Nov 4: Coral Bleaching

Coral bleaching occurs when corals experience stress, most commonly from **elevated sea temperatures, high solar radiation**, and/or **changes in salinity or water quality**.

Reading:

1) Van Woesik et al. (2022). Coral-bleaching responses to climate change across biological scales. GCB, 28(14), 4229-4250.

2) UNEP, The world's corals are bleaching. Here's why and what it means for the ocean's future; https://www.unep.org/news-and-stories/story/worlds-corals-are-bleaching-heres-why-and-what-it-means-oceans-future



https://news.mongabay.com/2015/10/massive-bleaching-event-puts-worlds-coral-reefs-at-risk/

Microalgal symbionts are microscopic algae that live in close association with another organism (the *host*), often forming a mutually beneficial relationship called **symbiosis**.

Example: Coral reefs

In coral ecosystems, microalgal symbionts are primarily photosynthetic dinoflagellates belonging to the family **Symbiodiniaceae**, commonly called *zooxanthellae*.

- **Photosynthesis:** The microalgae use sunlight and CO_2 to produce organic carbon compounds.
- **Carbon transfer:** They transfer a substantial portion of their photosynthetically fixed carbon to their coral hosts, supporting coral metabolism, growth, and calcification.
- **Nutrient exchange:** Corals provide the algae with shelter, inorganic nutrients (including nitrogen and phosphorus), and CO_2.
- **Environmental sensitivity:** Elevated ocean temperatures can disrupt this symbiotic relationship, resulting in coral bleaching.

Relationship to coral bleaching





Scleractinia corals and their photosynthetic microalgal symbionts has allowed corals to build coral reefs for millions of years.

Scleractinia corals and their photosynthetic microalgal

Corals can be found throughout the ocean, from the balmy waters of the Red Sea to the frigid depths of the North Atlantic. But perhaps the best known live in the **warm, shallow waters of the tropics**, where they form stunning, multi-colored reefs.

