GOBESHONA 5
8 - 11 January 2019
International Conference on Climate Knowledge

Response of Subtropical Coastal Sediment Systems of Okinawa, Japan, to Experimental Warming and High *p*CO_2

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Session: Ecosystem Resilience

frontiers in Marine Science

ORIGINAL RESEARCH
published: 28 June 2016
doi: 10.3389/fmars.2016.00100

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Increasing seawater temperatures and CO_2 levels associated with climate change affect the shallow marine ecosystem function. In this study, the effects of elevated seawater temperature and partial pressure of CO_2 (pCO_2) on subtropical sediment systems of mangrove, seagrass, and coral reef lagoon habitats of Okinawa, Japan, were examined. Sediment and seawater from each habitat were exposed to four pCO_2-temperature treatments, including ambient pCO_2- ambient temperature, ambient pCO_2-high temperature (ambient temperature + 4°C), high pCO_2 (936 ppm)-ambient temperature, and high pCO_2-high temperature. Parameters including primary production, nutrient flux, pigment content, photosynthetic community composition, and bacterial abundance


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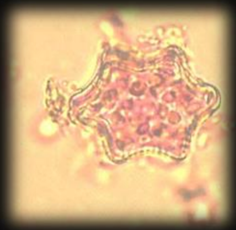

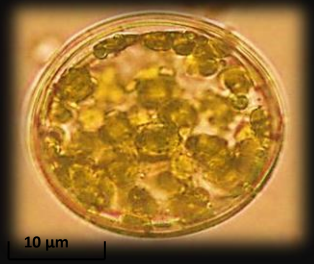
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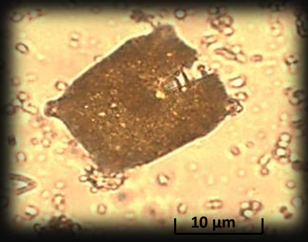
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Introduction

In shallow marine sediment systems, rising temperature, nutrient input, oxygen content, and ocean acidification, have potentially wide-ranging biological effects.

Sandy beaches and muddy bays help to mitigate the effects of environmental change via carbon sequestration, and the storage of carbon (Bouillon et al., 2008; Duarte et al., 2010; Pendleton et al., 2012; Chmura, 2013).

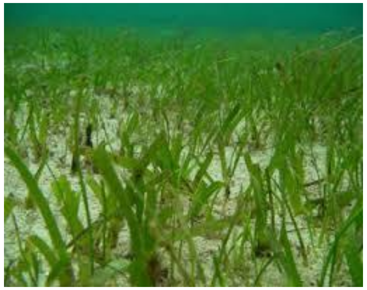
Mangrove, tidal salt marshes and seagrass are beneficial to adapt climatic extremes (Barbier et al. 2011, Cullen-Unsworth and Unsworth. 2013).

Some studies have shown that marine autotrophic communities are often insensitive to pCO_2 changes (Zimmerman et al., 1997)

Others revealed higher rates of photosynthesis under CO_2 enrichment (Delille, 2005).

High temperature influenced photosynthesis in seagrass sediment (Alsterberg, 2010).








Sediments

On the sediment surface there is a thin, brown upper layer of benthic microalgae, also known as microphytobenthos (MPB).

phototrophic microphytobenthos are important primary producers, contributing almost half of the primary production in estuarine ecosystems (Underwood and Kromkamp, 1999).

Ecosystems response to multiple stressors has generated considerable interest.

Folt et al. (1999) explained additive model.

The combined effect of two stressors are smaller or larger than the sum of effect from those two stressors to describe synergistic and antagonistic effect of among multiple stressors. (Folt et al., 1999)

