
# Coral Reef challenges
# &
# Objectives of the 'Future Maore Reefs' project

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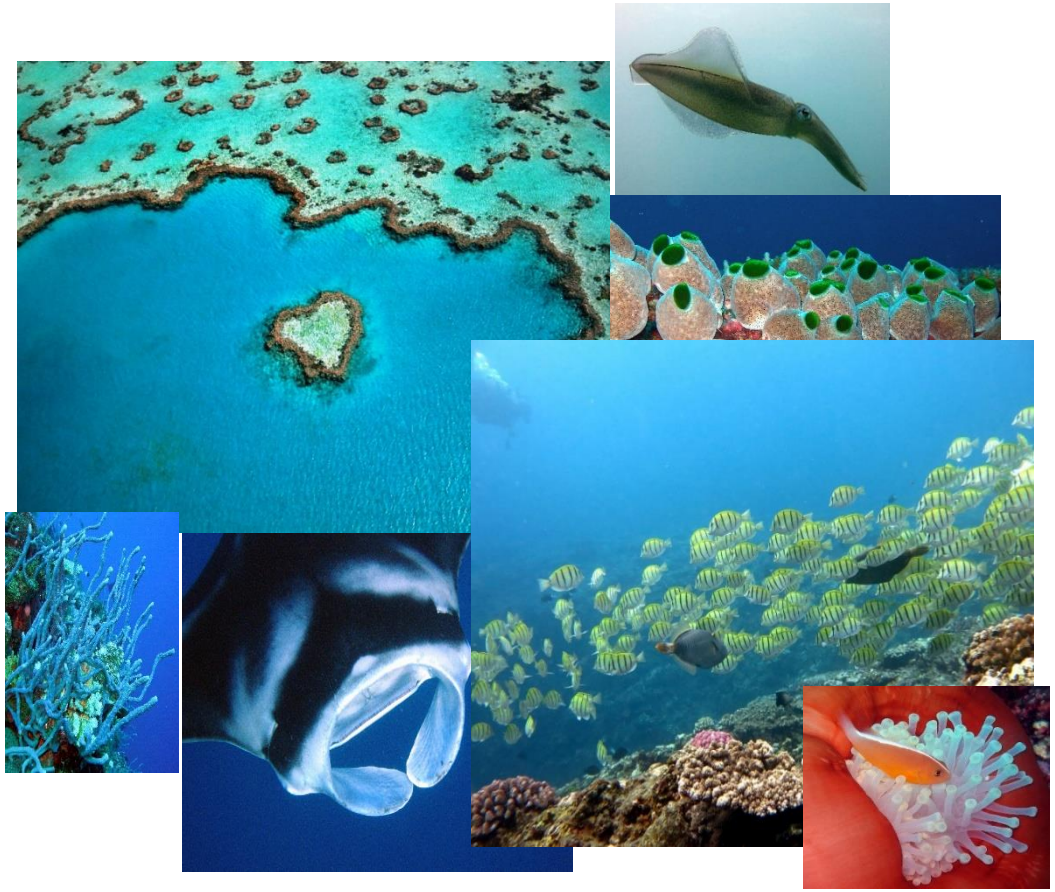
*UMR IPSL-LOCEAN*

**'Ecole d'été Future Maore Reefs'**
**25/09-01/10/2023, Mayotte**

# IMPORTANT ECOSYSTEMS



## Oasis of life!

- < 0,2% world ocean surface

- Hot spots of biodiversity
  **¼ marine biodiversity**

- **Natural barriers** (protection against storms, erosion…)

- **1/15 world population depends on reef systems**

- **>170 Md $US/year**

- **Carbon cycle**

- Biomolecules source

# IMPORTANT ECOSYSTEMS



**Coral reefs :**

**80% sand + ~ 20% hard substrates**

**~20% living corals worldwide (since 1998)**

# IMPORTANT ECOSYSTEMS

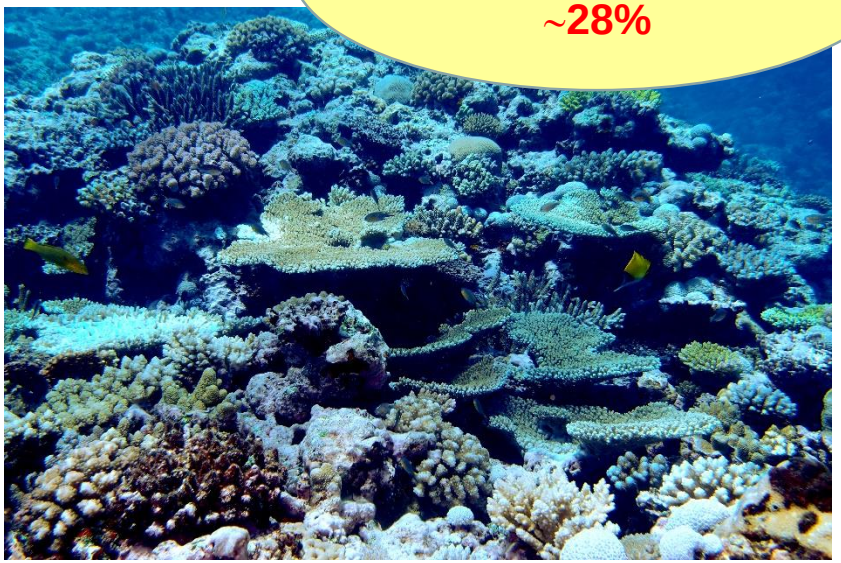


## Coral reefs :

**80% sand + ~ 20% hard substrates**

**~20% living corals worldwide (since 1998)**

Mozambique
Channel coral cover
**~28%**

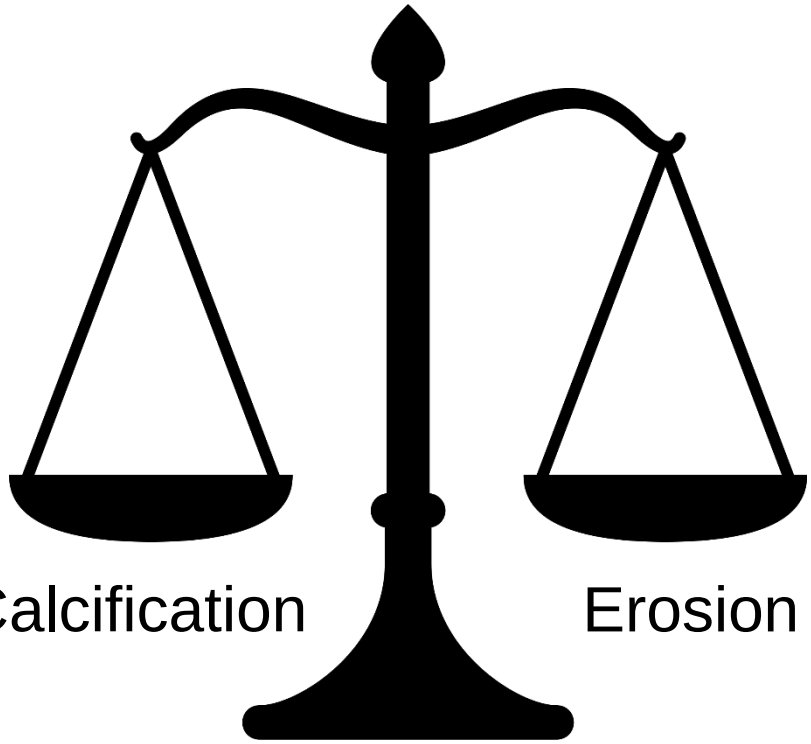


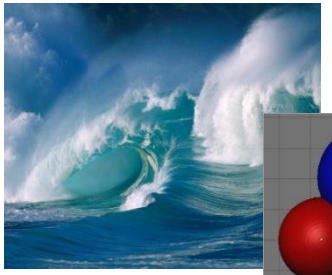
*Souter et al. (2020) Status of coral reefs of the world*

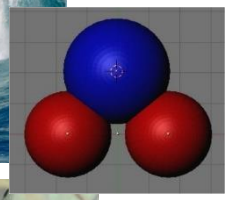
# A DELICATE BALANCE

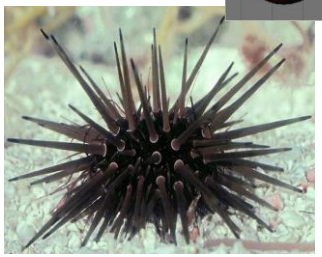


**Reef maintenance** = balanced carbonate budget

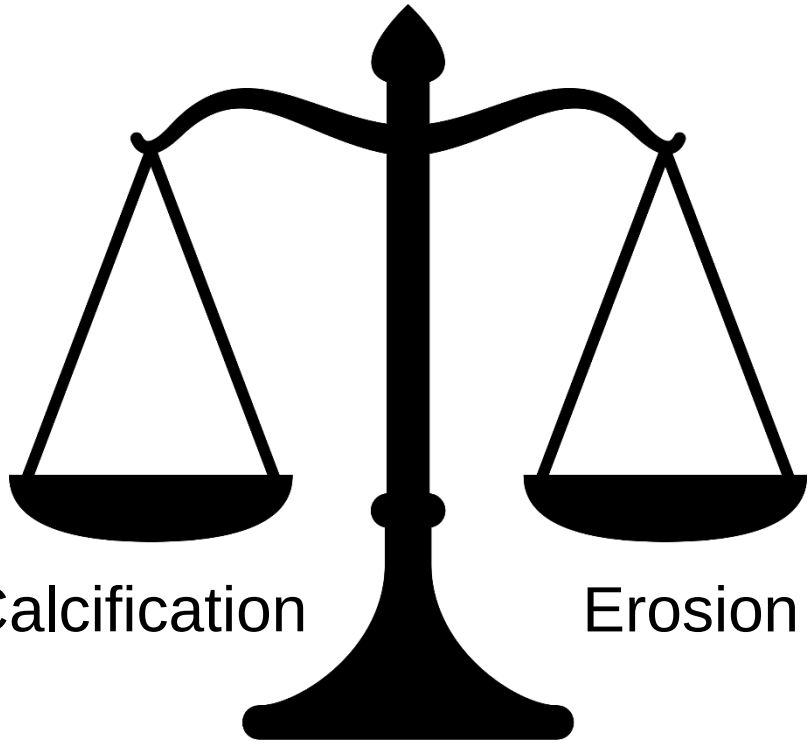




# A DELICATE BALANCE

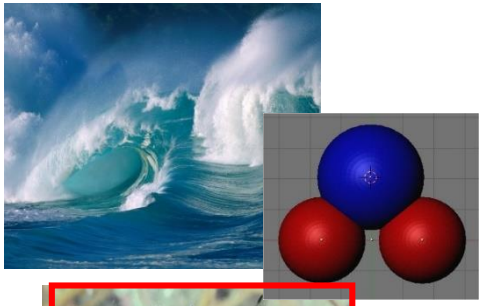
**Reef maintenance** = balanced carbonate budget