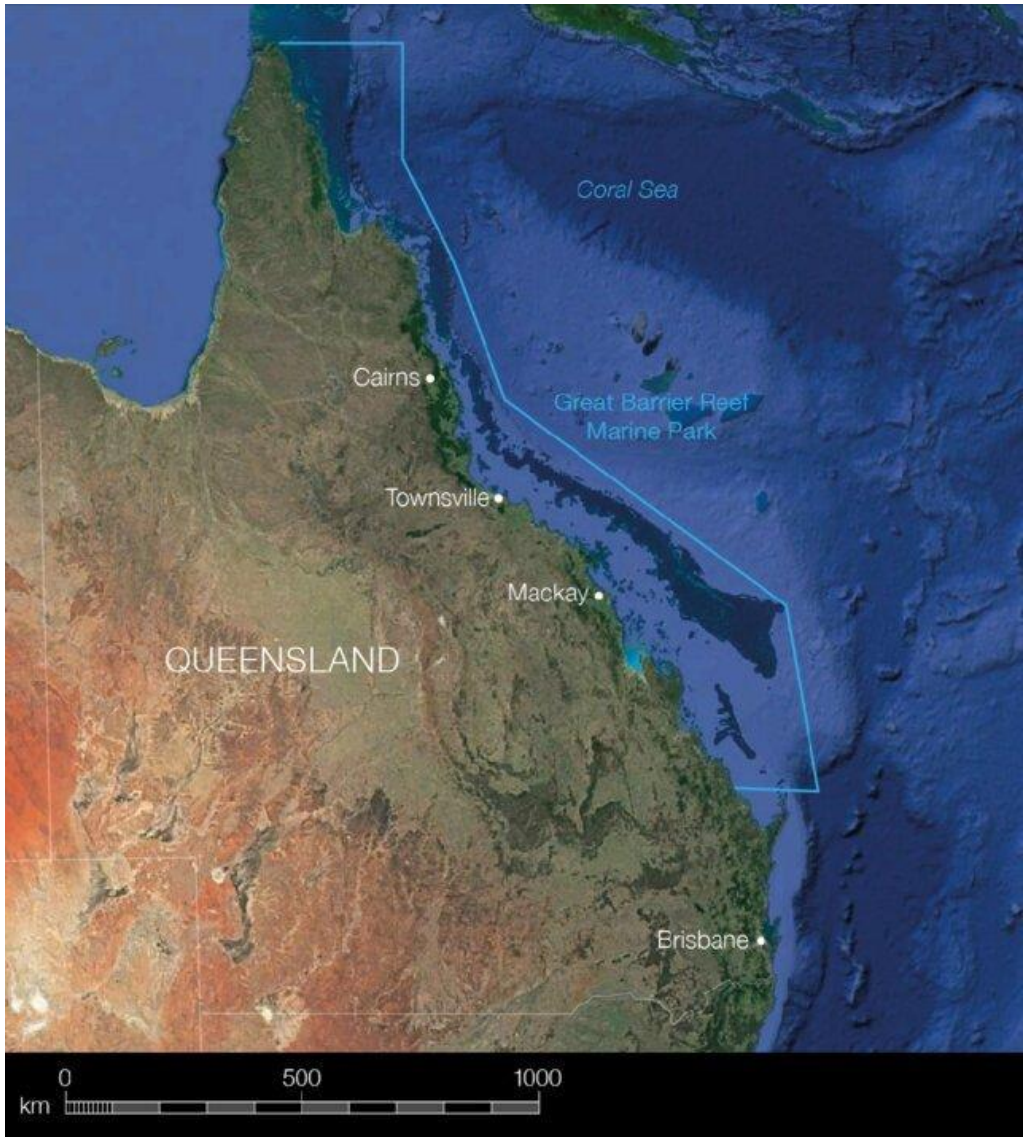


Corals get their **color** from thousands of plant-like organisms known as zooxanthellae, which live inside the corals and provide them with food.

Among the hardest hit areas is **the Great Barrier Reef**, where nearly 80% of coral outcrops had bleached, according to a report from the Australian government.

Corals along the Great Barrier Reef have turned a boney white as a bleaching epidemic sweeps across the UN World Heritage Site.

DEMO 3f6g&t=6s



Location of the Great Barrier Reef Marine Park. The reef systems show as dark against the blue of the ocean.





Westgate, J. (2023). Corals, Geo-Sociality, and Anthropocene Dwelling. *Exchanges: The Interdisciplinary Research Journal*, *10*(2), 74-105.

A before and after image of the bleaching in American Samoa.

Despite their tough exterior, **warm water corals are sensitive creatures**. When water temperatures rise, they become stressed and expel their zooxanthellae, leaving them prone to disease and starvation.



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https://www.unep.org/news-and-stories/story/worlds-corals-are-bleaching-heres-why-and-what-it-means-oceans-future

At the heart of each individual coral is a **polyp, a clear, tube-shaped animal with a ring of tentacles that it uses to catch prey**. Some corals surround themselves with a limestone skeleton forged from calcium absorbed from sea water.



Heat sensitive

When water temperatures rise, corals become stressed and bleach, leaving them prone to disease and starvation.



Ocean gardens

A lettuce coral is surrounded by fish in the Red Sea, off Egypt's coast.



A symbiotic relationship

Corals, like this Zoanthus, get their colour from thousands of plant-like organisms that live inside them.



Hub of life

About one-quarter of marine animals depend on coral reefs, which have been called rainforests of the sea because of their abundance of life.



