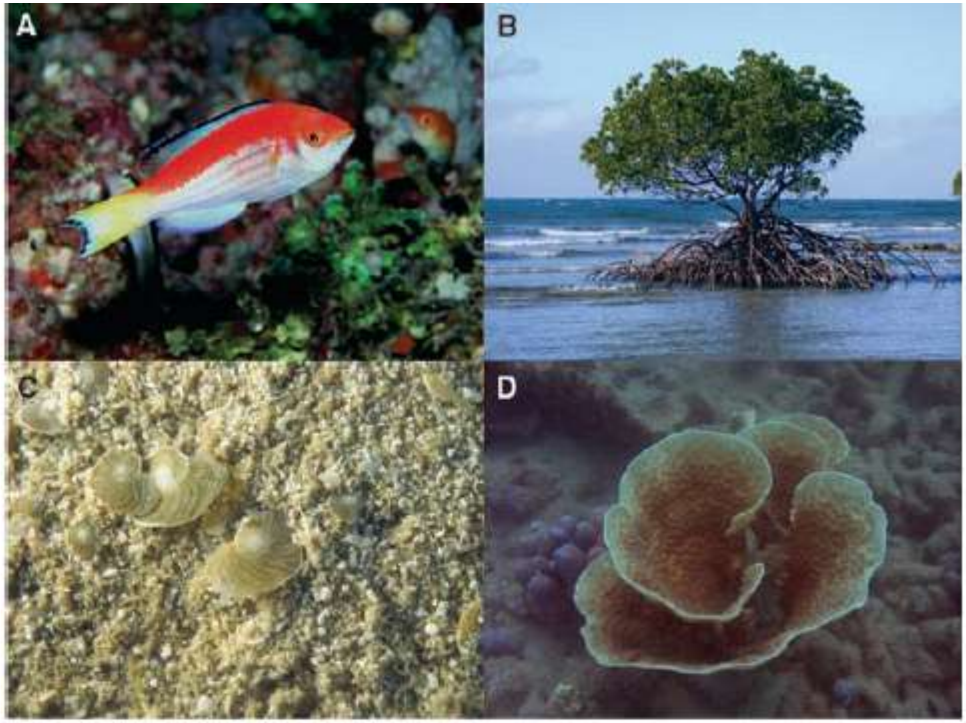