Coral growth

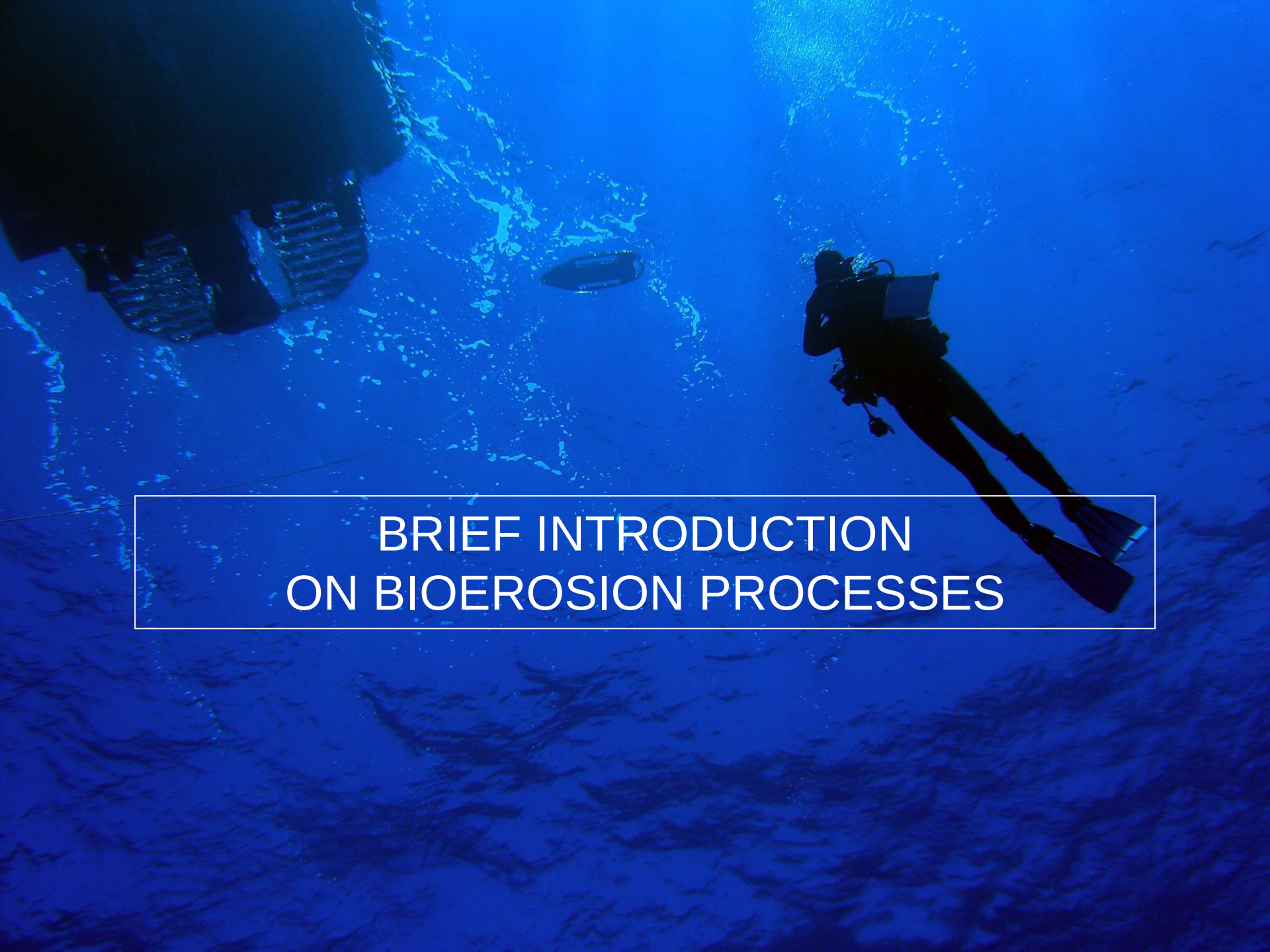
Calcification

Erosion



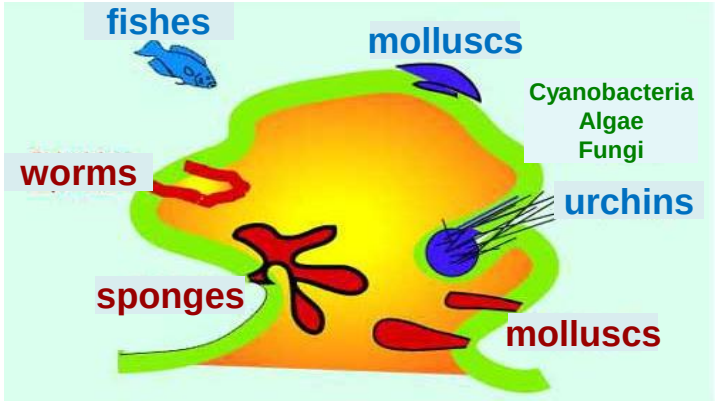
Bioerosion

*Scoffin et al. (1980); Glynn (1997); Tribollet et al. (2011); Schönberg et al. (2017)*



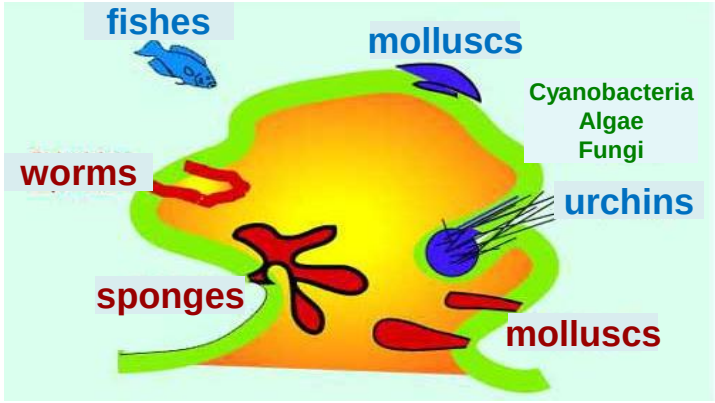
# BRIEF INTRODUCTION ON BIOEROSION PROCESSES

# BIOEROSION AGENTS & PROCESSES


*Hutchings (1986); Tribollet (2008); Tribollet et al. (2011); Schönberg et al. (2017)*

# BIOEROSION AGENTS & PROCESSES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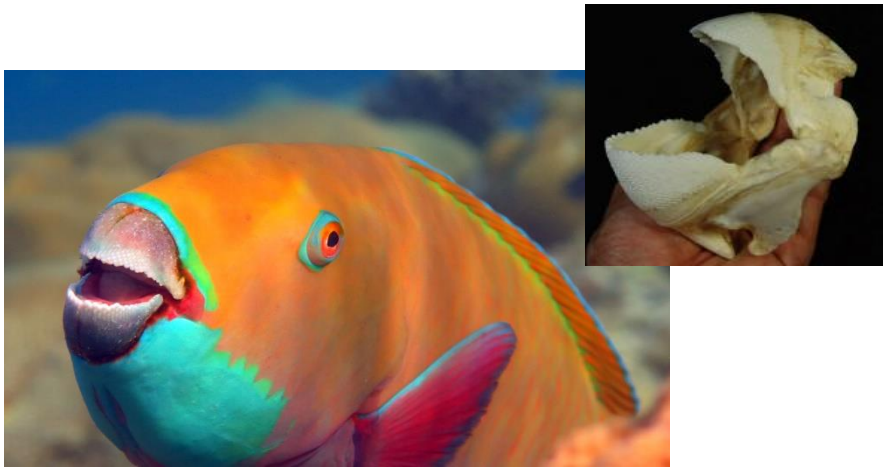
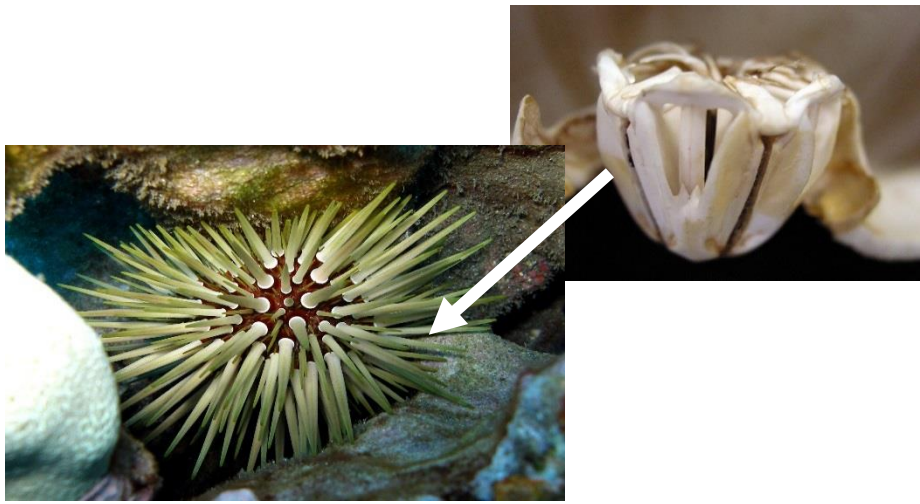
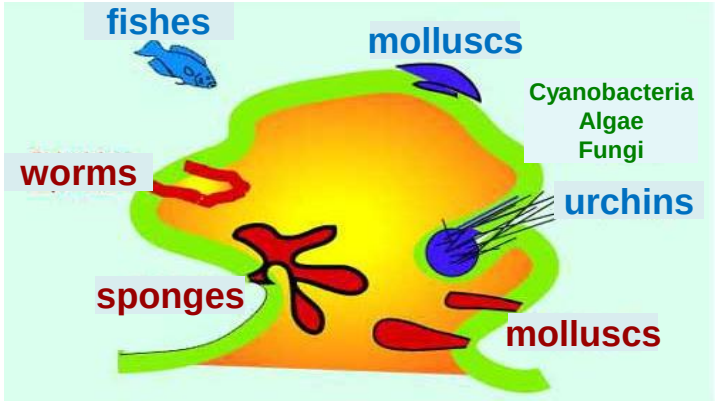
## GRAZERS : Mechanical process





