Global Warming-Related Photo- Physiological Stress and Bleaching in Scleractinian Corals at the Lagoon of Belle Mare, Mauritius.

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Mauritius: some facts

- **Land area**: 1865 sq. km
- **EEZ**: 2.1 million sq. kilometres
- **Length of coastline**: 322 km
- **Coral reefs & lagoonal system**: 243 sq. km
- **Species of corals**: 159 species of scleractinian corals, with the largest number of species belonging to the *Acropora* followed by *Montipora*, *Porites* and *Pavona*. (Field guide to corals of Mauritius, 2002)

Our coral reefs:

- The coral reefs of Mauritius surround most of the island as fringing reefs (**150 km**) except with breaks on the Southern and Western coasts.
- The coastline of the island of Mauritius is a complex region comprising bays, estuaries and large semi-enclosed where human population, recreational activities and industrial development are concentrated.

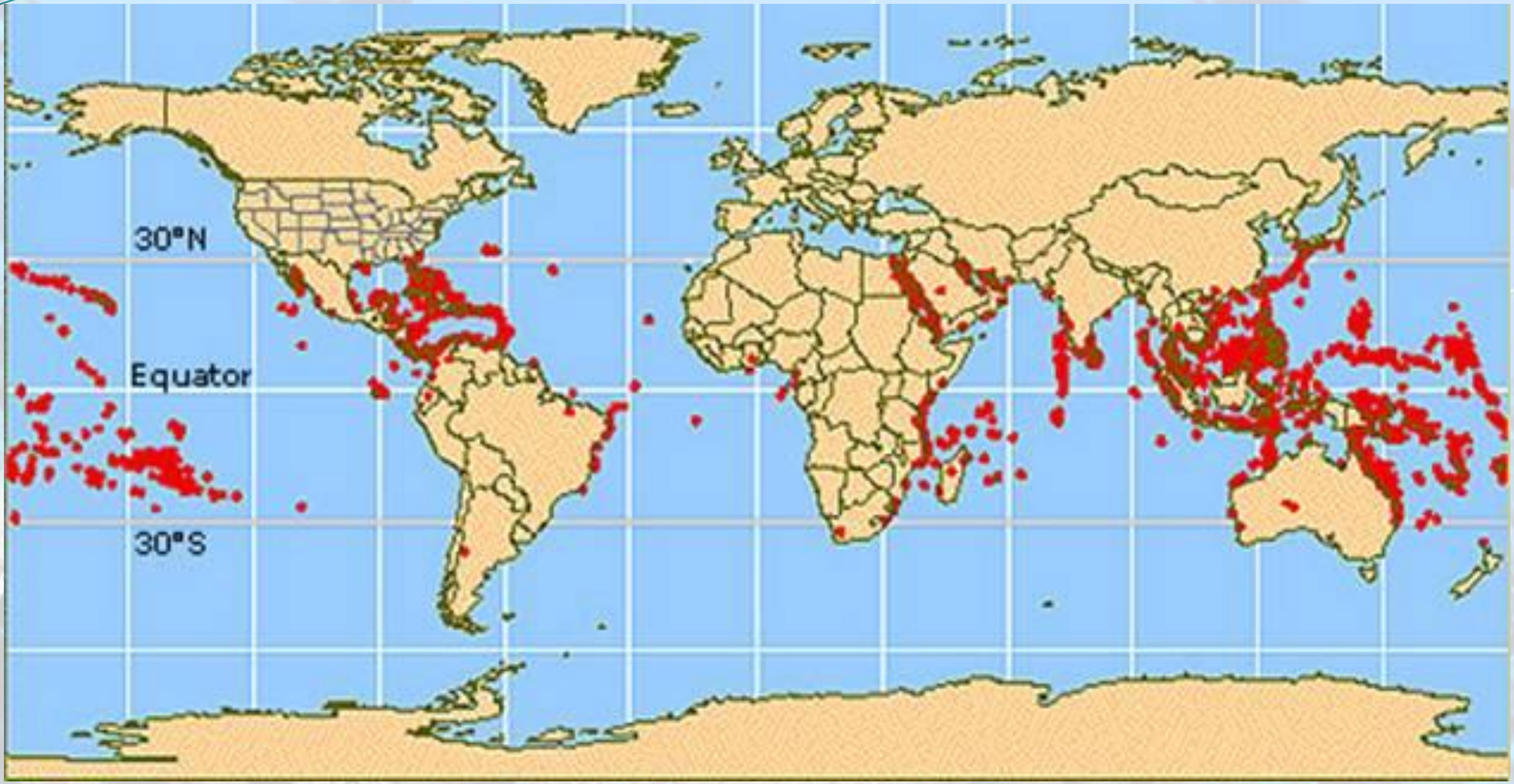
Coral reefs?

- Coral reefs are massive deposits of calcium carbonate, which are built over centuries by living polyps, corraline algae and sponges.

Brief facts:

- Coral reefs have been on the planet for over 400 million years.
- Corals are distributed widely in the oceans and seas within latitudes 32°N and 30°S extending from the Red Sea and East Africa through the Indo-pacific to the Caribbean and a few tropical Atlantic coasts.
- A coral reef is made up of thin layers of calcium carbonate (limestone) secreted over thousands of years by billions of tiny soft bodied animals called coral polyps.
- The largest coral reef is the Great Barrier Reef, which stretches along the northeast coast of Australia, from the northern tip of Queensland, to just north of Bundaberg. At 2,300km long, it is the largest natural feature on Earth.
- Coral reefs occupy less than one quarter of one percent of the Earth's marine environment, yet they are home to more than a quarter of all known fish species.

Coral reefs worldwide:



Corals are distributed widely in the oceans and seas within latitudes 32°N and 30°S extending from the Red Sea and East Africa through the Indo-pacific to the Caribbean and a few tropical Atlantic coasts. They are absent on the Pacific coast of South America where the cold Humboldt current flows and along the Atlantic coast of Africa due to the Benguela current from the Antarctic.