Interactive and cumulative effects of multiple stressors in marine systems

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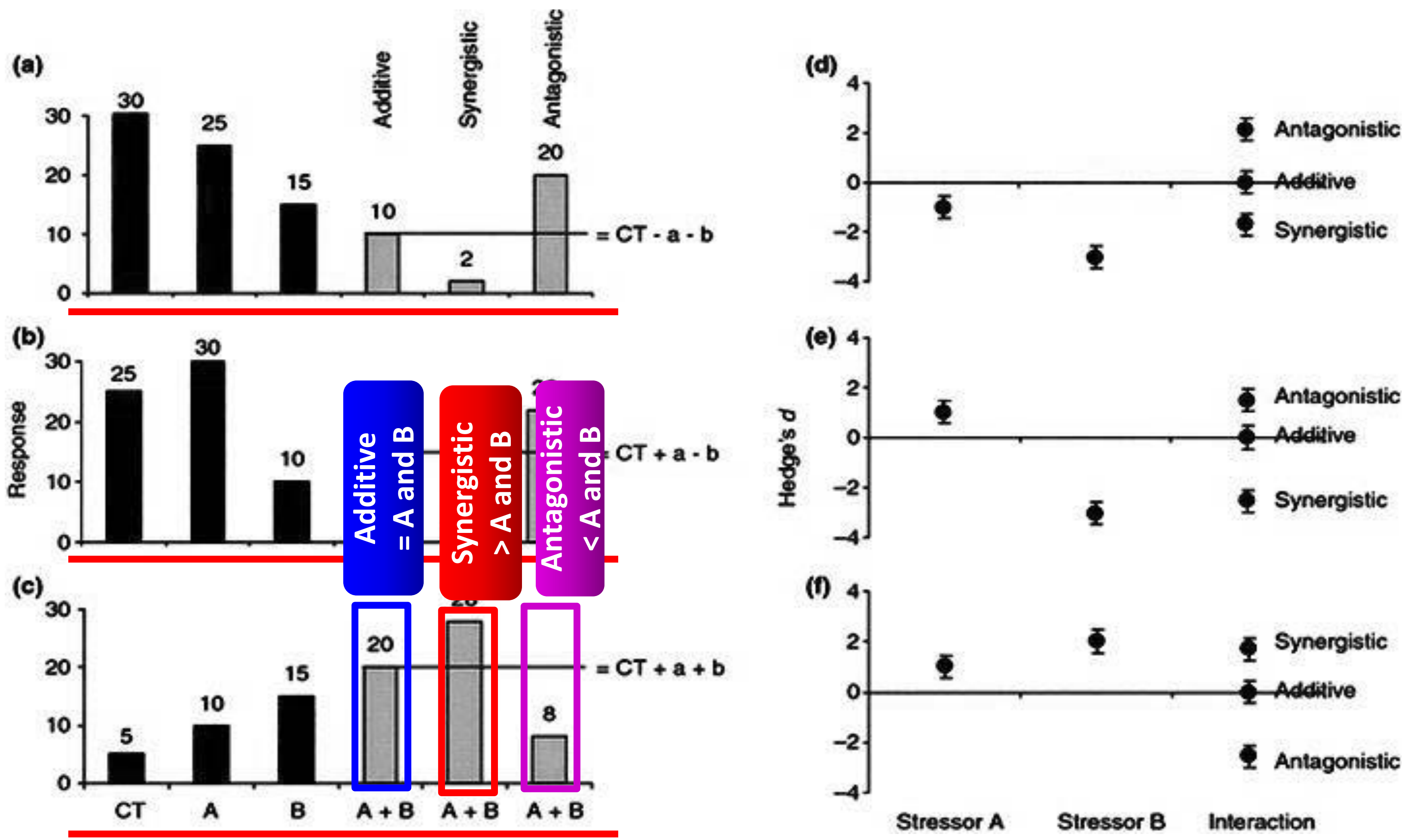

Crain et al., 2008, Ecology Letters, Adapted from Flot et al., 1999.