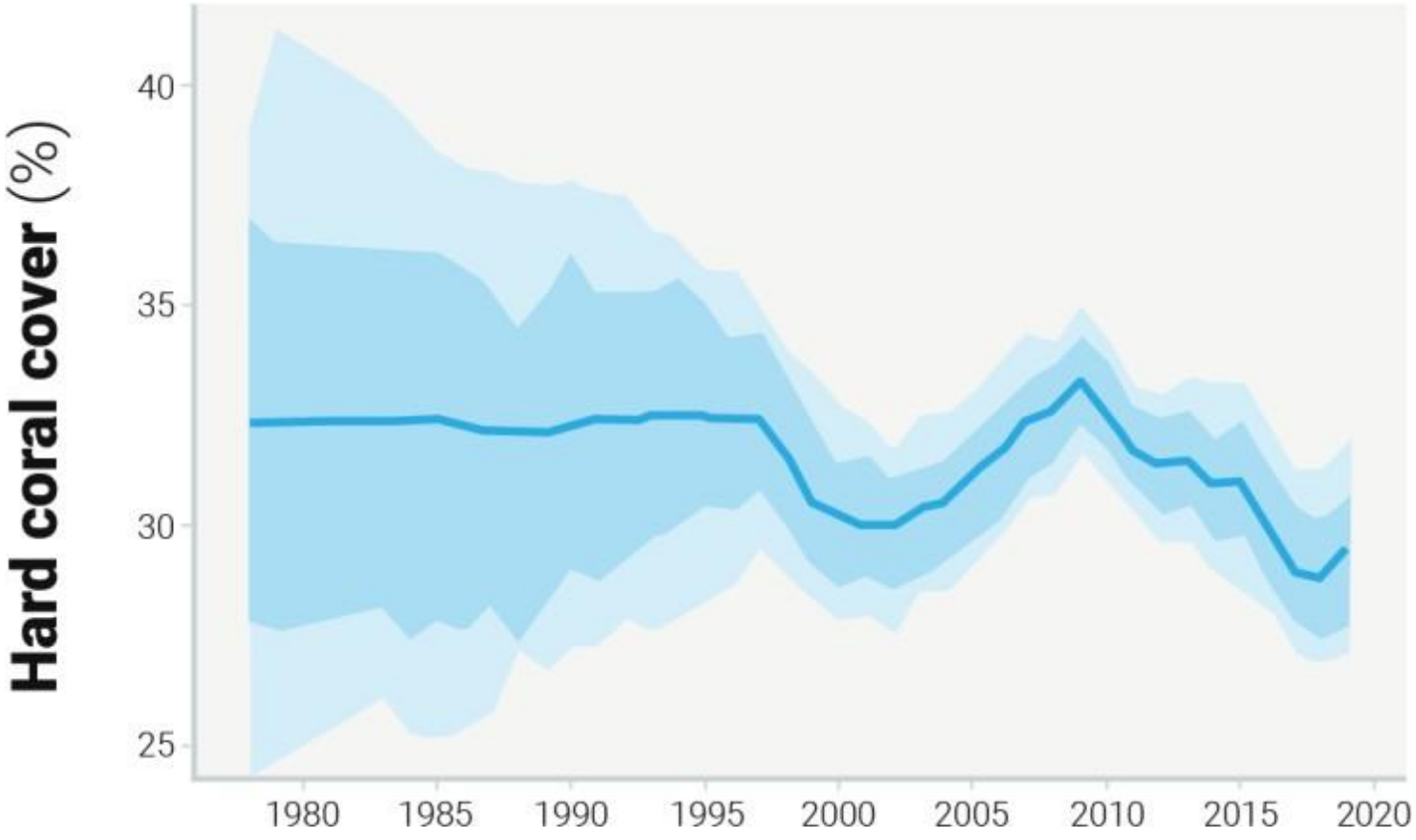
Safe havens

Researchers have found pockets of water, including those in the Red Sea, where corals are resisting the ravages of climate change.