# BIOEROSION AGENTS & PROCESSES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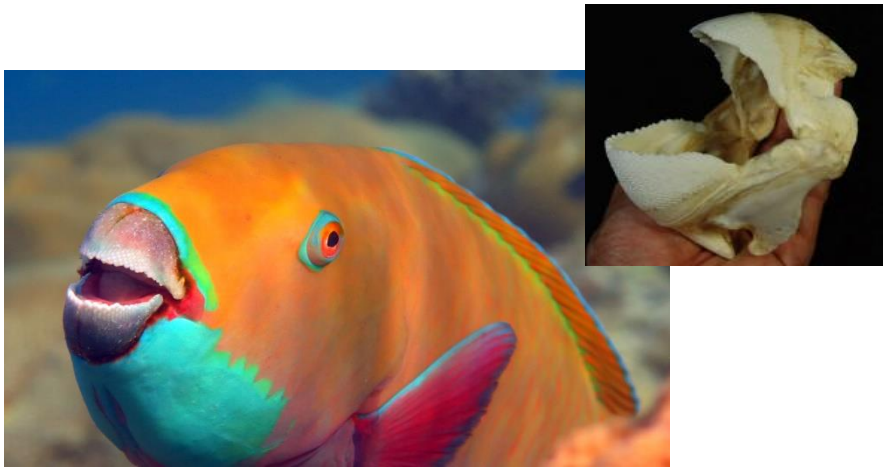
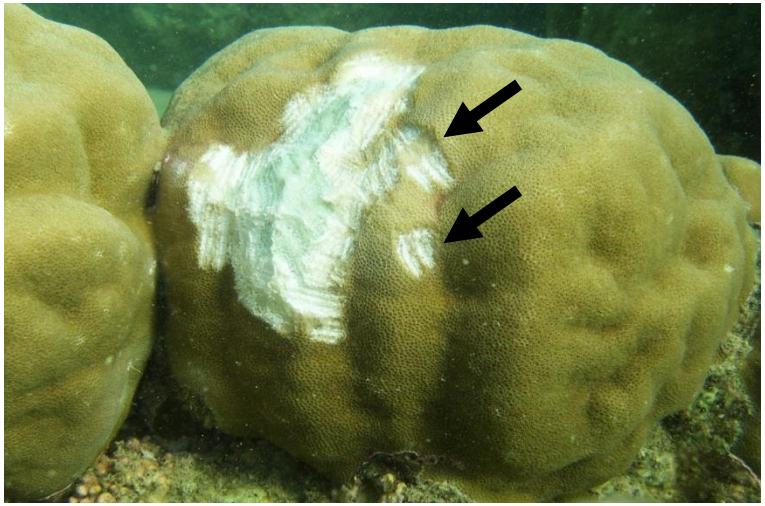
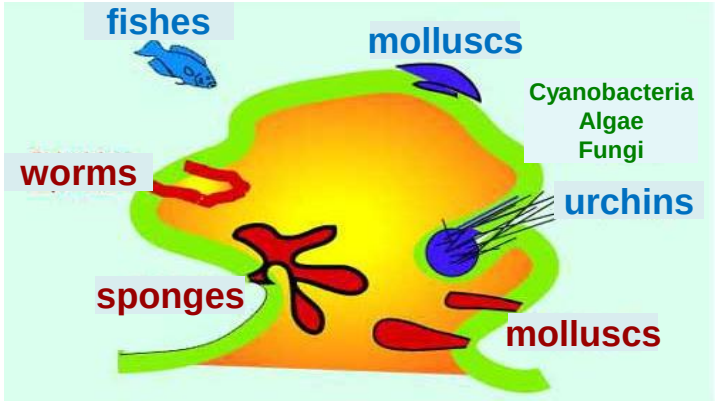
## GRAZERS : Mechanical process





Grazing rate : a few kg of $CaCO_3$ up to more than 20 kg $m^{-2}$ $y^{-1}$

# BIOEROSION AGENTS & PROCESSES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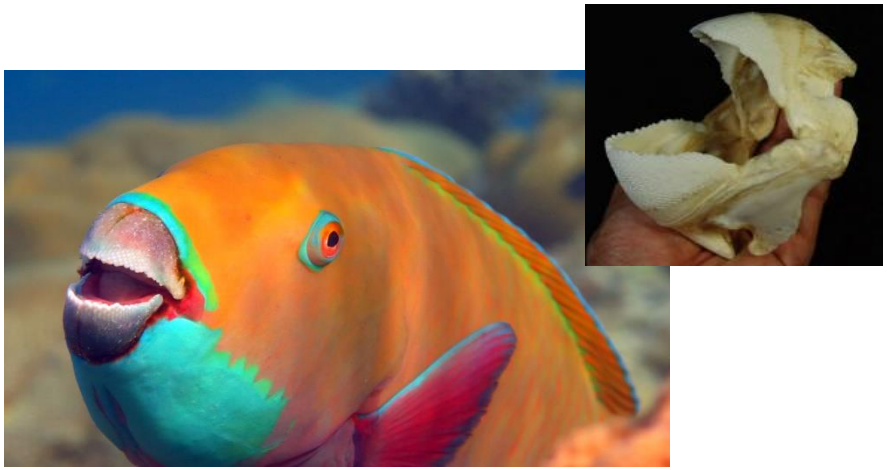
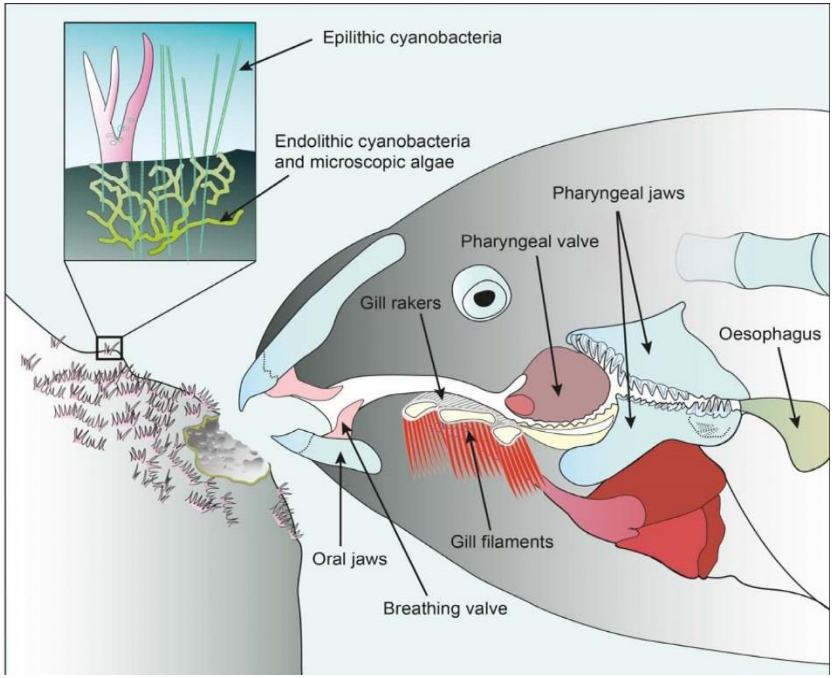
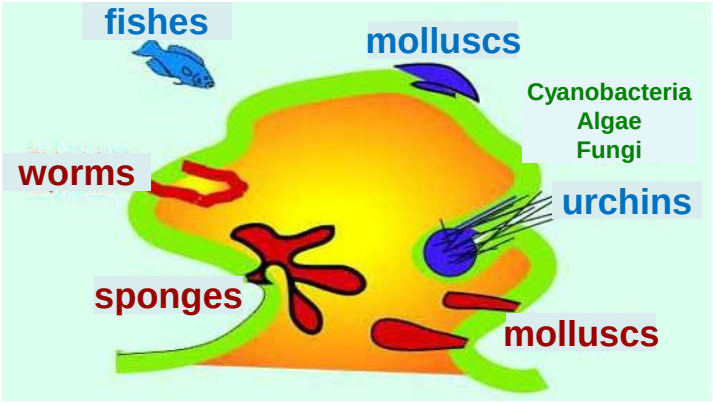




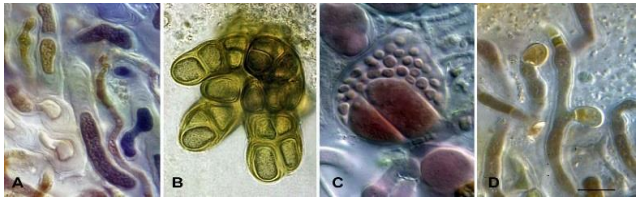

*Tribollet & Golubic (2005) Coral Reefs; Clements et al. (2017) Biol. J. Linnean Soc.*

# BIOEROSION AGENTS & PROCESSES

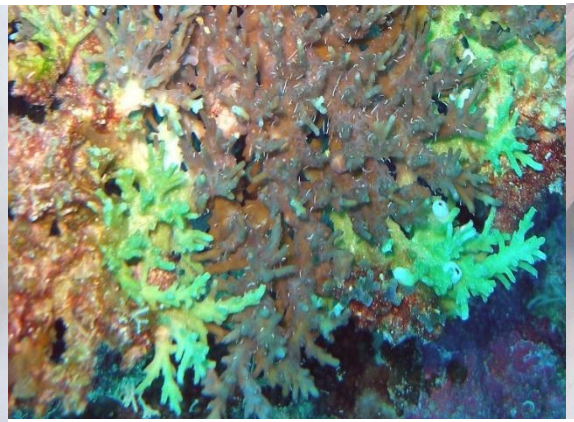



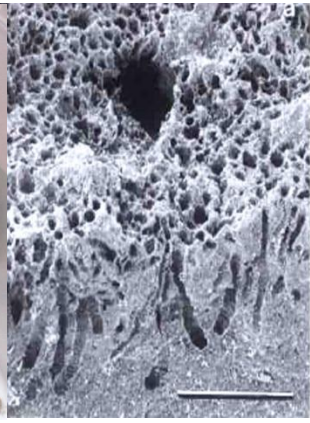

*Hutchings (1986); Tribollet (2008); Tribollet et al. (2011); Schönberg et al. (2017)*