[Volume 11, Issue 12,](http://onlinelibrary.wiley.com/doi/10.1111/j.1461-0248.2008.01253.x/full#f1) pages 1304-1315, 2 NOV 2008 DOI: 10.1111/j.1461-0248.2008.01253.x
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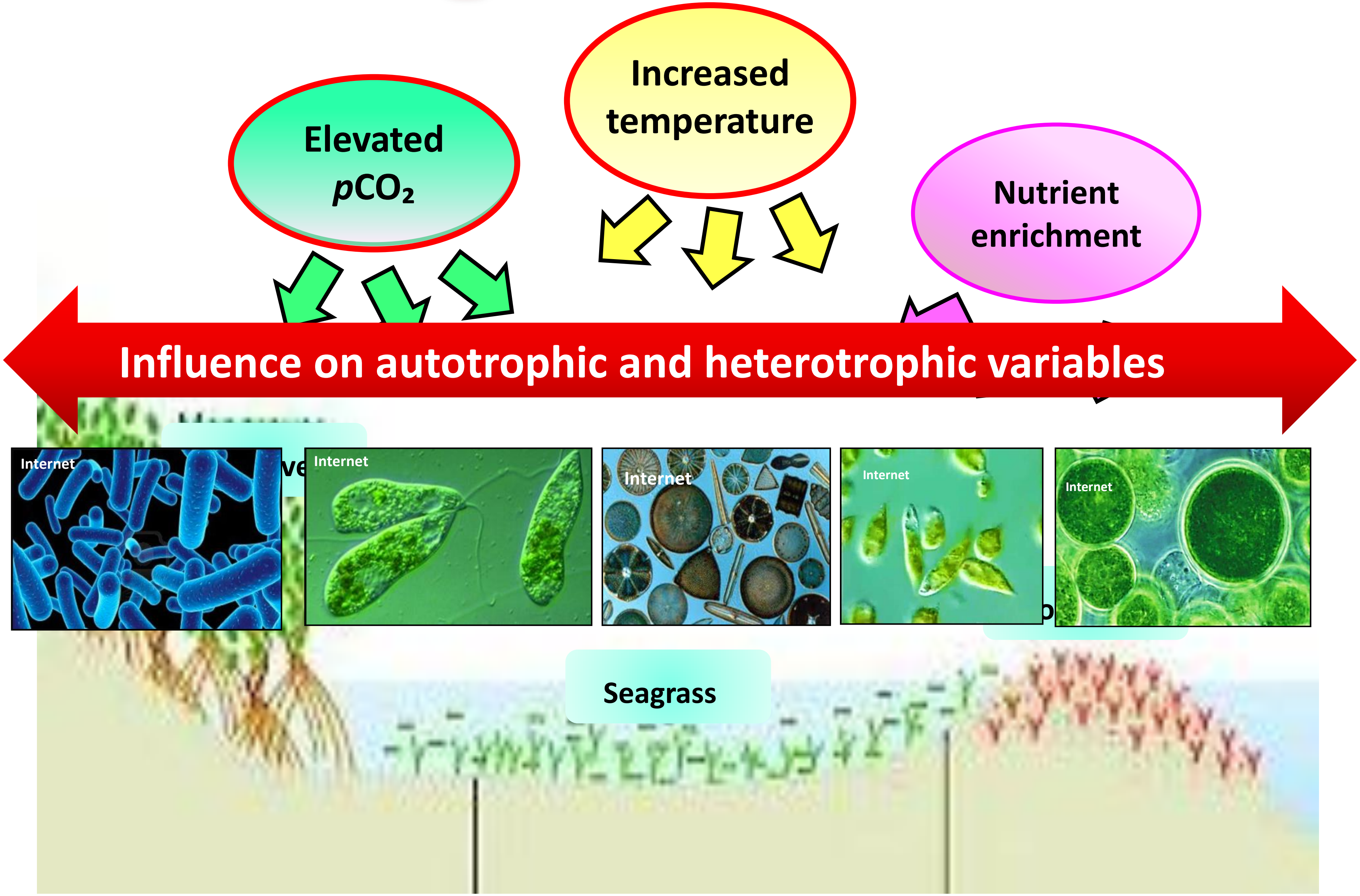
Targeted Stressors



Shallow marine areas are

- subjected to multiple stressors.

-There are strikingly few experimental studies (Alsterberg, 2011) .

Research gaps

Lagoonal and mangrove sediments' response under environmental stressors.

Impact of multiple stressors on coastal sediment ecosystem

Comparison among different habitats (such as mangrove, seagrass and coral reef lagoon).

Objective of the Study

This study aimed to understand the influence of elevated temperature (ambient + 4°C)* and $p\mathrm{CO_2}$ (936ppm)* on the coastal sediment ecosystems of different habitats (Mangrove, seagrass and coral reef lagoon).

Several questions were attempted to answer in this study

1) **Do sediments from the three habitats respond differently with respect to primary sediment production under individual and combined stress?**

2) **What is the effect of stress on nutrient flux?**

3) **How do sediment and seawater microbial abundances change under elevated temperatures and $p\mathrm{CO_2}$?**