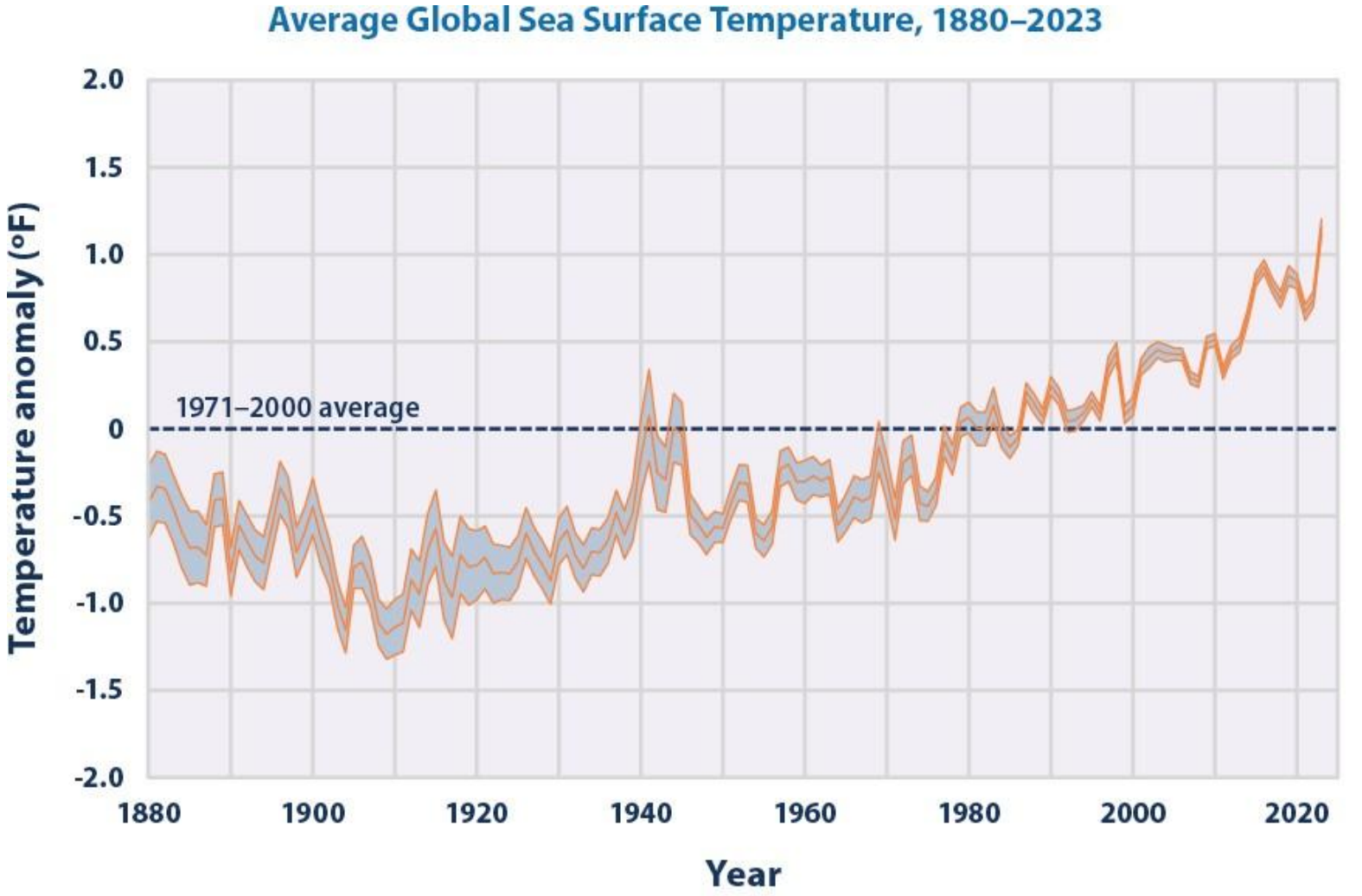
Percentage of tropical reefs that are covered in live corals. Coverage was stable until a series of mass bleaching events began in 1998. Credit: UNEP

Even if the world manages to reach the most ambitious goal of the Paris Agreement on climate change – limiting global temperature rise to 1.5°C – 70-90% of reef-building corals are expected to die. If temperatures rise 2°C, 99% will perish.