## MICROBORERS : Dissolution process



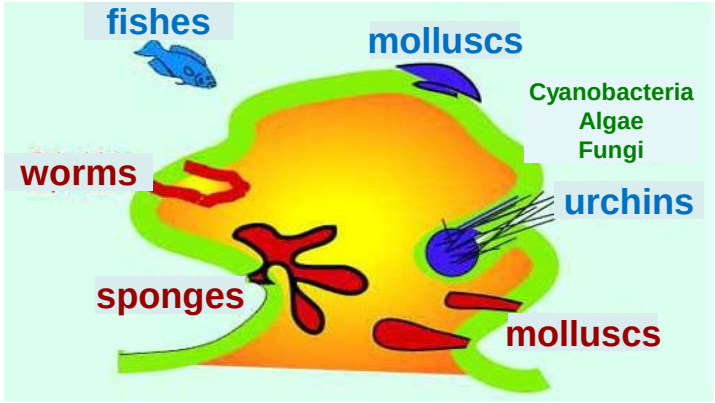




*Golubic et al. (1981); Le Campion-Alsumard et al. (1995); Grange et al. (2015); Tribollet et al. (2019); Alaguarda et al. (2023)*

# BIOEROSION AGENTS & PROCESSES


*Hutchings (1986); Tribollet (2008); Tribollet et al. (2011); Schönberg et al. (2017)*

**MICROBORERS +** **Grazers**

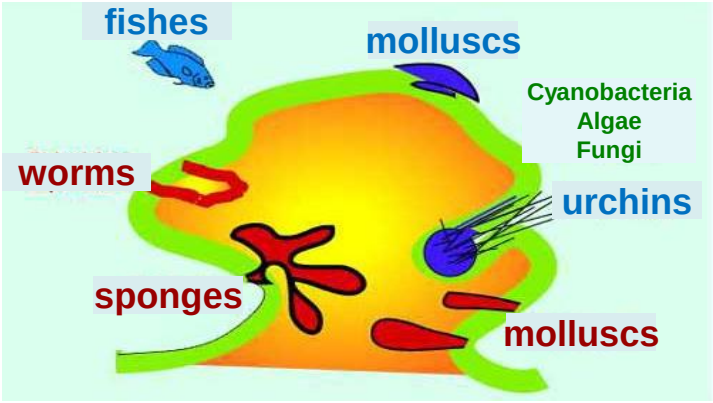
**Biokarst formation**
**Sediment production**
**Primary production**
**Recycling $CaCO_3$**

**(Dissolution rate : 0.05 – 1.1 kg $m^{-2}$ $y^{-1}$)**

*Tribollet et al. (2006); Perry & Hepburn (2008); Tribollet et al. (2011) ; Perry et al. (2015); Tribollet et al. (2019)*

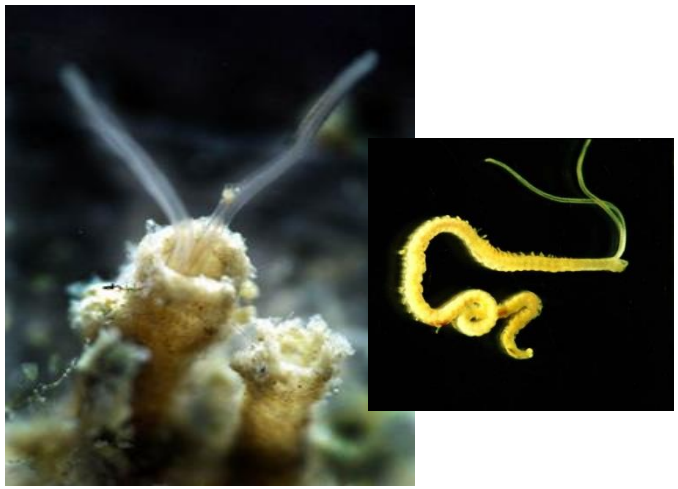
# BIOEROSION AGENTS & PROCESSES




*Hutchings (1986); Tribollet (2008); Tribollet et al. (2011); Schönberg et al. (2017)*

## MACROBORERS: Mechanical and/or chemical processes



**<u>Macrobioerosion rate</u>: < 1 kg $CaCO_3$ bioeroded $m^{-2}$ $y^{-1}$**

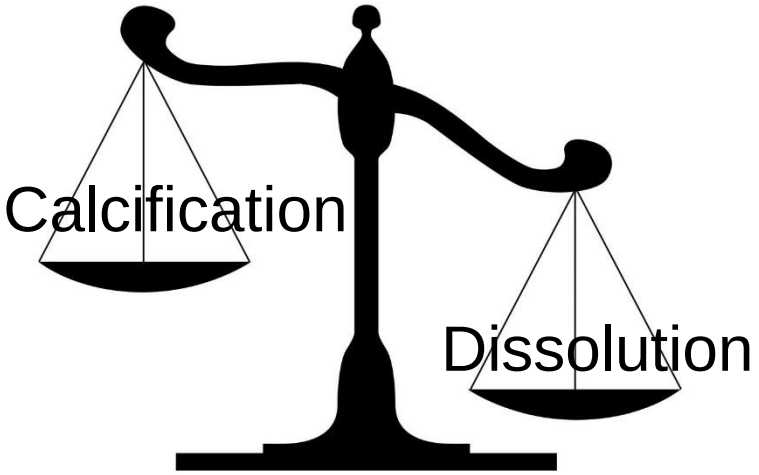
*Kiene & Hutchings (1994); Chazottes et al. (1995); Edinger et al (2000); Newman et al (2023)*


ARE REEFS IN BALANCE ?

# A DELICATE BALANCE

**Where do reefs stand & projections ?**

Reef degradation = Erosion > Calcification




Loss of complexity (3D), resources, protection…

**We already lost ~50% of world reef surface!**

(14% between 2009-2020 !)

*World status of coral reefs (2020)*

# FORCING FACTORS





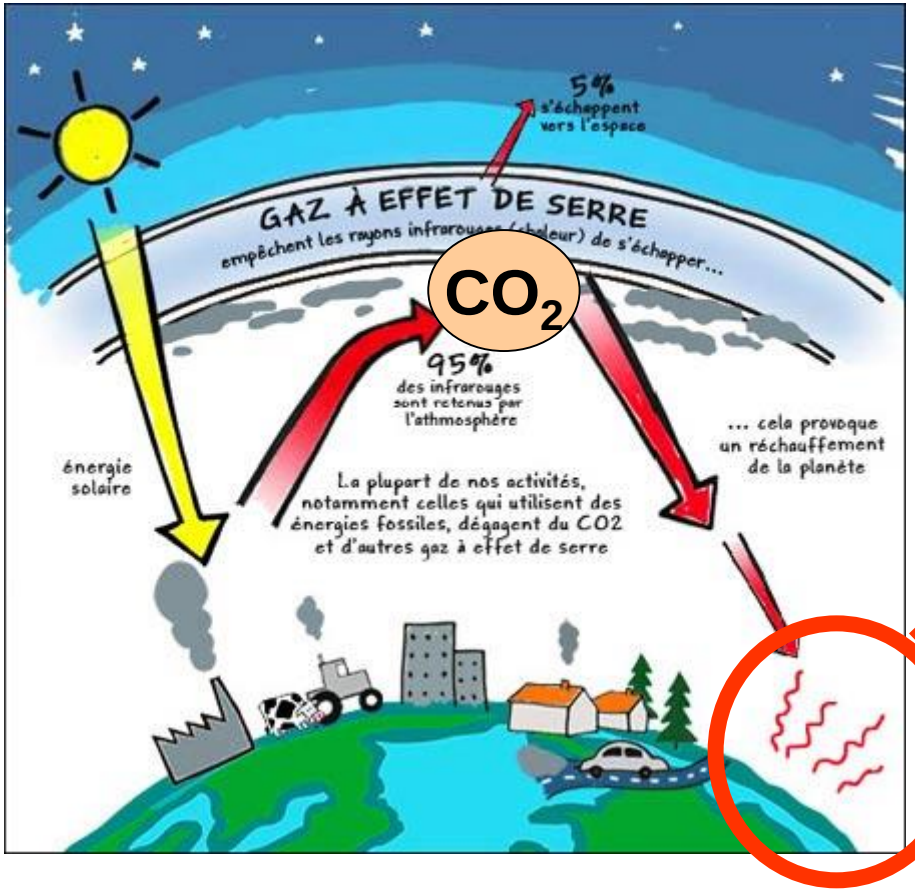
Climate change

IPCC 6th Ass. Report (fig. 15.4)


Local human disturbances

# CLIMATE CHANGE

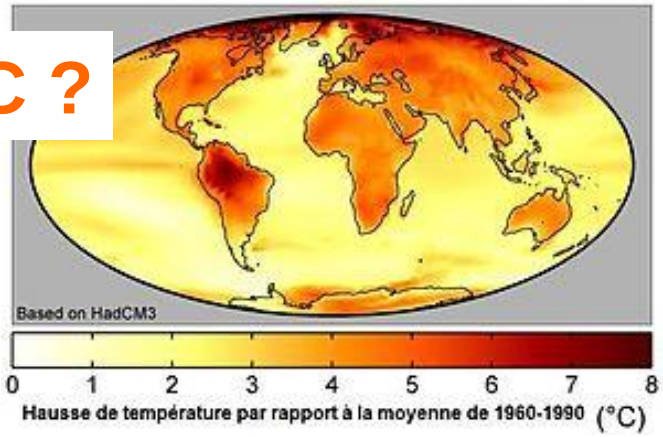





**Global warming**

**≥ 2°C ?**

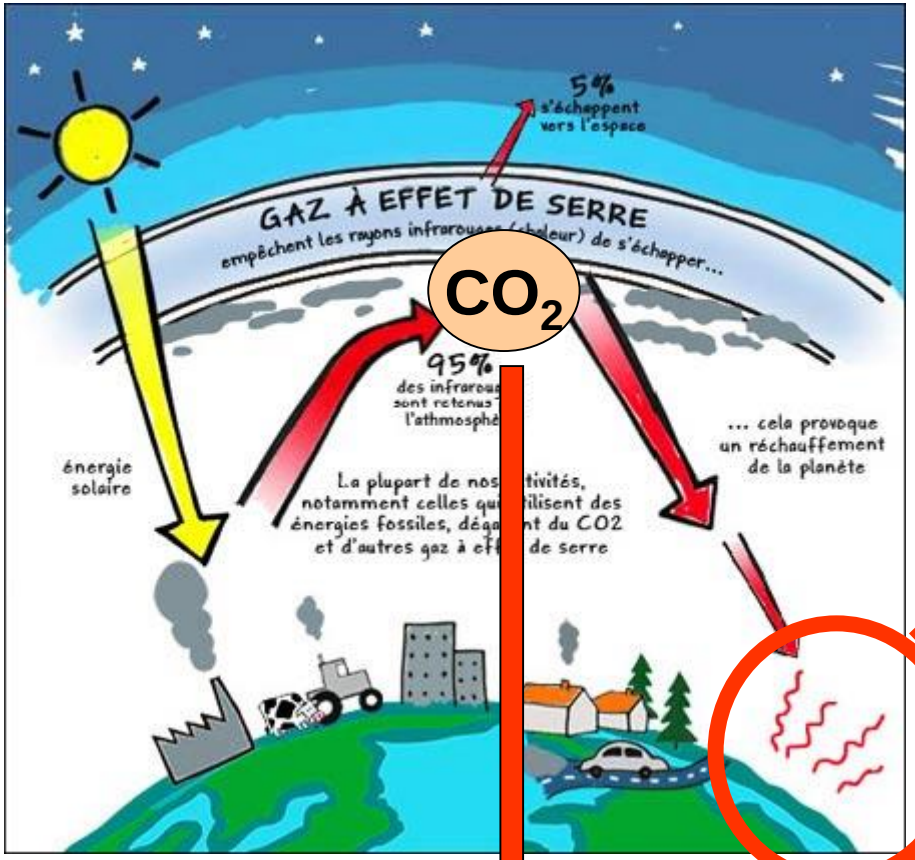
Prévisions des hausses de températures pour 2070-2100