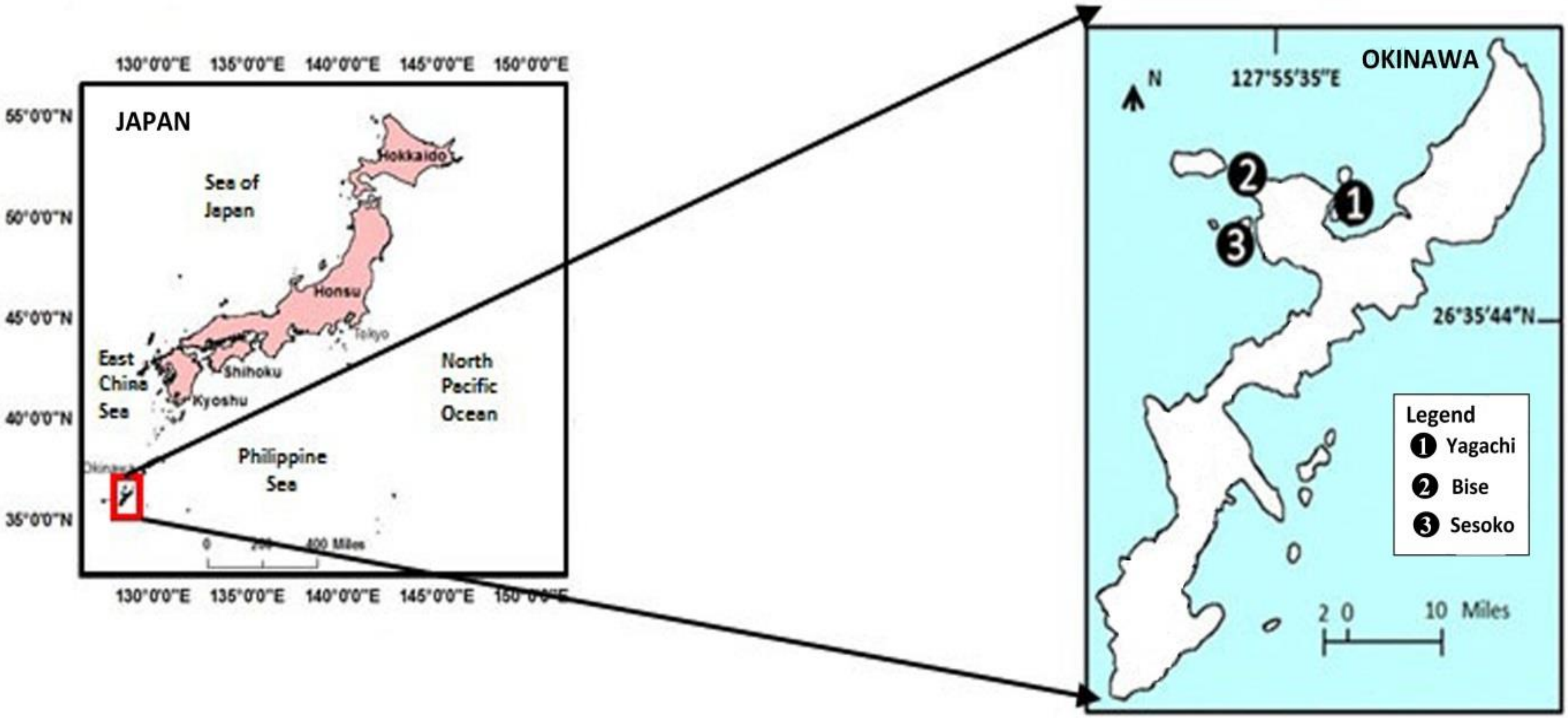
in three (mangrove, seagrass and coral reef lagoon) shallow marine ecosystems.

*** IPCC, 2013***

Location of study Sites

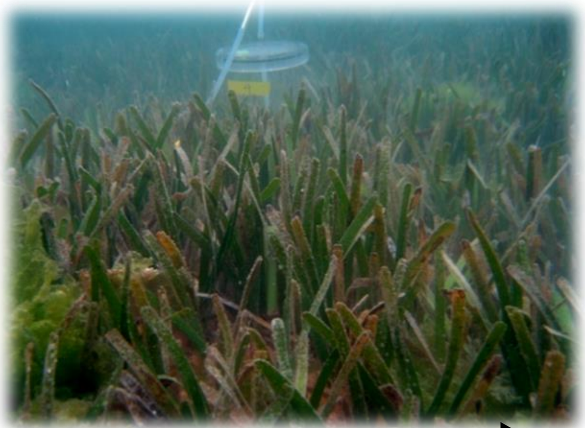
Three different site was selected in Okinawa Island

Mangrove Area		Seagrass Area		Coral Area	
Yagachi Island (St. 1)		Bise (St. 2)		Sesoko (St. 3)	
Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
26°38′N	128°00′E	26°42′N	127°52′E	26°39′N	127°51′E