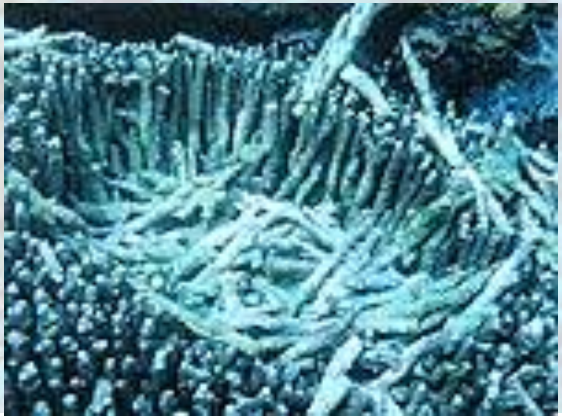
Why are our coral reefs important?

- Coral reefs are the world's most diverse marine ecosystems and are home to twenty-five percent of known marine species, including 4,000 species of fish, 700 species of coral and thousands of other plants and animals. Coral reefs are referred to as the "rainforests" of the ocean.
- Provide carbonate sediments that contribute to substrate and beaches
- They act as "living breakwaters" that protect our shoreline from storms and erosion.
- Act as net sinks for carbon in the form of calcium carbonate
- Supports the tourism industry
- Provide sources of food
- Provide opportunities for education and research
- Has enormous potential the pharmacautical and cosmetics industry.

Threats to coral reefs

- Global warming, associated increase in sea surface temperatures and coral bleaching
- Point source and non-point source pollution:
    - terrestrial run-off
    - nutrient enrichment
    - Increased turbidity
    - Sedimentation
    - Treated/ partially treated liquid waste disposal in sea
- Over-exploitation and physical destruction:
    - unsustainable fishing practices,
    - irresponsible anchor usage,
    - undersea walk, diving and snorkelling activities
- Sea level rise
- Ocean acidification
- Predicted increase in severe tropical storms
- *A natural enemy: Acanthaster planci "Crown of Thorns" starfish*