Coral Bleaching

Surging ocean temperatures, driven in part by climate change, are responsible for the latest bleaching event



Data source: Huang, B., Thorne, P. W., Banzon, V. F., Boyer, T., Chepurin, G., Lawrimore, J. H., Menne, M. J., Smith, T. M., Vose, R. S., & Zhang, H.-M. (2024). *NOAA Extended Reconstructed Sea Surface Temperature (ERSST), version 5* [Data set]. Retrieved February 1, 2024, from https://doi.org/10.7289/V5T72FNM

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature

Coral Bleaching: through the loss of intracellular microalgal symbionts, which can result in coral mortality and changes in reef communities over

BOX 1 The coral bleaching phenomenon

The term 'bleaching' was coined to describe the visible paling of the coral surface, as the white skeleton becomes visible through the animal's translucent tissue that has lost pigmentation and symbionts (Glynn, 1983; Goreau, 1964). Coral bleaching is synonymous with the breakdown of the symbiotic relationship between the coral host and its microalgal symbionts (family Symbiodiniaceae). Yet, bleaching does not imply a physiological pathology per se because bleaching can result from multiple biotic and abiotic stressors, including freshwater, disease, pollutants, UV radiation, and suboptimal seawater temperatures (Glynn, 1996; Goreau, 1964). Most recent coral-bleaching events are caused by anomalously high seawater temperatures (Glynn, 1996; Hoegh-Guldberg, 1999; Hughes et al., 2018; Sully et al., 2019) resulting from climate change. Under extreme temperature stress, coral tissue deterioration or detachment from the skeleton can occur, often leading to mortality (Gates et al., 1992; Leggat et al., 2019). In many cases, however, the coral tissue remains intact during bleaching, albeit severely compromised and deprived of a nutrition source due to the loss of symbiotic microalgae that provide energy from photosynthesis to the coral host. Without sufficient heterotrophic compensation (Grottoli et al., 2006; Levas et al., 2016) or high enough energy reserves (Anthony et al., 2009), the bleached coral may eventually die from starvation.

Van Woesik et al. (2022). Coral-bleaching responses to climate change across biological scales. GCB, 28(14), 4229-4250.

Mechanisms

Processes involved in the establishment and maintenance of the coral-microalgal symbiosis provide insights into bleaching mechanisms. On establishment of symbiosis, the microalgal cells are taken into the coral gastrodermis, coral immune responses are repressed (Voolstra et al., 2009), and the cells are incorporated into the symbiosome (Davy et al., 2012). There the microalgal symbionts are maintained in a vegetative, immobile, nutrient-limited state that stimulates the release of excess photosynthetic carbon for the coral host to harvest (Barott et al., 2015; Jokiel et al., 1994). Recognition and signaling between both partners are crucial for maintaining nutritional demands (Rädecker et al., 2021). Under environmental stress, translocation of microalgal photosynthates to the coral host slows (Hughes et al., 2010), reducing the coral's primary source of organic carbon, signaling starvation and amino acid digestion (Rädecker et al., 2021).

The onset of physiological stress and bleaching is strongly dependent on the rate of heating, the accumulated thermal stress, and the maximum temperature (Middlebrook et al., 2010; Savary et al., 2021; Voolstra et al., 2020). Thermal stress affects multiple processes in both partners, resulting in direct impairment of key cellular functions, homeostasis, and nutrition (Rädecker et al., 2021; Roach et al., 2021a). In the microalgal symbiont, several factors have been implicated as pressure points during thermal stress, especially when combined with high irradiance. These factors include photosystem II repair, thylakoid membrane stability, and both photosynthetic and heterotrophic carbon assimilation pathways (Hughes et al., 2010; Iglesias-Prieto et al., 1992; Tchernov et al., 2004; Warner et al., 1999).