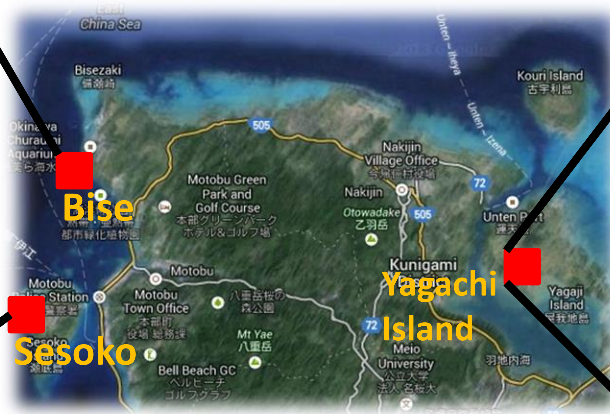
Sampling time: Summer (August-September, 2014)

Study Sites



Seagrass area at Bise ,

Mangrove area at Yagachi Island



Okinawa

Coral Reef area at Sesoko

Mangrove area at Yagachi Island

Research Design

Sediment and Seawater collection From study sites (August-September, 2014)

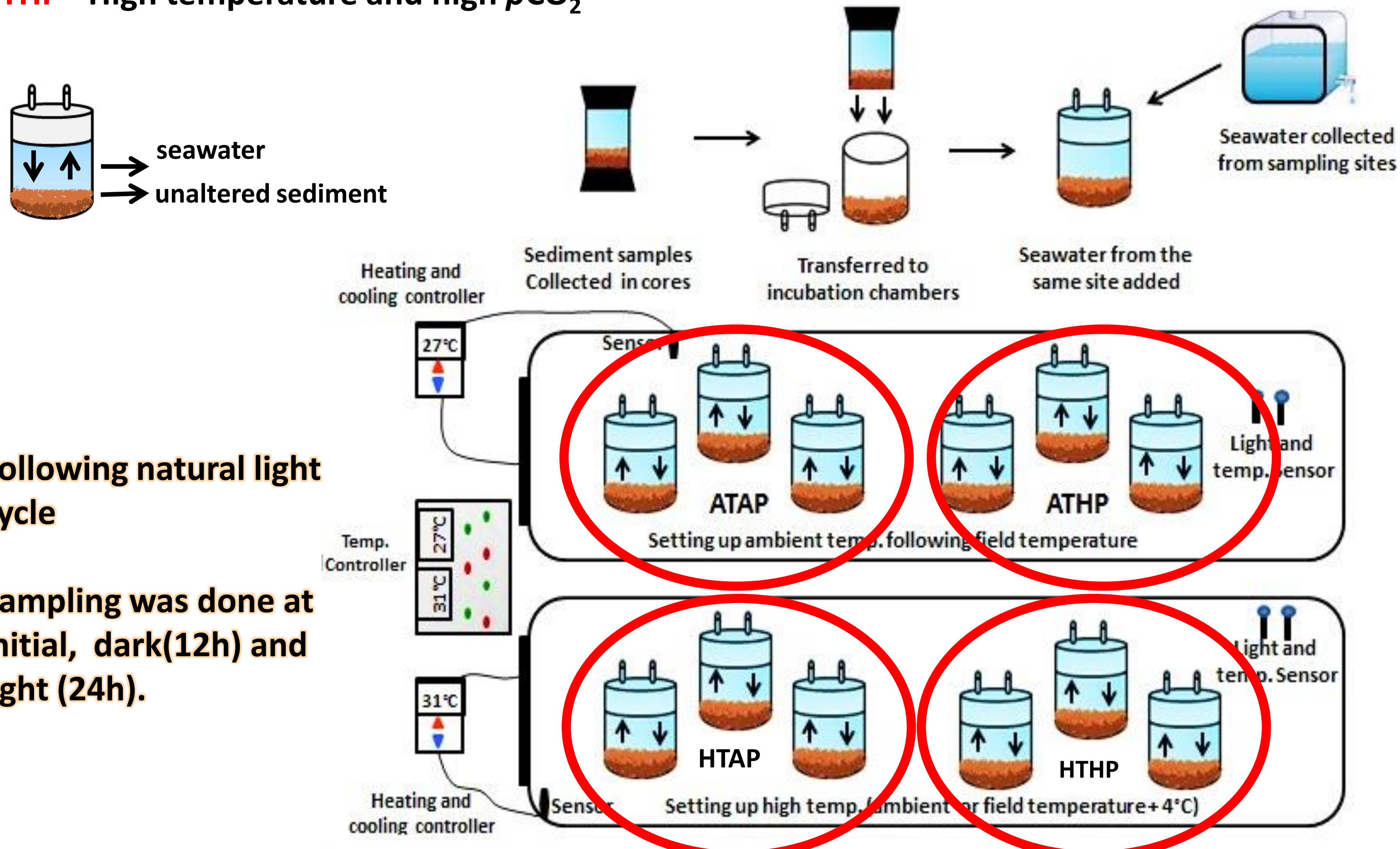
Setting up incubation In laboratory (under different temperature and *p*CO_2 level)