CORAL DAMAGE



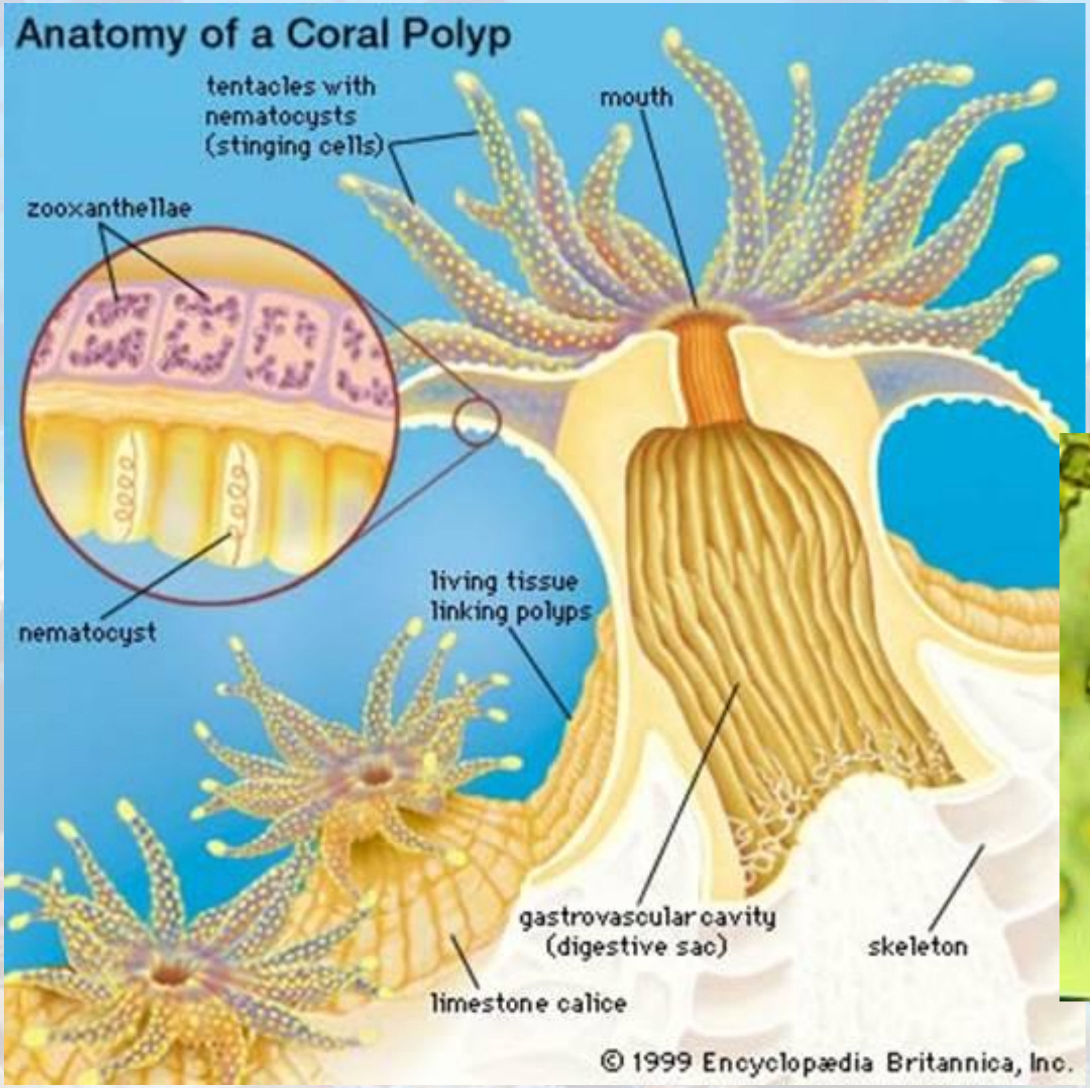
Corals: a symbiotic relationship

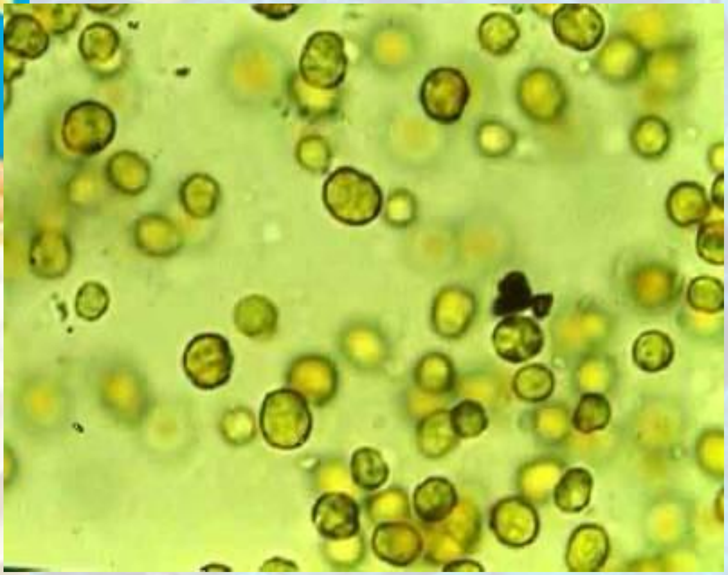
- Reef corals are made of tiny animals called polyps (Phylum Cnidaria). The size of the polyp is highly variable from 1 mm in diameter in some species to more than 20 mm in others. The polyp is sedentary in habit and more or less cylindrical in shape.

- The coral polyps live in a symbiotic relationship with unicellular algal cells called zooxanthellae (Genus Gymnodinium, *Symbiodinium sp*.). The zooxanthellae are unicellular yellowish brown algae, spherical in shape, which live symbiotically in the gastrodermis of reef-building corals (Goreau et al., 1959). They vary in diameter from 5-15 µm.

- The very existence of the reef habitat is dependent on the metabolic activities of the coral symbiosis, including photosynthesis, mineral recycling and, above all, enhancement of the synthesis of the corals calcareous skeleton (Smith and Douglas, 1987).

Corals: a symbiotic relationship cont'd





Corals: a symbiotic relationship cont'd

- Together, the they function as important primary producers in reef communities, with a productivity of 1500 – 3500 g $cm^{-2}yr^{-1}$ (Muscatine, 1973).

- The very existence of the reef habitat is dependent on the metabolic activities of the coral symbionts 'zooxanthellae', including photosynthesis, mineral recycling, and above all, enhancement of the synthesis of the corals calcareous skeleton (Smith and Douglas, 1987).

- Zooxanthellae being autotrophic are capable of manufacturing their own food by photosyntheis and sharing it with the host from which they derive not only protection but also a source of inorganic nutrients required for the synthesis of carbohydrates and proteins (Muscatine, 1973; Johannes, 1974).

- Because of the need for light, corals containing zooxanthellae only live in ocean waters less than 100 meters deep (Goreau et al., 1959). They also live in waters above 20 degrees Celsius and are intolerant of low salinity, high salinity exceeding 40‰ and high turbidity (Goreau at al., 1959).

What is coral bleaching?

- Coral bleaching events have been increasing in frequency and extent world-wide in the past 20 years.

- Worldwide coral reef bleaching, also known as whitening of coral reefs, originally referred to as the loss of pigments by corals (*Younge & Nichols, 1931*), is characterized by the loss of symbiotic algae and/or loss of photosynthetic algal pigment (*Kleppel et al. 1989*).

- This bleaching is triggered by environmental stress factors such as predicted increases in sea surface temperature due to climate change , high irradiance and the degradation of coral reefs from anthropogenic pollution and ocean acidification (which may also decrease the ability of corals to produce calcium carbonate (chalk).

Coral bleaching (cont'd)

- Devastating effects of coral bleaching include:
  - reduced skeletal growth
  - Reduced reproductive activity
  - Lowered capacity to shed sediments
  - Lowered capacity to resist invasion of competing species and diseases (Bhagooli, 2001).

- Severe and prolonged bleaching can cause partial to total colony death resulting in diminished reef growth, the transformation of reef-building communities to alternate, non-reef-building community types, bioerosion and ultimately the disappearance of reef structures (Brown & Ogden 1993, Buddemeier & Fautin 1993, Goreau & Hayes, Glynn 1996).

This Study:

- Aim: to investigate the effects of increasing temperature of seawater on the natural bleaching event of some hard corals in our lagoon.
- Study site: lagoon of Belle Mare, on the east coast of Mauritius

Objectives of study:

- To investigate bleaching and mortality responses of different species of hard corals in Belle Mare lagoon.
- To compare the PSII functioning of the microalgal symbionts (zooxanthellae) in 8 different coral species with differential bleaching susceptibilities:
  - non- bleached (
  - partially-bleached and
  - bleached.

Coral bleaching (cont'd)

- These stresses are believed to manifest through the impairment of the CO_2 fixation mechanism and the breakdown of the photosynthetic machinery (photosystem II, PSII) *via the accumulation of oxidative stress at PS II and the degradation of the D1 reaction centre protein in the* symbionts.

- Generally, photodamaged PSII is rapidly and efficiently repaired through the replacement of photodamaged proteins with newly synthesised proteins.

- Thus, photoinhibition occurs only when the rate of photodamage to PSII exceeds the rate of its repair. A moderate increase in temperature accelerates photoinhibition, primarily through inhibition of the repair process (Baird *et al*, 2008)

Coral bleaching (cont'd)

- Photoinhibition might be classified as **dynamic or chronic** based on the recovery time:
  - **Dynamic photoinhibition** describes reversible phtoprotection process which divert excess excitation energy away from the PSII reaction centre; while
  - **chronic photoinhibition** involves irreversible photodamage to PSII, so that *de novo* synthesis of primary reaction centres is required before normal phtoocjemistry may resume (Karuse 1988; Owens 1994; Demmig-Adams & Adams 1996, young and Frank 1996)

- Recent experimental evidence (Baird *et al*., 2008) has demonstrated that photodamage to PSII occurs in two steps:
  - **Primary damage**: occurs in the oxygen-evolving complex of PSII caused by ultraviolet radiation (UV) and strong blue light (and less effectively by other visible light), whereas
  - **Secondary damage :** is caused by light absorbed by photosynthetic pigments in the reaction centre of PSII.