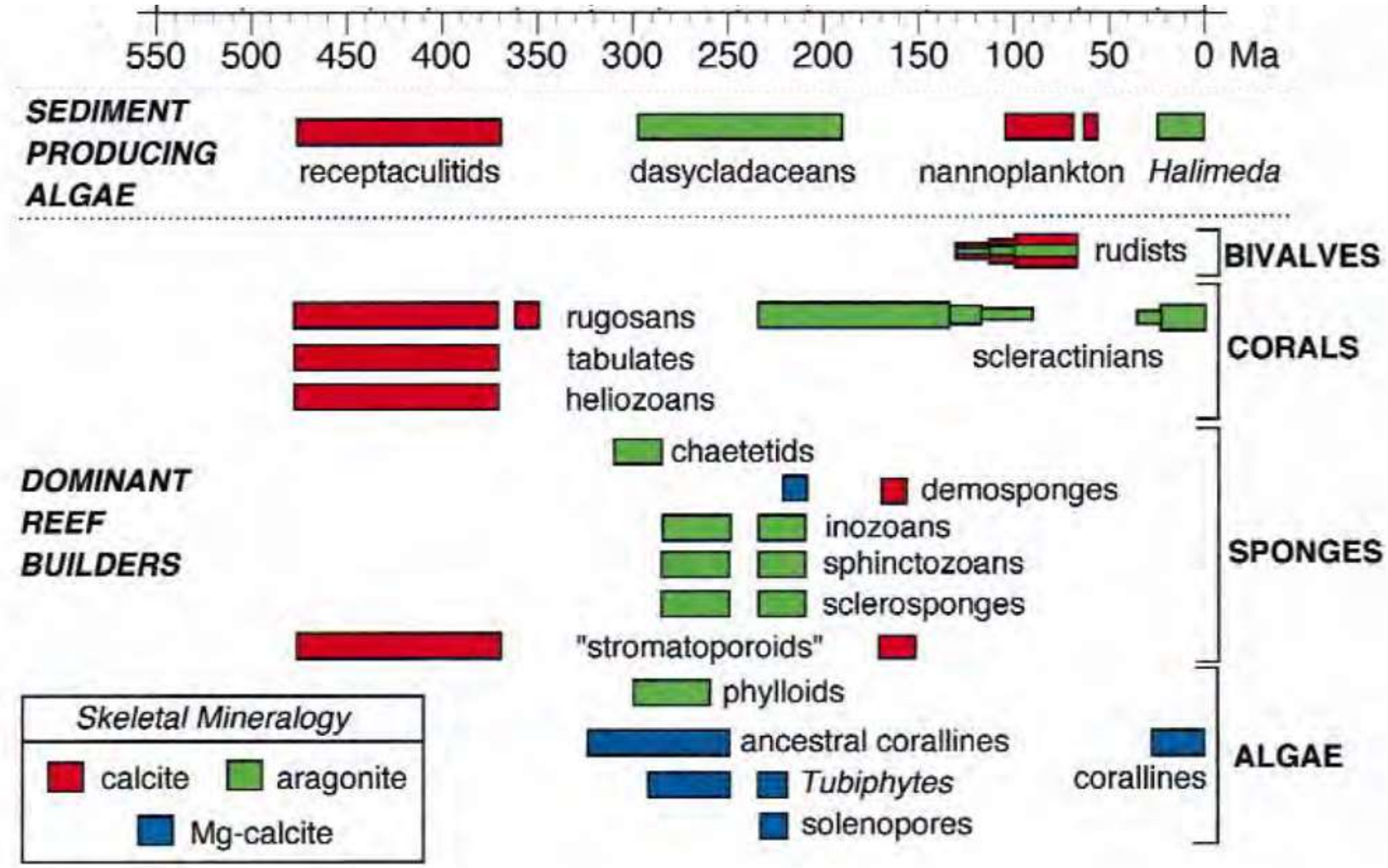