*SROCC, IPCC (2019)*

# CLIMATE CHANGE



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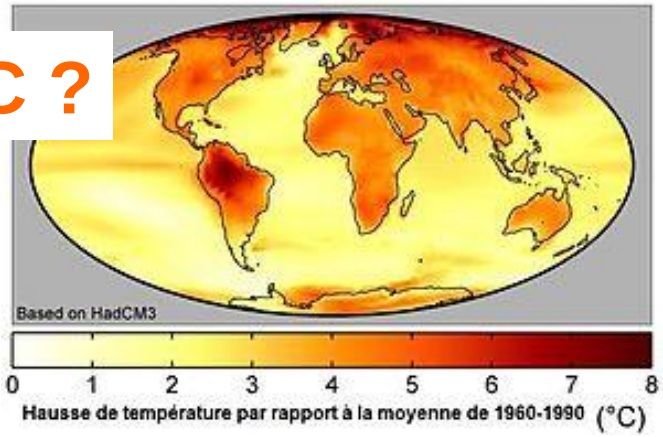
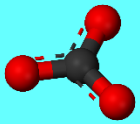



≥ 2°C ?

*SROCC, IPCC (2019)*

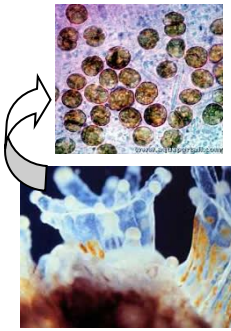
**Ocean acidification**



$CO_2$ + $H_2O$ ⟶ **pH**

| 2015 | 2100 |
|---|---|
| (8.1 | ⟶ 7.93) |

## Coral bleaching

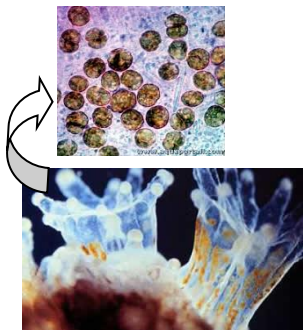

Hughes et al. (2017)

**Massive coral mortality**

(MHW increase in frequency & intensity)

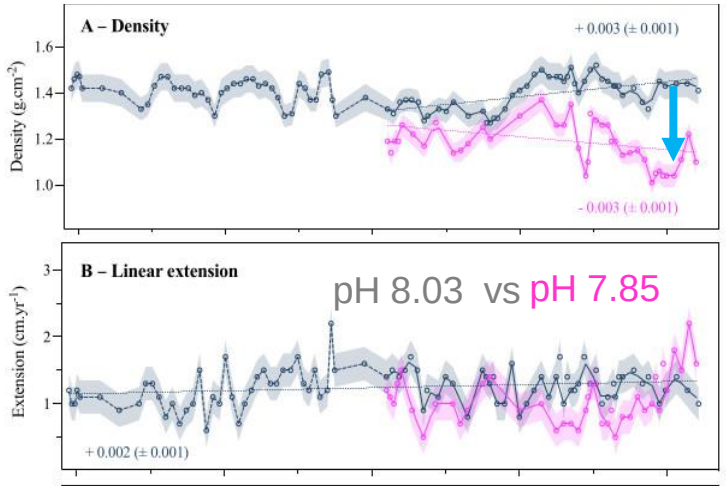
## Coral bleaching


## Coral density & growth

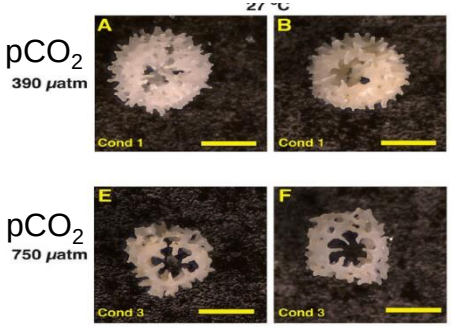



Hughes et al. (2017)

**Massive *Porites* (Palau)**




Canesi thesis (2022)




***Acropora millepora* (ex situ conditions)**

Wu et al. (2017)

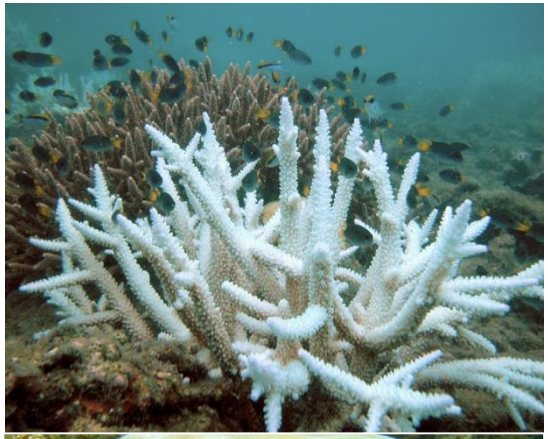
**Massive coral mortality**
(MHW increase in frequency & intensity)

**Coral density, growth decrease**
(± combined to warming /species)

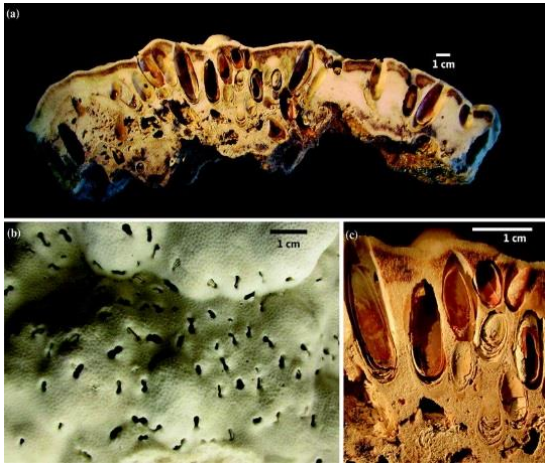
# LOCAL DISTURBANCES



**<u>Soil erosion</u>:**
Hypersedimentation
Eutrophication
Lower salinity
Plastic pollutions…



*Edinger et al. (2000); Tribollet & Golubic (2005); Aeby et al. (2015)*



# LOCAL DISTURBANCES



**<u>Mining activities</u> :**
Metal pollutions, turbidity…

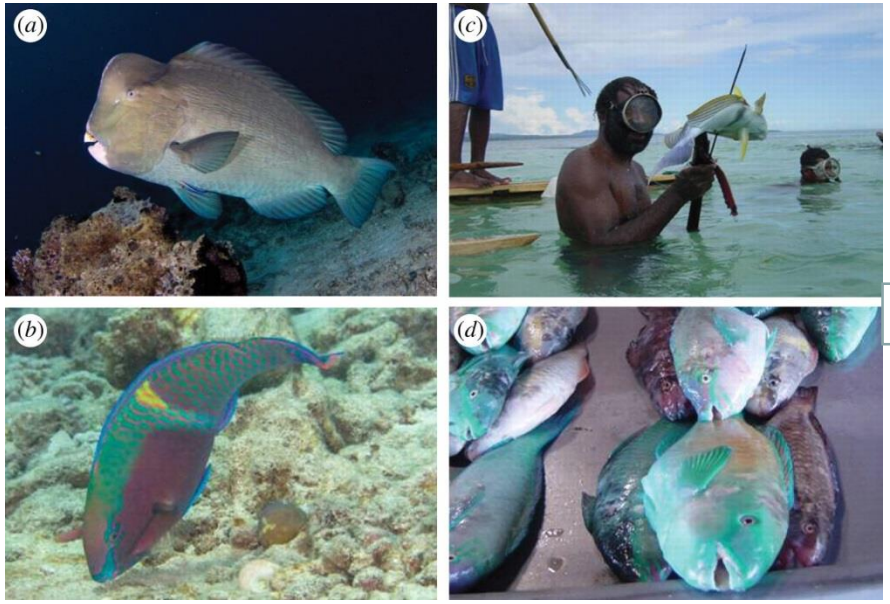
*Prouty et al. (2013); Allen et al. (2017)*

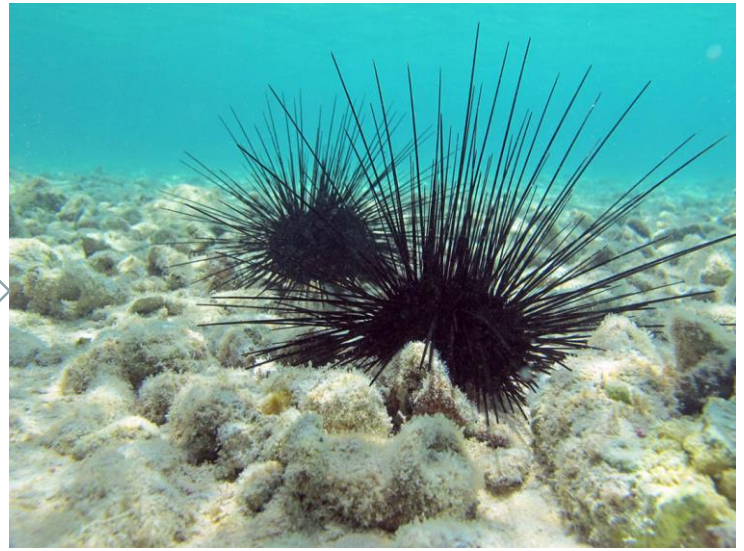
**<u>Plastics</u>:**
Toxicity, diseases...