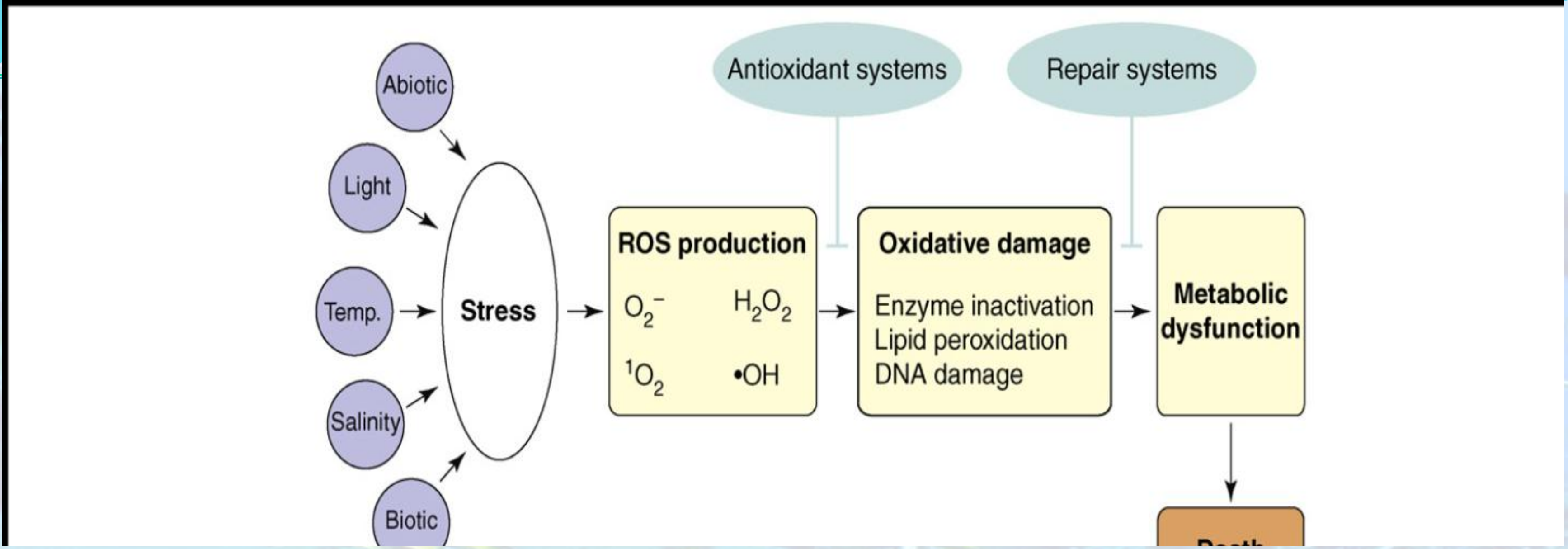


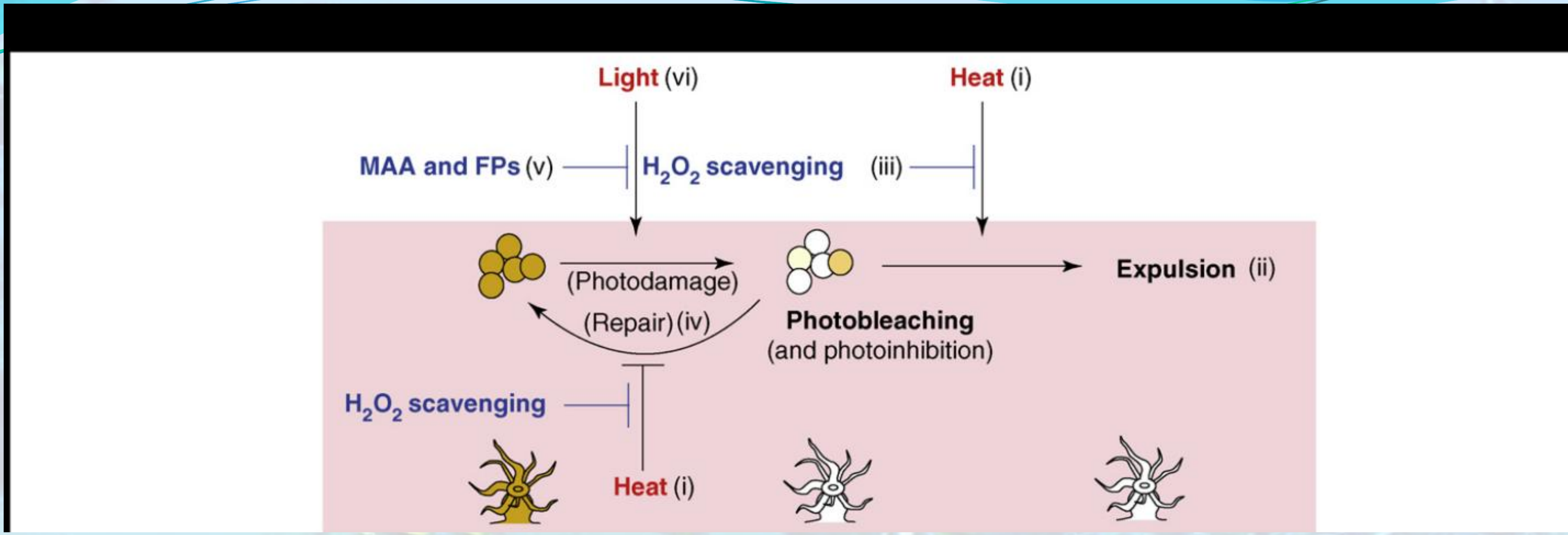
Figure is a generalised sequence of stress. In most stress responses, the production of reactive oxygen species (ROS), Superoxide, in cells is a common early event. Hydrogen peroxide (H2O2), which is the only diffusive ROS molecule, is produced secondarily.

In animal cells, ROS production is associated with the mitochondria; in photosynthetic organisms, it is also associated with the chloroplasts.