Collecting sample during and after incubation

Lab analysis (PP, pigment, nutrient, Bacterial abundance)

Experimental set up

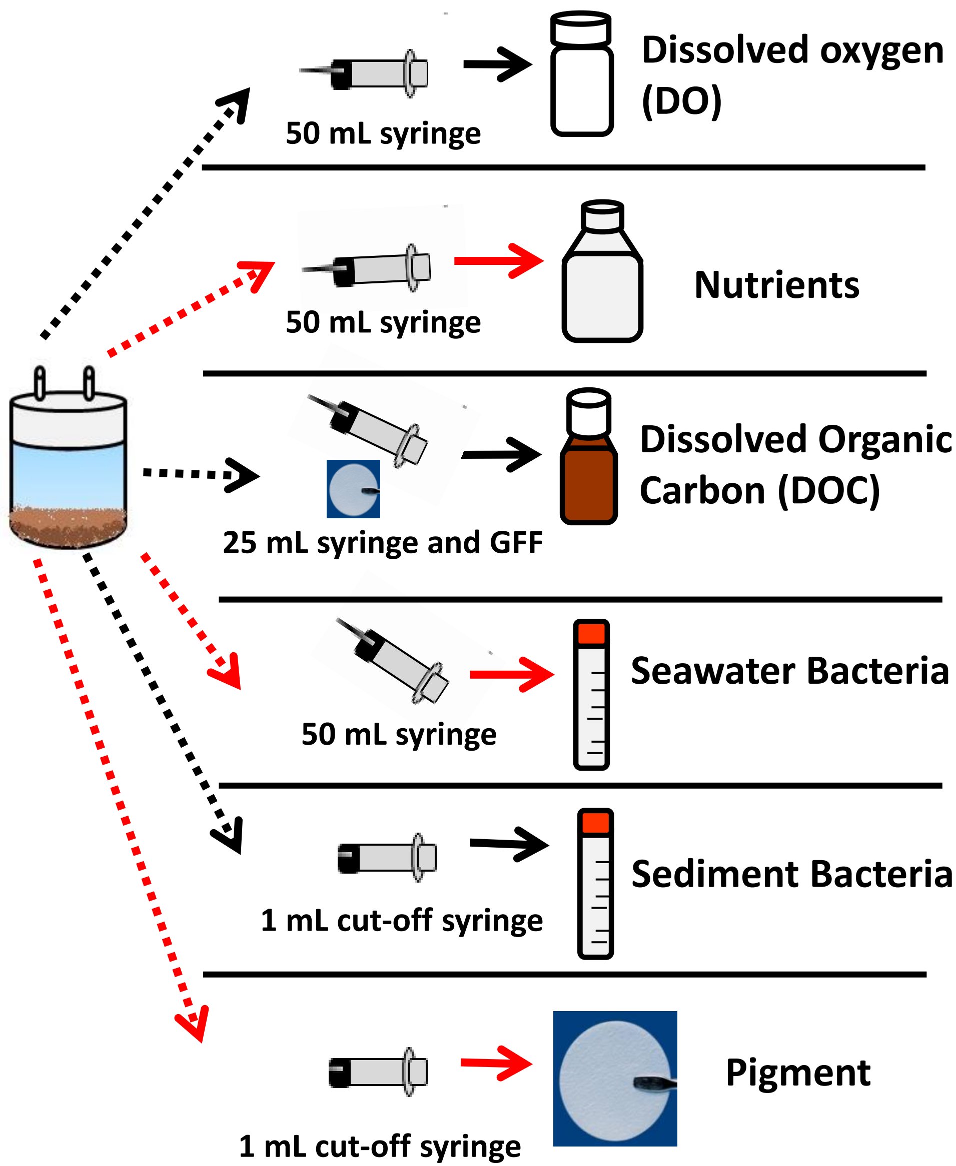
ATAP = Ambient Temperature and ambient pCO_2 (400ppm), ATHP = Ambient temperature and high pCO_2 (936ppm) HTAP= High temperature (ambient + 4°C) and ambient pCO_2 and HTHP= High temperature and high pCO_2



Following natural light cycle

Sampling was done at initial, dark(12h) and light (24h).