# LOCAL DISTURBANCES



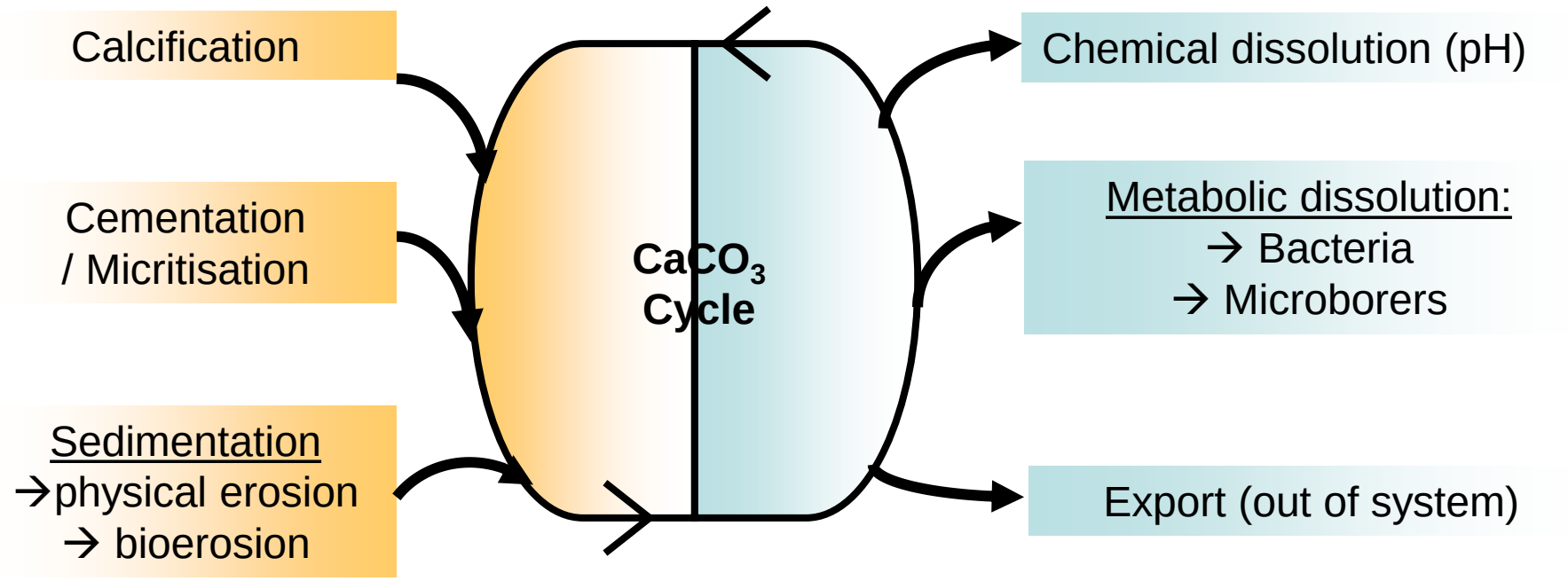
**<u>Overfishing, fishing techniques</u>:**
Habitat destruction, removal of key organisms (grazers, …)



# CONSEQUENCES ON CARBONATE BUDGET

## Acidification ± combined to other factors?




*Andersson & Gledhill (2013)*

# CONSEQUENCES ON CARBONATE BUDGET

## Acidification ± combined to other factors?

Calcification

-30%

Cimentation / Micritisation

Sedimentation
→physical erosion
→ bioerosion

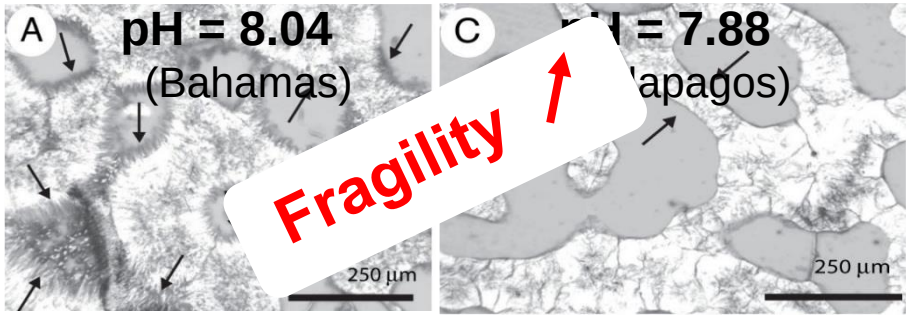
$CaCO_3$ Cycle

Chemical dissolution (pH)

Metabolic dissolution:
→ Bacteria
→ Microborers

Export (out of system)


*Aeby et al. (2015), Hughes et al. (2017)*




*Manzello et al (2008)*

# CONSEQUENCES ON CARBONATE BUDGET



## Acidification ± combined to other factors?

Calcification
-30%
Cimentation / Micritisation

Sedimentation
→physical erosion
→ bioerosion

$CaCO_3$ Cycle

Chemical dissolution (pH)
+ 25 to 575%
Metabolic dissolution:
→ Bacteria
→ Microborers
+ 50 to 300%

Export (out of system)

High Mg-calcite + soluble
/ aragonite et low Mg-calcite

Rising dissolution

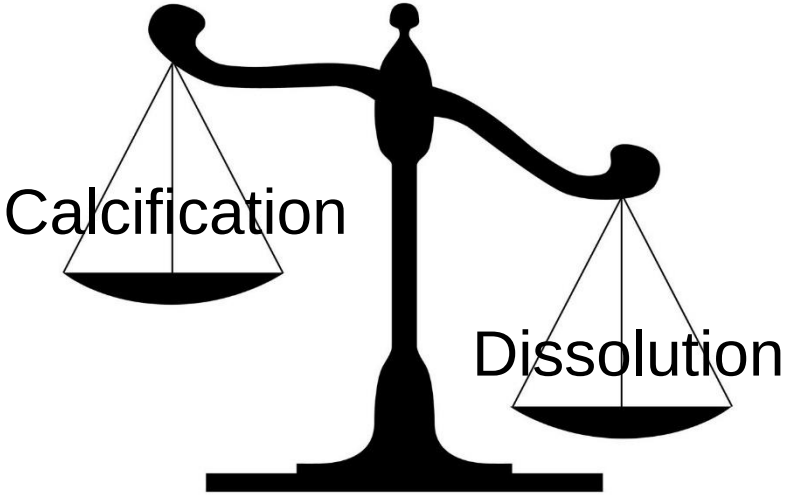
*Andersson et al. (2007) ; Eyre et al. (2018) ; Tribollet et al. (2009, 2019)*

# UNBALANCED BUDGET



## MAJOR LOSS OF REEFS BY 2050 ?

**IPCC (AR6)** : 70-90% reef loss with +1.5°C
99% reef loss with +2°C




**But uncertainties remain (coral adaptation, buffering processes…)**
**& actions can be done to target a warming ≤ 2°C !**


FUTURE MAORE REEFS OBJECTIVES


## MAYOTTE

- 3rd largest lagoon in the world
- One of the rare double barrier reef
- A hot spot of biodiversity
  (~ 350 coral species / 1500 worldwide)
- Highly resilient reefs
- Highly dynamic demography
  (→ rising human pressure)
- Major needs for development

*World status of coral reefs (2020)*


# *Sustainable science for a better protection of the reef socio-ecosystems and coastal populations' development*

*PIs: Aline TRIBOLLET & François Guilhaumon (IRD)*
*with Georgeta Stoica (CUFR)*

Financé par l'Union européenne NextGenerationEU

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Fraternité

IRD Institut de Recherche pour le Développement FRANCE

OFB OFFICE FRANÇAIS DE LA BIODIVERSITÉ

Parc naturel marin Mayotte

Centre Universitaire MAYOTTE


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Centre Universitaire MAYOTTE

LOCEAN

ENTROPIE Ecologie Marine Tropicale des Océans Pacifique et Indien

ICARE

LSCE

Parc naturel marin Mayotte

ASSOCIATION SCIENCE OUVERTE

PALAIS DE LA PORTE DORÉE
AQUARIUM TROPICAL

Ecole A. Boulloche, Ile de France
Ecoles Pamandzi 2 et 5, Mayotte

ACADÉMIE DE MAYOTTE
Liberté
Égalité
Fraternité

ACADÉMIE DE CRÉTEIL
Liberté
Égalité
Fraternité

# FMR OBJECTIVES



- ✓ **Better understand reef dynamics and resilience in Mayotte in a changing environment**
- ✓ **Study of new reef restoration approaches based on Nature**
- ✓ **Understand the diverse interactions that the Mayotte population has with its marine patrimony (reefs)**
- ✓ **Develop innovative outreach education approaches based on the interdisciplinarity (human & marine sciences) & evaluate their efficiency and relevance**

# FMR OBJECTIVES




***How to better protect coral reefs in a changing world ?***

✓ Study of past and present effects of global change on coral growth and bioerosion agents

→ ***Improvement of prediction models & identification of refuge zones***

✓ Understand reef community complexity and functioning under diverse environments (5 sites)

→ ***Identify the main functional corals structuring communities and their spatio-temporal variability***

✓ Understand the diverse interactions between Mayotte society and reefs

→ ***Adapt outreach tools and involve as much as possible people in the protection of their environment***

# FMR OBJECTIVES



***How to support Mayotte' development while preserving and restoring reefs?***

✓ Implementing a long-term study of coral assemblages designed on the basis of natural observations and fixed on original artificial reefs produced locally

→ ***Capacity of assemblages to grow and reproduce functional naturel reefs***

✓ Study artificial substrates used for marine infrastructures and their interactions with corals

→ ***Identify the best compromises for a sustainable coral restoration / blue economy dvlpt***

✓ Creation of a public underwater trail at Musical Plage with an artificial reef on which coral frags (nubbins) prepared by school children have been affixed

→ ***New tool for outreach eductation & participatory science***

# FMR OBJECTIVES




***Evaluate the efficiency of the new outreach activities via a double human sciences' approach (anthropology/education sci.)***

✓ School twinning between Mayotte and Bondy (4 classes involved in 2 yrs)

→ ***Teaching of coral biology, socio-ecosystems, coral observations, coral fragging practice***

✓ Combined study (anthropology/education sciences) to evaluate knowledge acquisition by children, how teachers seize the project opportunity to reach their educational goals…