Potentially toxic ROS are removed by antioxidant systems, which include enzymatic antioxidants such as superoxide dismutase and catalase, ascorbic acid, carotenoids, Fluorescent Proteins (FPs) and mycosporine glycine. As long as these scavenging mechanisms are functional, ROS will not accumulate.

Under severe stress, however, these antioxidant systems might not be able to destroy all ROS produced, in which case oxidative damage will occur, leading to metabolic dysfunction, cell destruction or mutation.

In addition to antioxidant systems, there are repair systems to remove damaged molecules and to replace them with new ones. In this context, antioxidant systems function as the primary line of defence and the repair systems act as a secondary line of defence against oxidative stress. If these mechanisms cannot limit or suppress stress damage, living organisms will eventually die.



In corals, moderate heat (i) accelerates the production of hydrogen peroxide (H_2O_2) in the chloroplasts of the algal symbionts either by damaging the thylakoid membrane or disrupting the Calvin cycle.

H_2O_2 can spread from here to the host cell, where it activates a cellular cascade akin to an innate immune response, which results in expulsion of symbionts (ii).

The potential to scavenge H_2O_2 (iii) varies among host species and, therefore, might influence difference in susceptibility to coral bleaching. In addition, H_2O_2 inhibits the repair of photodamage in PSII (iv), causing an acceleration of photoinhibition and photobleaching of pigments in symbionts .

Finally, some coral hosts can intercept UV light by accumulating UV-absorbing compounds, such as MAAs and FPs, thereby limiting photodamage to PSII and preventing light-dependent coral bleaching (vi).

Methodology used

- A preliminary survey was carried out by snorkelling in the lagoon to assess the percentage of bleaching taking place.
- Temperature and other physical parameters (pH, DO, salinity) were recorded from October 2008 till May 2009
- The corals were sampled on a monthly basis and kept in sealed plastic bags in seawater and kept in the dark for a minimum of 4 hours.
- Coral bleaching and recent mortality was quantified in the lab using the Pulse Amplitude Modulated (PAM) fluorometer, with special focus on eight coral species: Acropora cytherea, A. hyacynthus, A. formosa, A. sp., Pocillopora damicornis, P. eydouxi, Galaxea fascicularis and Fungia sp.
- **Chlorophyll a** fluorescence ratio, Fv/Fm, was recorded (Kraus & Weis, 1991) in the partially bleached (PB), pale (P), bleached (B) and non-bleached (NB) corals for the 8 species under study.

Sampled coral species: A. Tabular *Acropora*; B. *Pocillopora damicornis*; C. *Fungia* sp.; D. *Galaxea fasicularis*

Methodology (cont'd)

Figure 2.0: Pulse-Amplitude-Modulated (PAM) fluorometer

- Chlorophyll a fluorescence was measured with a PAM fluorometer.
- The initial fluorescence (Fo) was measured by applying pulses of weak red light (< 1 µmol quante m-2 s-1) and a saturating pulse (8000 µmol quanta m-2 s-1, 0.8-s duration) was applied to determine the maximal fluorescence (Fm).
- The change in fluorescence (Fv) caused by the saturating pulse , in relation to the mximal fluorescence yield(fm), has been shown to be a good measure of maximum quantum yield (Genty et al, 1989).
- Thus, the ratio of the change in fluorescence (Fv= Fm-Fo) caused by the saturating pulse to the maximal fluorescence (Fm) in a dark-adapted sample is equal to maximum quantum yield of PSII.
- In the present study, all coral samples were dark-adapted for about 6 hours before measurement of Fv/Fm