Disrupted photosynthetic and mitochondrial electron flow leads to elevated reactive-oxygen and nitrogen species. These disruptions alter redox homeostasis, create oxidative stress (Brown et al., 2002; Krueger et al., 2014; Lesser, 1997), and trigger a coral-innate-immune response. Transcriptomic analyses show that oxidative stress disrupts calcium (Ca^{2+}) homeostasis, which leads to altered cytoskeletal and cell-adhesion, reduced calcification, and expression of stress-response genes (DeSalvo et al., 2008; Rodriguez-Lanetty et al., 2009)—however, gene-network analyses indicate that additional, but less understood, mechanisms are also involved in coral bleaching (Dixon et al., 2020; Rose et al., 2016). Persistent disruption to cellular homeostasis under thermal stress can cause both the coral and the microalgal symbiont to undergo necrotic and apoptotic cell death (Dunn et al., 2012; Lesser & Farrell, 2004) and can lead to fatal coral bleaching.

1) Coral bleaching is most common in localities with a **high intensity and high frequency of thermal-stress**, and is less common in localities with highly variable seawater temperatures
2) The most extensive coral bleaching has been recorded between latitudes 15° and 20°, north and south
3) Although anomalously **high seawater temperatures** are the main driver of coral bleaching, there are other environmental factors that can exacerbate or mitigate coral bleaching during thermal stress: **light intensity, nutrient concentrations, zooplankton availability, and water-flow rates**

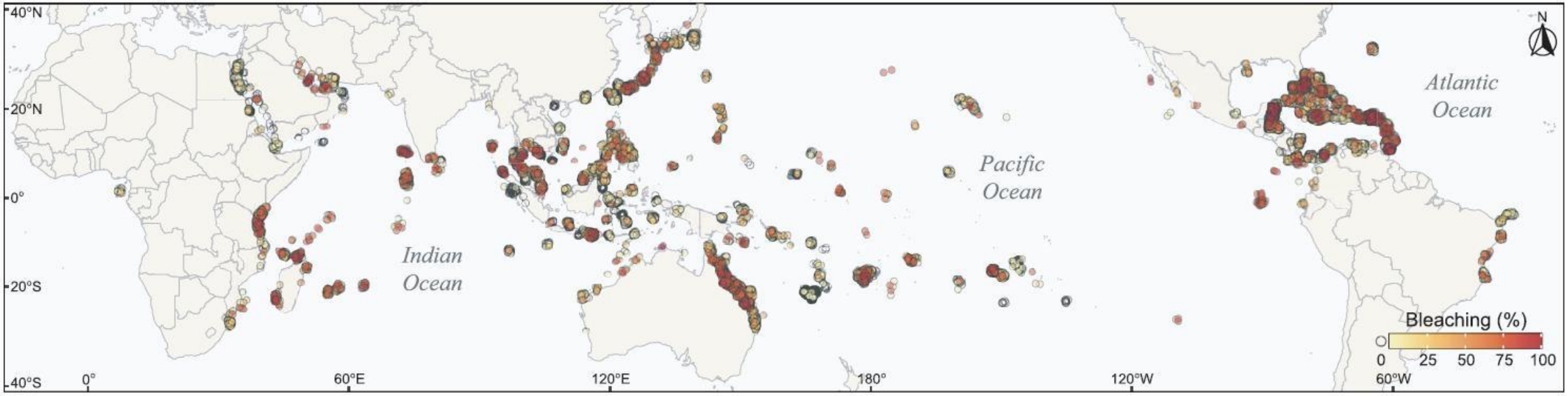
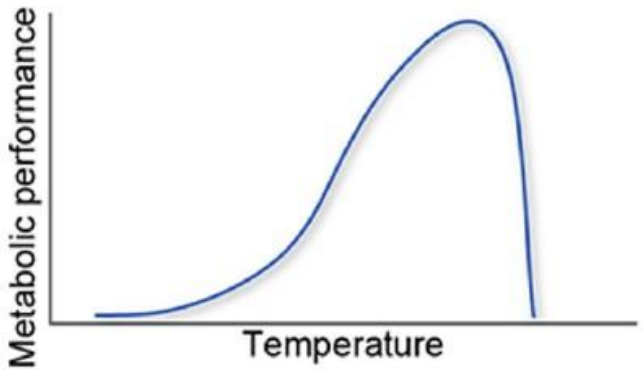
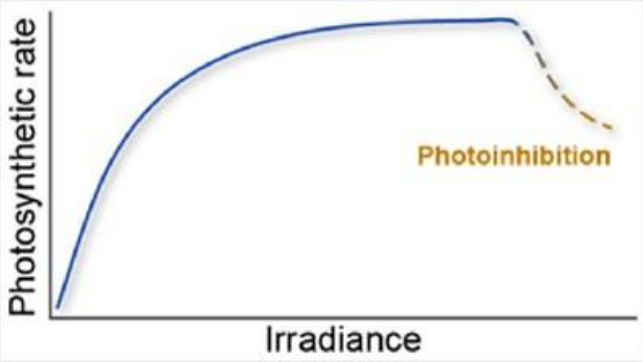
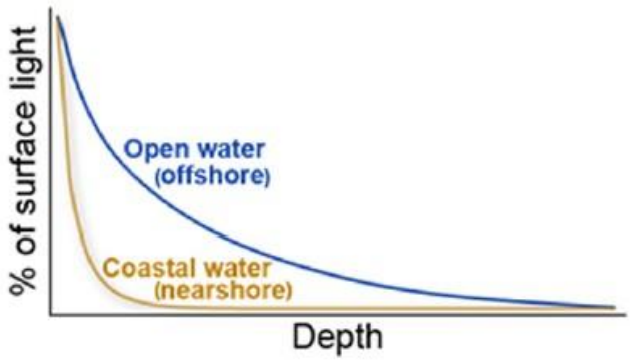