→ **Impacts of the project on children, their families, teachers…**

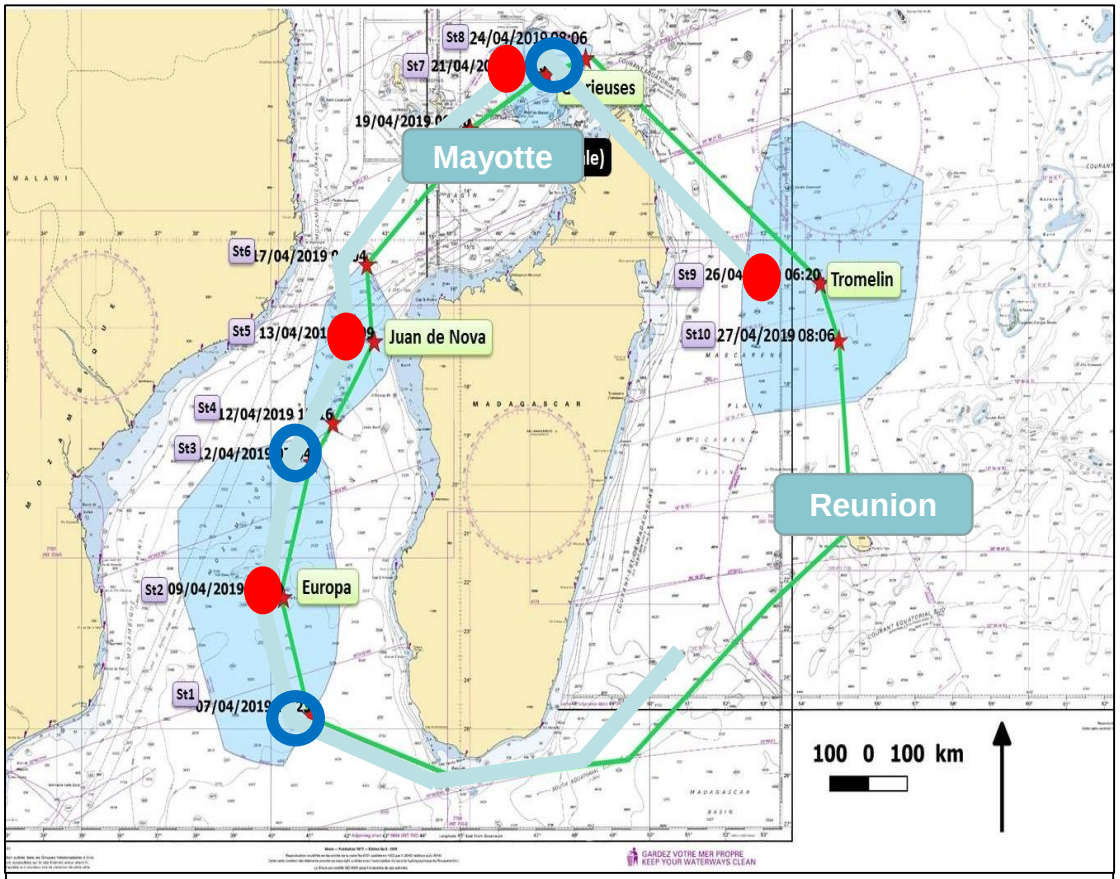
✓ Propose improvements to the approach if necessary

→ **E.g. Better meet school cycle expectations by developing children's critical thinking skills**

# Environmental changes


## CLIM-EPARSES' project (2019-2021)

### 2 oceanographic campaigns in Avril 2019 et 2021




**Suivi chimie marine / acidification :**

- Continuous measurements of surface fCO2, SST, Salinity
- 48h measurements near islands and on reefs
- Offshore stations (0-1000m)



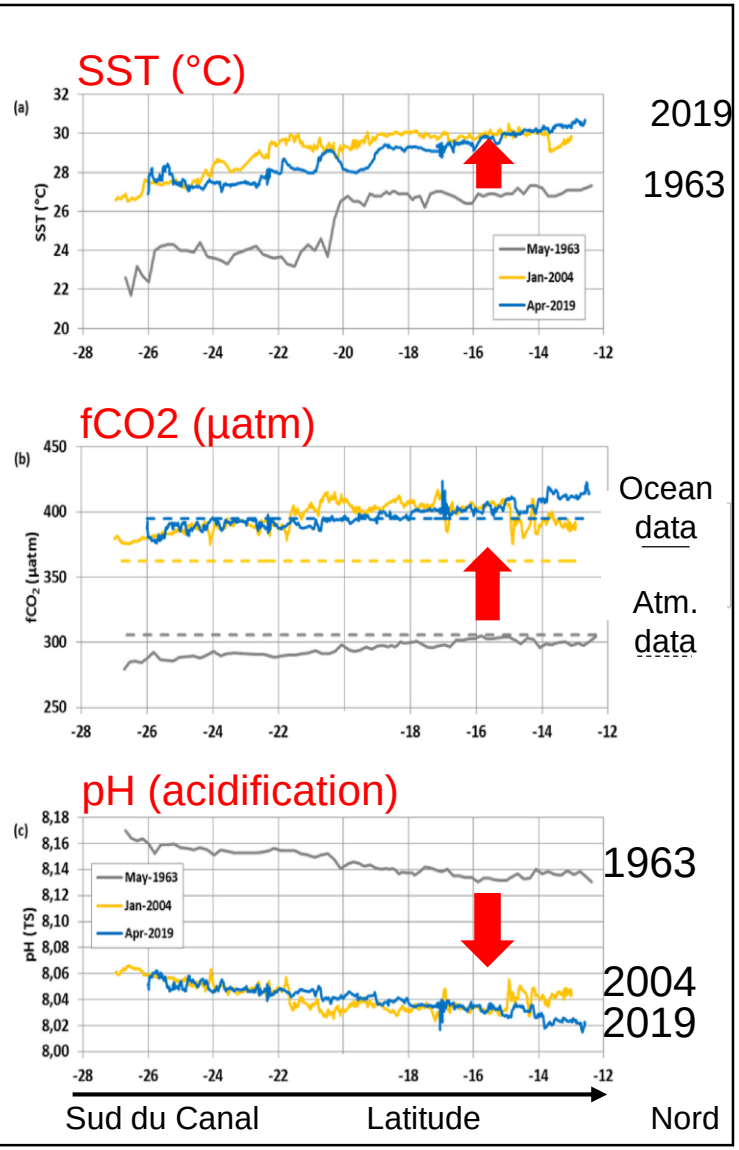
## Study of

- C cycle /acidification
- Water masses
- Impacts of pH/SST & metal traces on corals and bioeroders

# Environmental changes

## CLIM-EPARSES' project (2019-2021)

*Lo Monaco, Metzl, Fin, Mignon, **Cuet**, Douville, Gehlen, Chau, **Tribollet** (2021) Deep Sea Res. II*




## Main results:

- **Rising SST in the Channel: + 0.11°C/ decade**
- **Comparison 1963-2004-2019 : increase of $fCO_2$ in the Channel due to $CO_2$ emissions** (+ 90 µatm) ; only 10 µatm due to SST
- **Ocean Acidification in the channel has accelerated during the last 20 yrs**
- **Important spatial variability of pH along the Channel but seasonal variability poorly known → Reef refuges / hot spot of vulnerability ?**

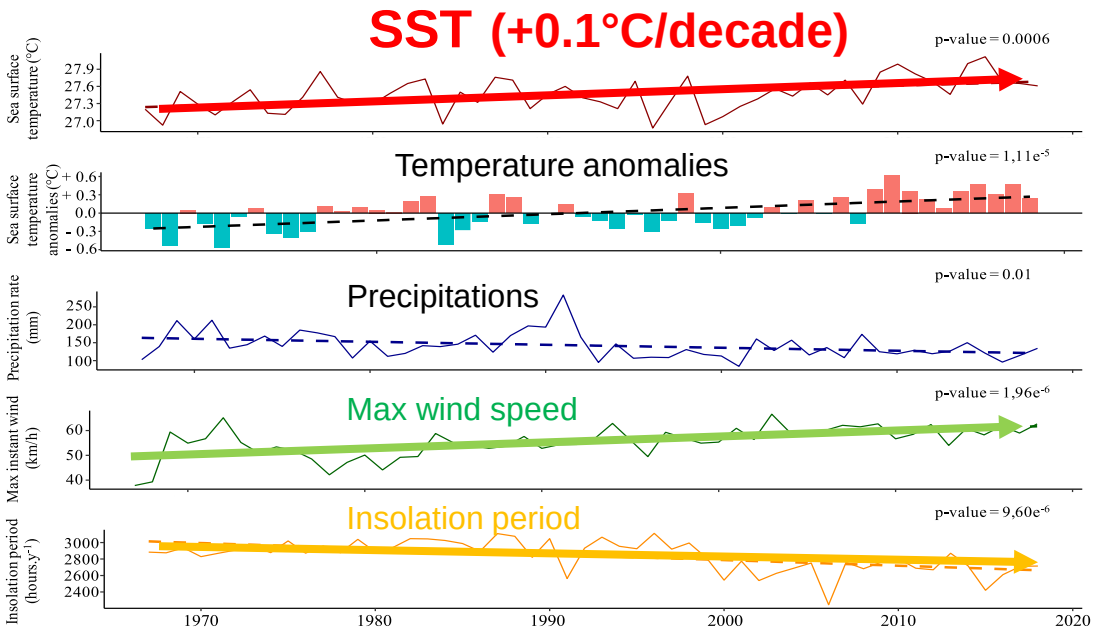
*Keeling & Waterman (1968) ; Metzl (2009)*