PS II functioning v/s temperature

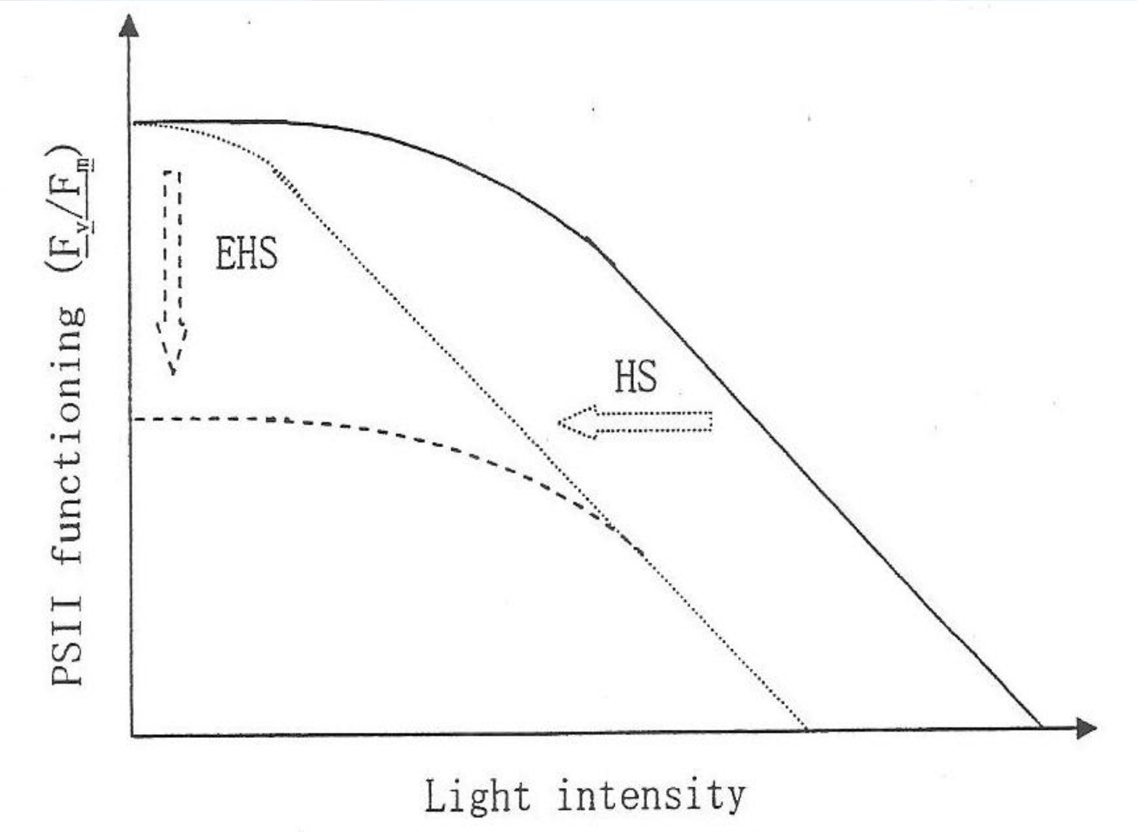
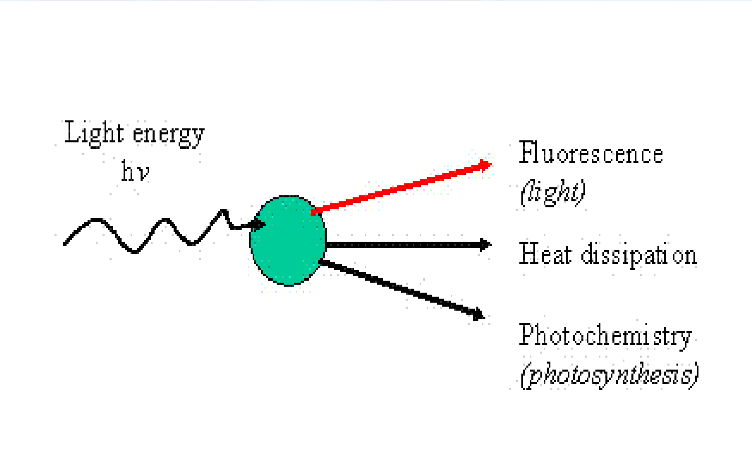
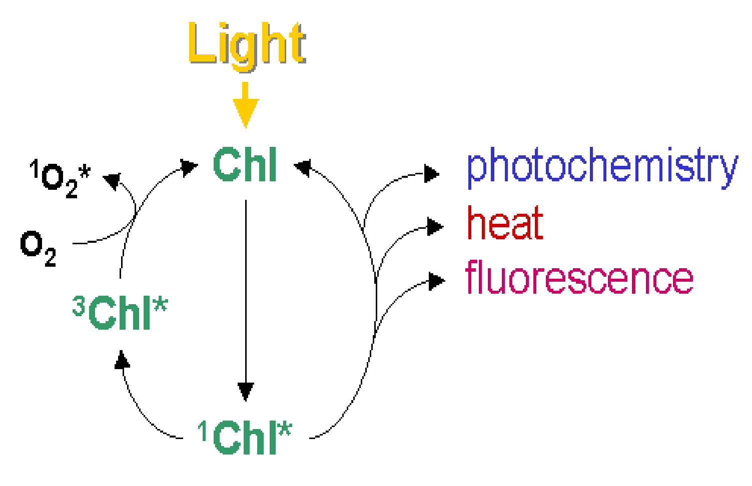
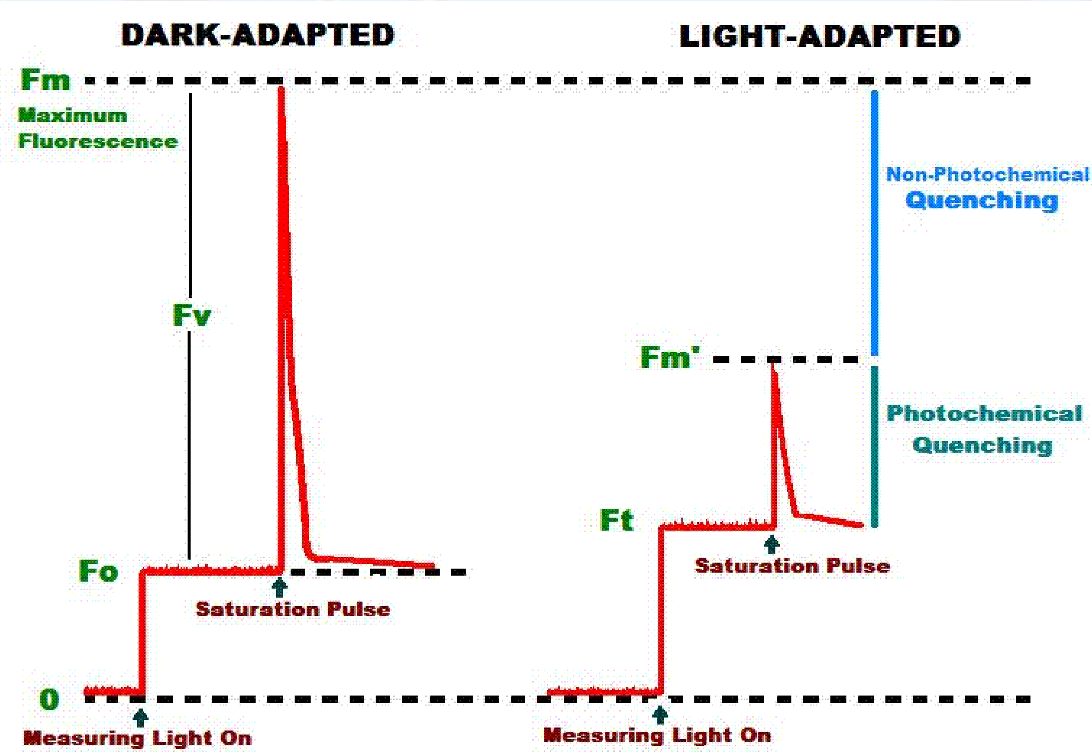


Figure: shows a theoretical model for effect of heat stress on photoinhibitory light levels. HS = heat stress; EHS = excessive heat stress. The curves illustrate PSII functioning in relation to light intensities at normal temperature (solid line), high temperature (dotted line) and excessively high temperaute (dashed line), respectively.