FIGURE 1 Global coral bleaching from 1980 to 2020. Coral bleaching was calculated as a percentage of the coral colonies that were bleached at the time of survey, from 11,068 sites in 89 countries ($n = 23,298$; data from van Woesik & Kratochwill, 2022)

TABLE 1 Conceptual summaries of general responses of coral holobionts to thermal stress and relevant environmental factors. Processes are described and several references are listed, where Temperature = °C, Irradiance = photosynthetically available radiation, Depth = m, Thermal stress = degree heating weeks (DHW; https://coralreefwatch.noaa.gov/product/5km/index_5km_dhw.php), and Exposure time = days. DHW is a measure of the accumulated bleaching heat stress during the most recent 12-week period. Coral bleaching tends to occur when DHW values reach 4°C-weeks, and at 8°C-weeks bleaching is generally widespread and followed by substantial mortality

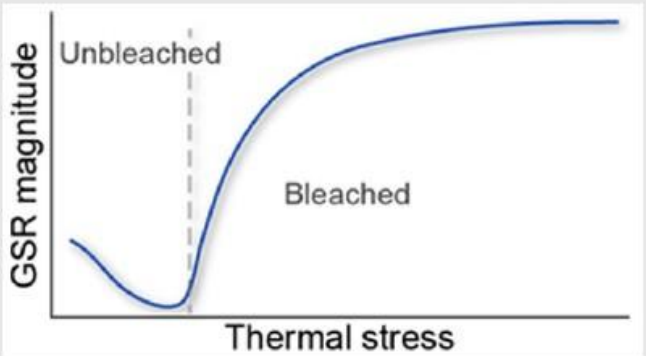
Process description	Response	References
Hypothetical thermal metabolic performance curve of corals, with the optimum close to the upper thermal limit. When corals are exposed to temperature above their optimum, it causes a decline in metabolic function		Pörtner (2012), Sinclair et al. (2016)
Photosynthetic rate increases with irradiance (light) availability up to a threshold, beyond which photoinhibition (a process whereby photosynthesis is impeded) occurs. Thermal stress can accelerate photoinhibition		Iglesias-Prieto et al. (1992), Warner et al. (1999), Takahashi and Murata (2008)

Light attenuates exponentially with depth. In turbid, nearshore reefs light attenuates more rapidly than in clear, offshore reefs. Since high light can exacerbate thermal stress, corals in low light conditions may suffer less bleaching