Fig. 2. Congruent biogeographic patterns are characterized by multiple taxa within the IAA biodiversity hotspot. Evidence exists from the molecular genetics of (**A**) fishes and the fossil record of (**B**) mangroves, (**C**) larger benthic foraminifera, and (**D**) corals.

Fig. 1. Generic α-diversity of large benthic foraminifera in (A) the late Middle Eocene (42 to 39 Ma), (B) the Early Miocene (23 to 16 Ma), and (C) the Recent. Solid lines delimit the West Tethys, Arabian, and

Renema et al. 2008, Science 321: 654

There have always been reef building organisms, albeit from different taxa



Stanley et al. 1999, GSA Today 9:23

140 M years

Rudist bivalves

ig. 6.11 A substantial monospecific aggregation of the large Cretaceous rudist *Vaccinites vesicularis*. The view probably hows a succession of communities. Individual size is remarkably uniform within each community suggesting that it grew s a consequence of colonization of adults of the same species by larval spat-falls that showed philopatric behaviour. On the basis of well-preserved growth bands, it has been estimated that such rudists had a life span of between 20 and 0 years. Upper Cretaceous (Campanian), Central Oman. Hammer = 32 cm long. (Photograph: D. Schumann.)

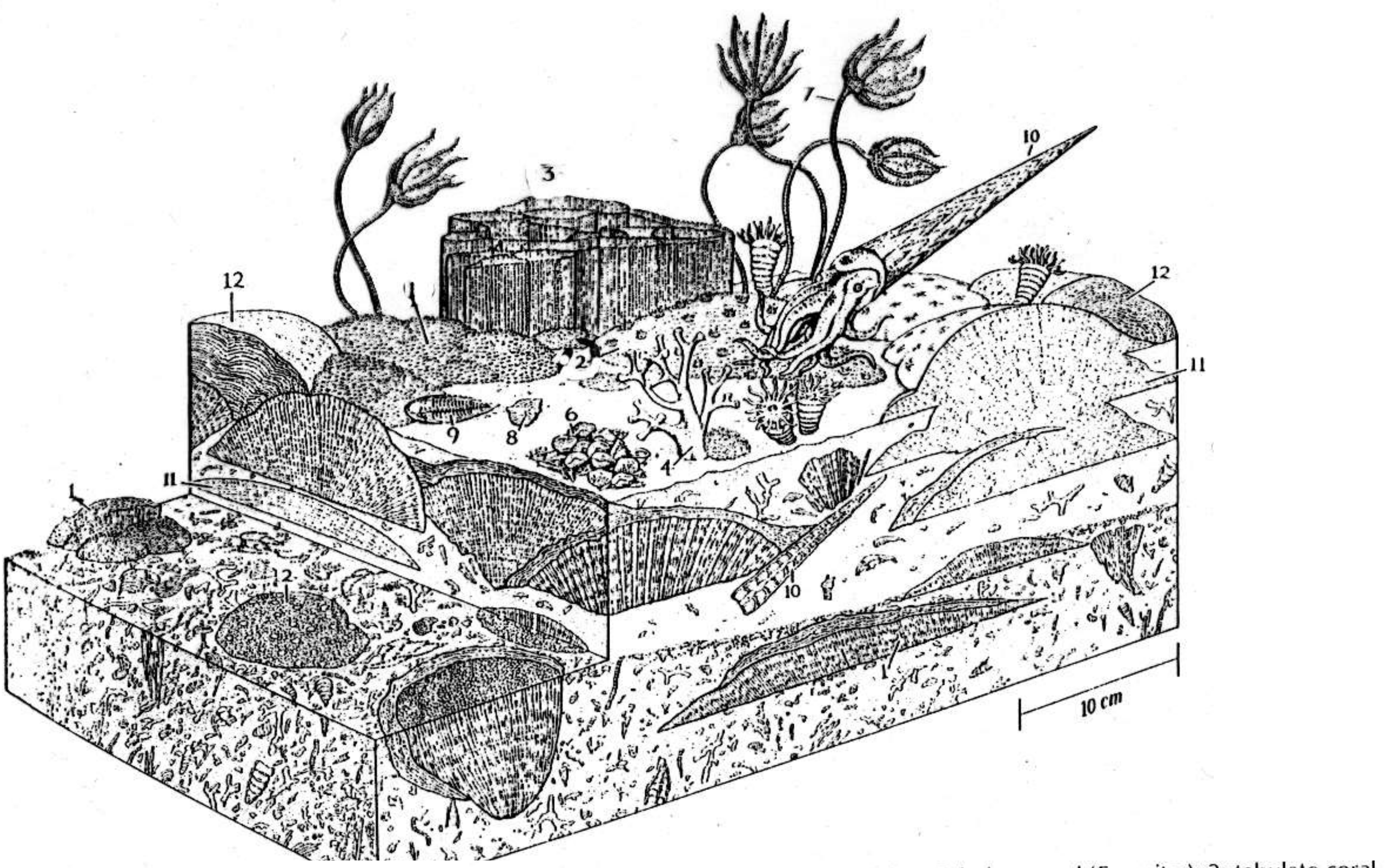


Fig. CS 3.4 Reconstruction of Silurian (Wenlock) patch reef, England. 1: Tabulate coral (*Favosites*); 2: tabulate coral (*Heliolites*); 3: tabulate coral (*Halysites*); 4: bryozoan (*Hallopora*); 5: streptelasmatid rugose coral; 6: spirifid brachiopod (*Atrypa*); 7: crinoid; 8: brachiopod (*Leptaena*); 9: trilobite (*Dalmanites*); 10: orthocone nautiloid; 11: stromatoporoid (*Actinostroma*); 12: thrombolite. (Modified from McKerrow 1978; copyright, John Sibbick.)