Sampling and analysis



NPP and respiration R were measured using the oxygen fluxes during day (light) and night (dark) respectively (Alsterberg, 2011).

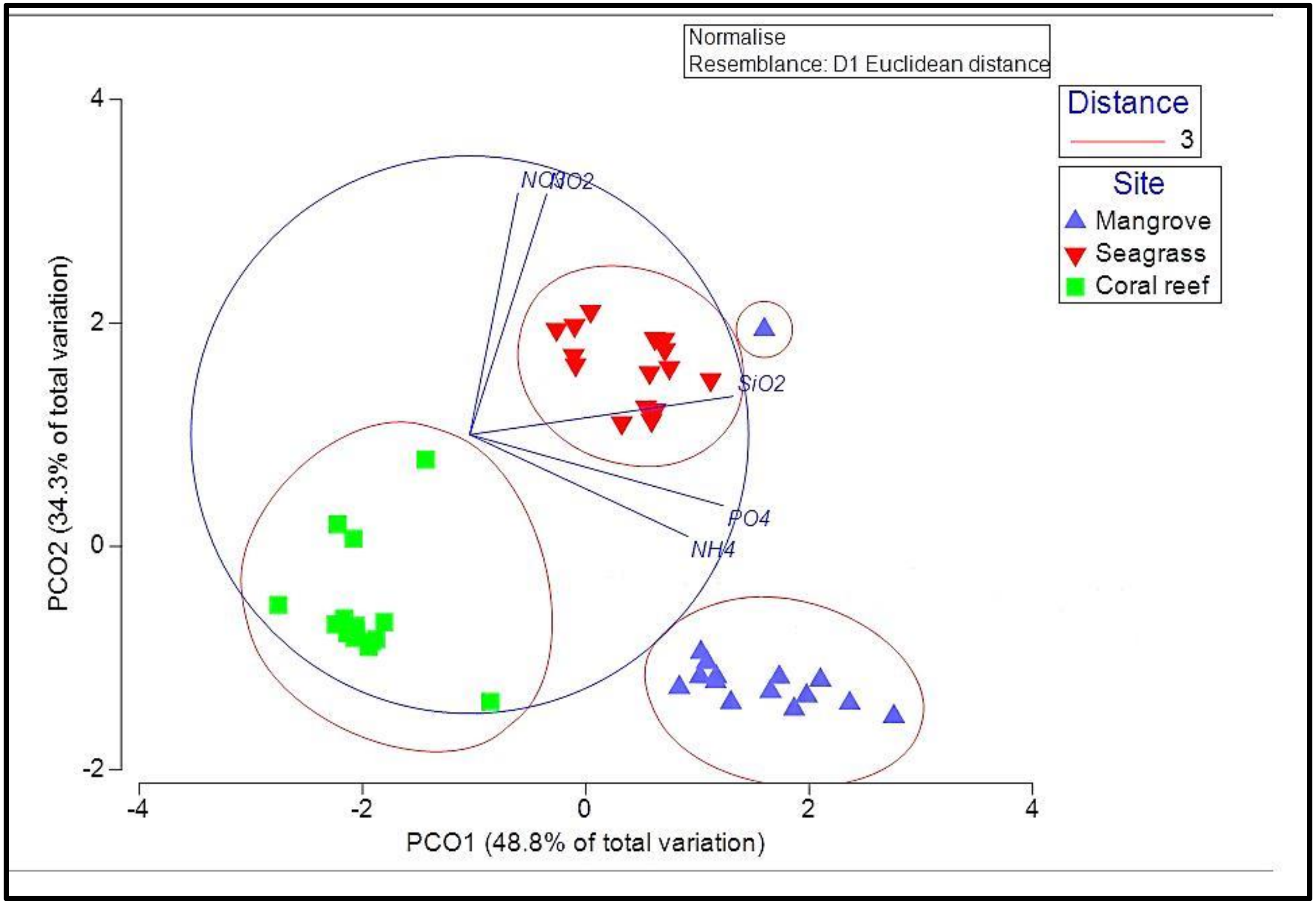
Using auto-analyzer (TRAACS-2000: BRAN + LUBE) according to Hansen Koroleff (2007)

High temperature catalytic combustion (HTC) method using a Shimadzu TOC-5000A analyzer (Japan) (Suzuki et al., 1992).