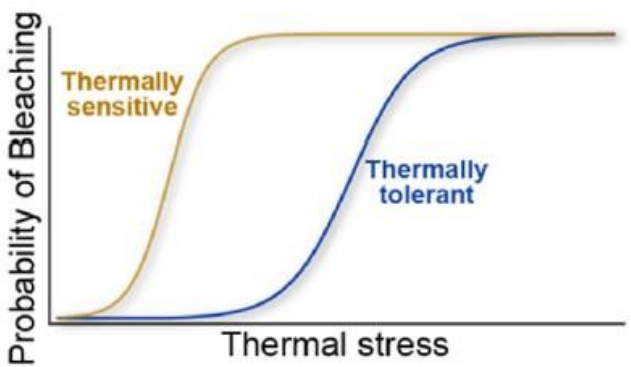
van Woesik et al. (2012), Morgan et al. (2017), Kahng et al. (2019)

Eigengene expression of the generalized stress response gene-network module. This generalized gene-expression response was similar under different stressors (in *Acropora* spp.) and illustrates the underlying response to thermal stress



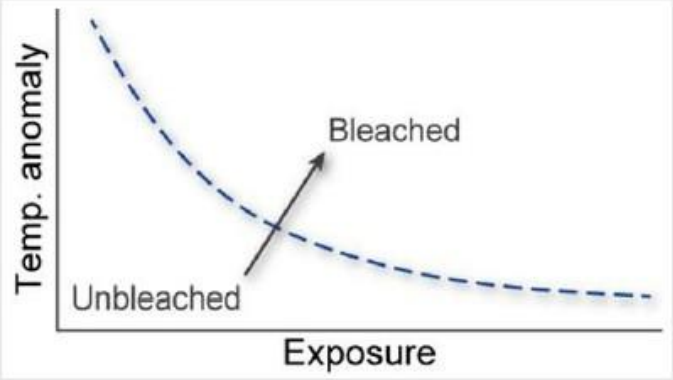
Rose et al. (2016), Wright et al. (2019), Dixon et al. (2020)

Corals bleach as the intensity of thermal stress increases. Some genotypes, species, and localities are more sensitive than others to thermal stress. How corals respond depends on the innate and adapted thermal tolerance of individuals and populations



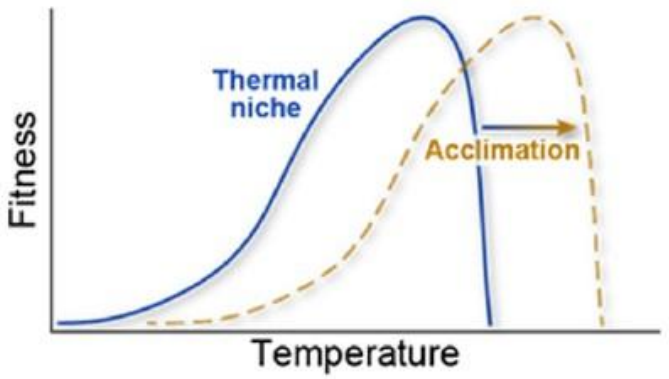
Glynn (1996), Hoegh-Guldberg (1999), Loya et al. (2001)

Coral bleaching is a function of cumulative exposure to thermal stress, which depends on duration, rate, and intensity of exposure. Coral mortality tends to increase as exposure increases



Berkelmans (2002), Berkelmans et al. (2004), Middlebrook et al. (2010)

Some coral genotypes and species adjust to thermal stress through acclimatization, adaptation, and epigenetics



Pörtner (2012), Matz et al. (2018), Jury and Toonen (2019), Liew et al. (2020)

Take-home-messages

1) Major drivers: **high seawater temperatures,** light intensity, nutrient concentrations, zooplankton availability, and water-flow rates
2) The most extensive coral bleaching has been recorded between latitudes 15° and 20°, north and south
3) There exist multiple mechanisms for coral bleaching

Next Lecture (Nov 9): Climate Zones and Global Ecosystems

Call for Photos from students

Quiz 3