430 M years

sponges

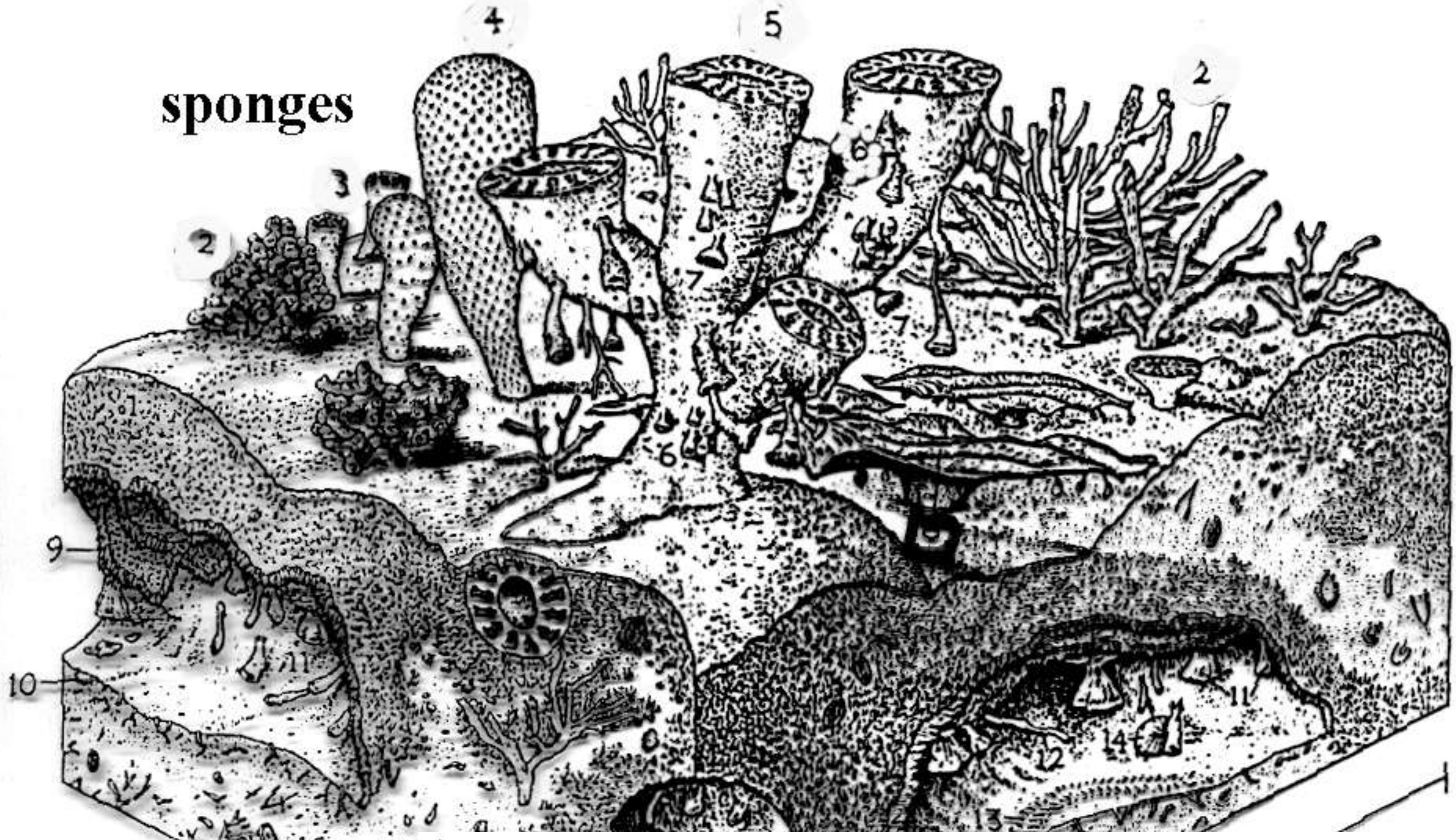


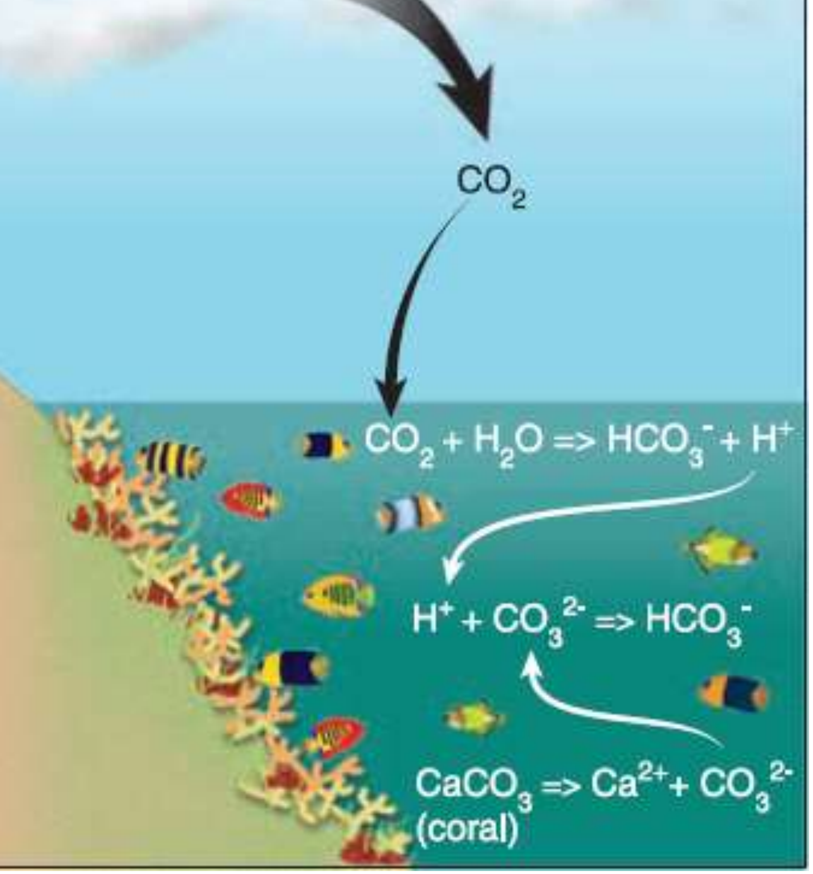
Figure 1 Reconstruction of a Lower Cambrian reef community (from 97). 1. *Renalcis* (calcified cyanobacterium); 2: branching archaeocyath sponges; 3: solitary cup-shaped archaeocyath sponges; 4: chancellorid (?sponge); 5: radiocyath (?sponge); 6: small, solitary archaeocyath sponges; 7: cryptic 'coralomorphs'; 8: *Okulitchicyathus* (archaeocyath sponge); 9; early fibrous cement forming within crypts; 10: microburrows (traces of a deposit-feeder) within geopetal sediment; 11: cryptic archaeocyaths and coralomorphs; 12: cryptic cribricyaths (problematic, attached skeletal tubes); 13: trilobite trackway; 14: cement botryoid; 15: sediment with skeletal debris.

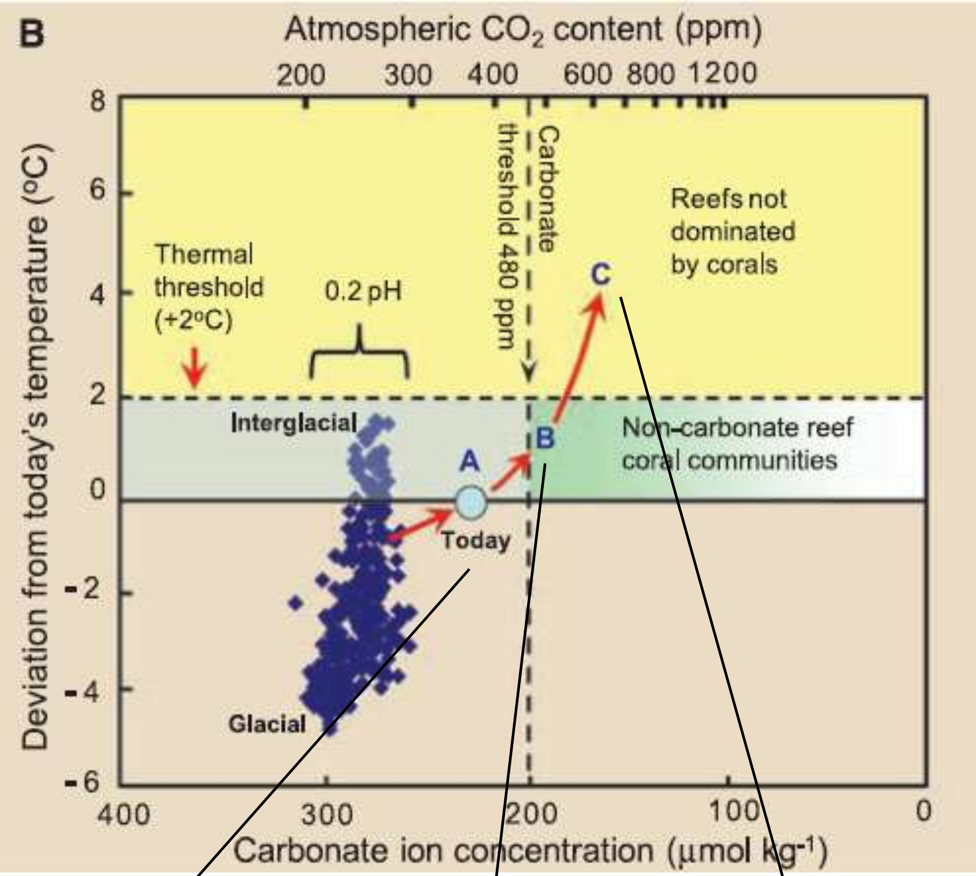
535 M years

Threats to coral reefs:

- coral bleaching
- destructive fishing
- nutrients and sediments
- increasing CO_2 concentration in atmosphere

Fig. 7.3 Crown-of-thorns starfish (*Acanthaster plancii*) feeding on the branching coral *Acropora*. (Photograph: R. Steene.)

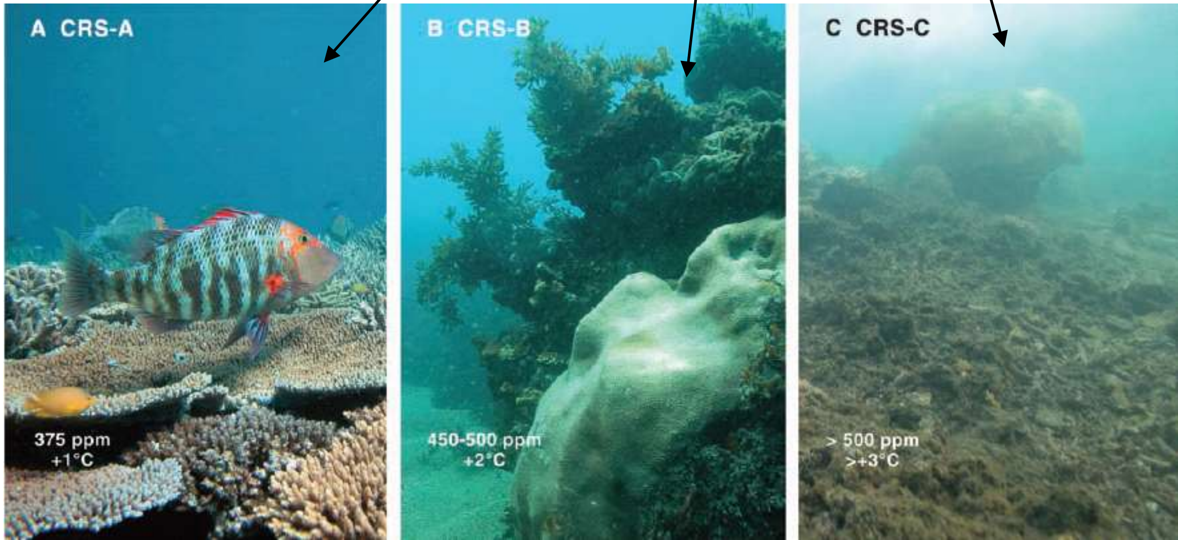




Ocean acidification and coral building

Fig. 1. (**A**) Linkages between the buildup of atmospheric CO_2 and the slowing of coral calcification due to ocean acidification. Approximately 25% of the CO_2 emitted by humans in the period 2000 to 2006 (*9*) was taken up by the ocean where it combined with water to produce carbonic acid, which releases a proton that combines with a carbonate ion. This decreases the concentration of carbonate, making it unavailable to marine calcifiers such as corals. (**B**) Temperature, $[CO_2]_{atm}$, and carbonate-ion concentrations reconstructed for the past 420,000 years. Carbonate concentrations were calculated (*54*) from $CO_{2\ atm}$ and temperature deviations from today's conditions with the Vostok Ice Core data set (*5*), assuming constant salinity (34 parts per trillion), mean sea temperature

Hoegh-Guldberg, O. 2007. Science 318:1737



Once dissolved in seawater, CO_2 reacts with water, H_2O, to form carbonic acid, H_2CO_3. Carbonic acid dissolves rapidly to form H^+ ions and bicarbonate, HCO_3^-. Seawater is naturally saturated with another base, carbonate ion (CO_3^{2-}) that acts to neutralize the H+ forming more bicarbonate HCO3−, decreasing thus carbonate saturation in water.