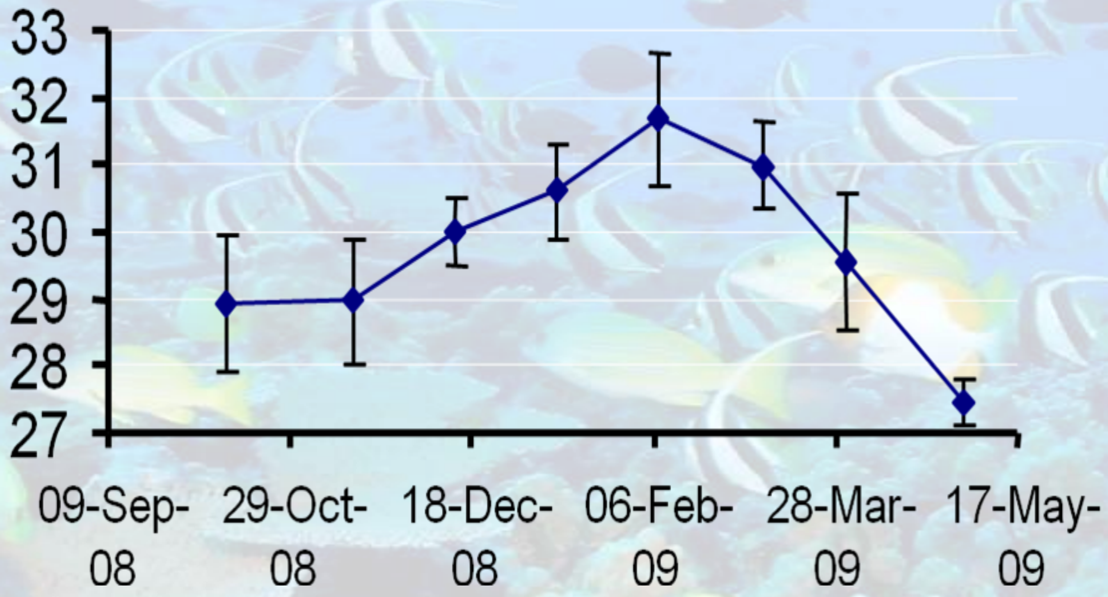
Chlorophyll *a* fluorescence





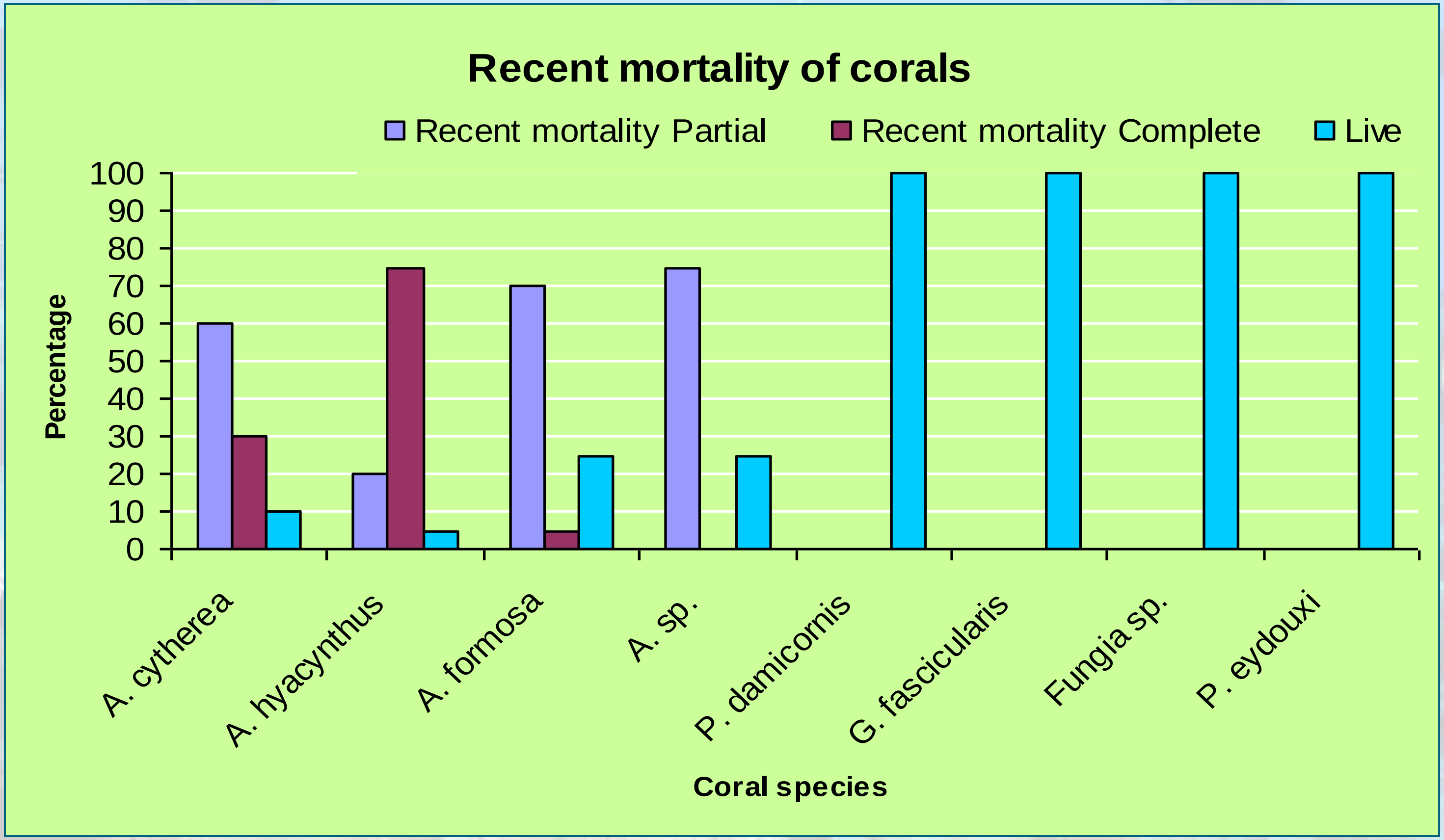


Results:



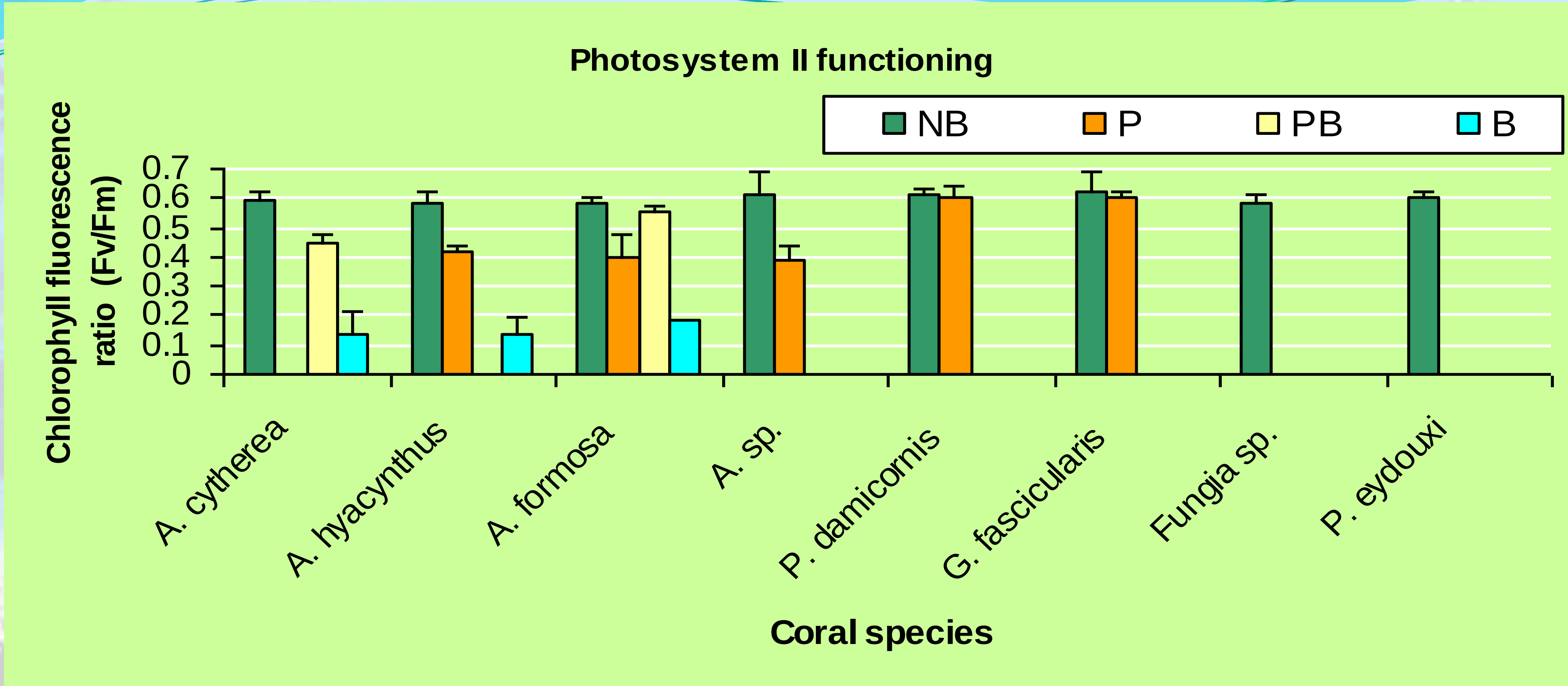
There has been a warming trend with highest seawater temperatures recorded above 31 ºC in February 2009 (Fig. 3)

Results:



Observations (Fig. 4) indicate highest complete mortality in *A. hyacynthus* and highest partial mortality in *A. cytherea*, *A. formosa* and *A. Sp.*, whilst relatively no mortality was observed in *P. damicornis*, *G. fascicularis*, *Fungia sp*. and *P. eydouxi.*

Results:



Chlorophyll fluorescence *ratio* was highest (*Fv/Fm =0.6)* in non-bleached colonies in the eight species under study and lowest (*Fv/Fm <0.2)* in bleached colonies of *A. cytherea, A. hyacynthus* and *A. formosa*, indicating direct relationship between chlorophyll fluorescence and bleaching (Fig. 6).

There was no significant difference in Fv/Fm in pale and non-bleached colonies of *P. damicornis* and *G. fascicularis*, whilst pale colonies in *A. hyacynthus*, *A. formosa* and *A. sp*. showed an Fv/Fm ≤ 0.4. No bleaching was recorded in *Fungia sp.* and *P. eydouxi*.

Results

- The above results suggest that the tabular corals, *A. cytherea* and *A. hyacynthus* are the thermally most vulnerable while *P. damicornis*, *P. eydouxi*, *G. fascicularis* and *Fungia* sp. are among the most tolerant coral species in the Belle Mare lagoon.

Conclusion:

1. There are variable responses among the 8 studied coral species. The order of susceptibility/ mortality is as follows:

Tabular Acropora > Branching Acropora > Massive-like Corals / Solitary Corals

2. In susceptible corals (tabular and branching Acropora), zooxanthellae had the lowest Fv/Fm indicating damage to their photosynthetic machinery. However, zooxanthellae of pale corals of P. damicornis and G. fascicularis had normal Fv/Fm indicating non-selective release of zooxanthellae with respect to their PSII functioning.

Outcome and future works:

- Projected increases in SST caused by global warming have led some authorities to predict that reefs might disappear entirely within 20–50 years

- However, this prediction is based largely on the assumption that corals will not be able to adapt to accelerating rates of environmental change.

- Baird *et al*, 2008, predicts that the fate of corals in response to climate change requires both members of the symbiosis to be considered equally

- Baird et al. (2008) highlighted that an understanding of the threat climate change poses to reef corals will remain incomplete unless both members of the symbiosis holobiont (the animal and symbiont in combination) are considered equally.

- To effectively address the issue of rates of adaptation in corals, and whether or not they will be exceeded by rates of environmental change, long-term demographic studies are also required to detect temporal trends in life-history traits and to explore the sensitivity of population growth to these changes and to predict how climatei - induced changes in coral demography will influence the future of coral reefs.

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Thank you for your attention