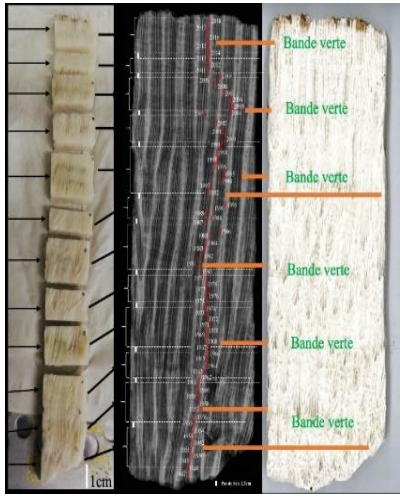
# Environmental changes & impacts



## Core of *Diploastrea* sp.
### (NE lagoon, Mayotte) ~ 54 yrs record

*Alaguarda et al (2023) Frontiers in Marine Sci.*



# Environmental changes & impacts



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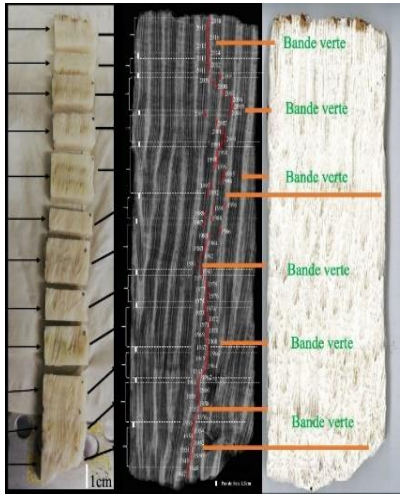
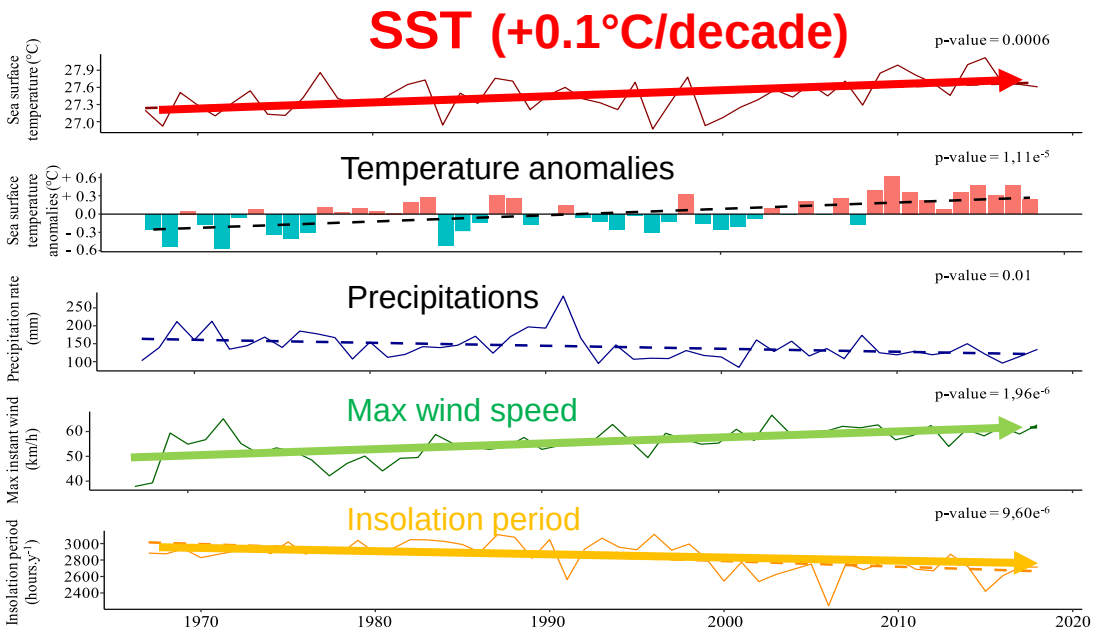
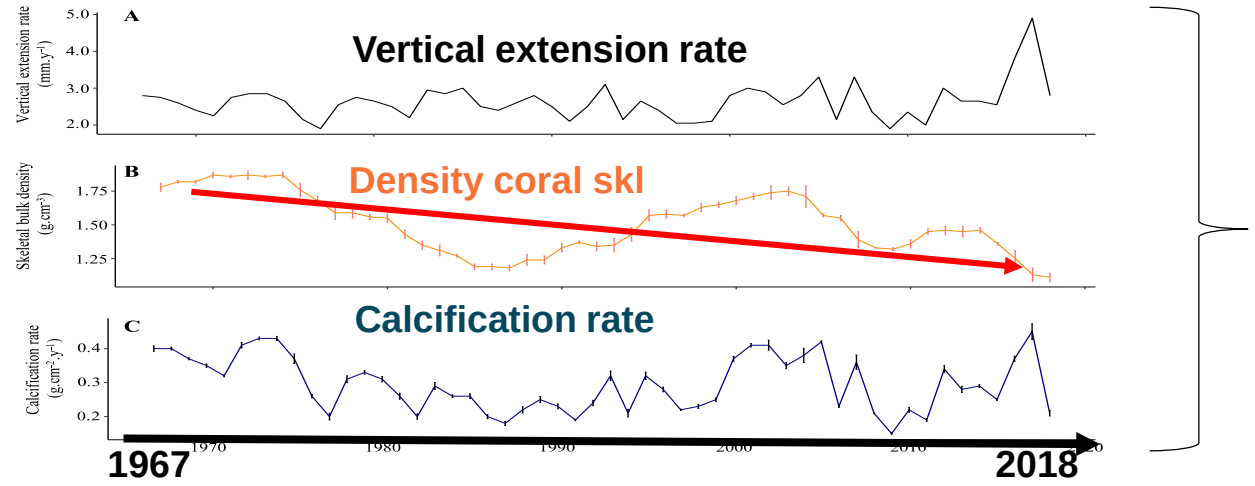


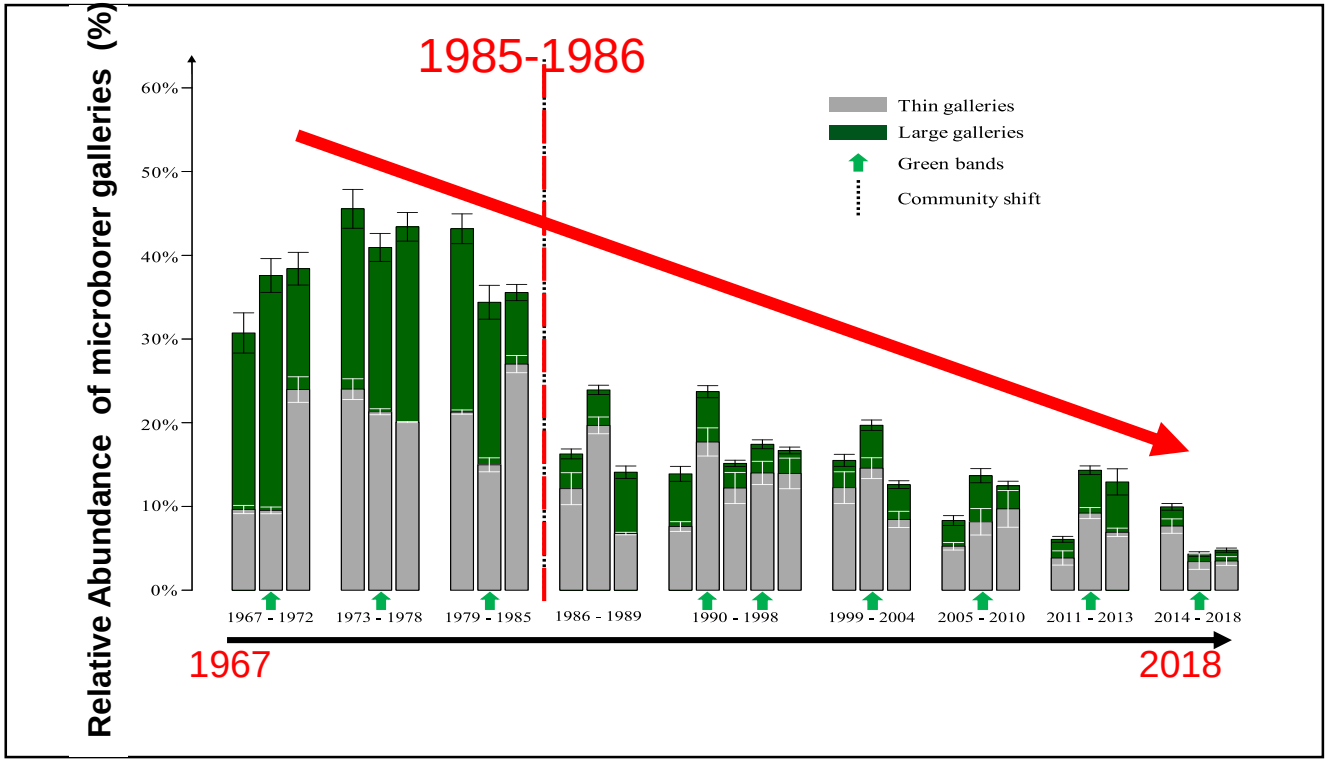




Negative effect of global warming on coral density (-40% in 50 yrs)

# Environmental changes & impacts

## Core of *Diploastrea* sp.
**(NE lagoon, Mayotte) ~ 54 yrs record**

*Alarguarda, Brajard, Coulibaly, Canesi, Douville, Le Cornec, Lelabousse,* ***Tribollet*** *(2021) Frontiers*

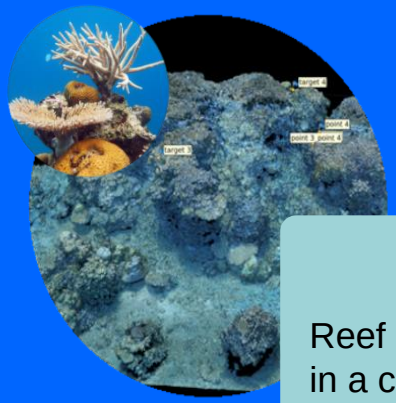



Reduction of microboring communities by **90%** in 54 yrs
and shift in their species composition due to SST, precipitations & insolation

**→ Consequences on coral survival in the context of global warming?**

# Future Maore Reefs

*Sustainable science for reef conservation & Mayotte development*

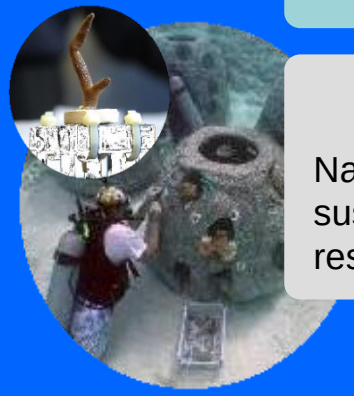


## Science

Reef functioning/resilience in a changing world

## Society Awareness

Interdisciplinary education approaches (ecology & social sciences)



## Innovation

Nature based solutions & sustainable substrates for reef restauration & compensation

**Society dvlpt & adaptation**

ONE OCEAN SUMMIT

## Transfer

Training of reef managers & students to new methods

LOCEAN, ENTROPIE, CUFR, ICARE, LSCE, Association Sci. Ouverte,
Aquarium Trop. Porte Dorée, Primary schools Mayotte/Bondy, & other private companies

# Thank you for your attention !