The DAPI-stained cells were counted under UV light using epifuorescence microscopy (Nikon; Eclipse/E6000, Japan)

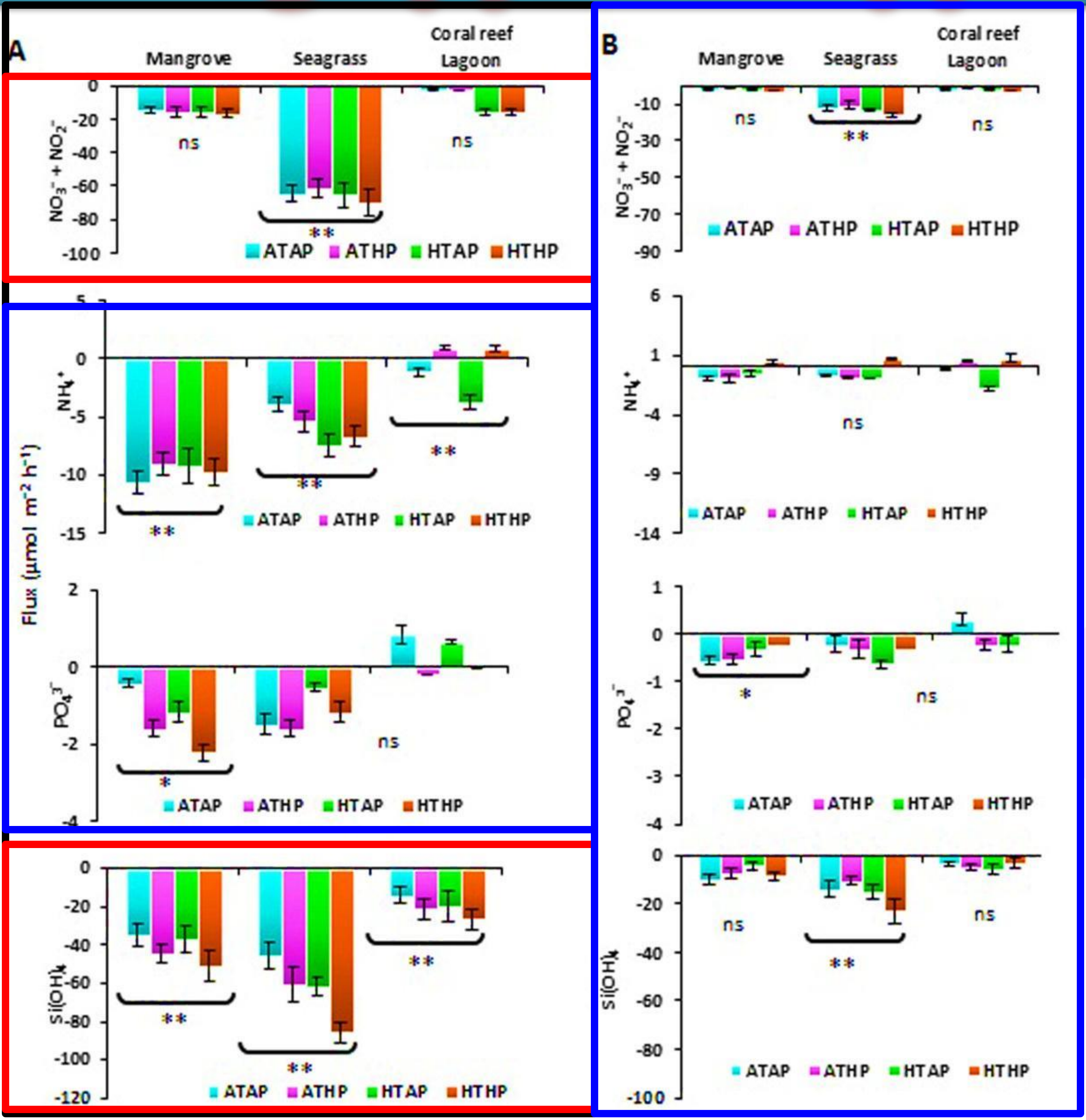
Using HPLC (Zapata et al., 2000)

Nutrient Concentration



Result from PERMANOVA (Permutational analysis of variance) including of five variable represented significant (P = .017) difference depending on study site. Result is depicted by principal coordinate analysis (PCoA).

Light (A) and dark (B) nutrient fluxes



ATAP = ambient temperature and ambient pCO_2, ATHP = ambient temperature and high pCO_2, HTAP = high temperature and ambient pCO_2, and HTHP = high temperature and high pCO_2

Nutrients were generally taken up in both light and dark periods

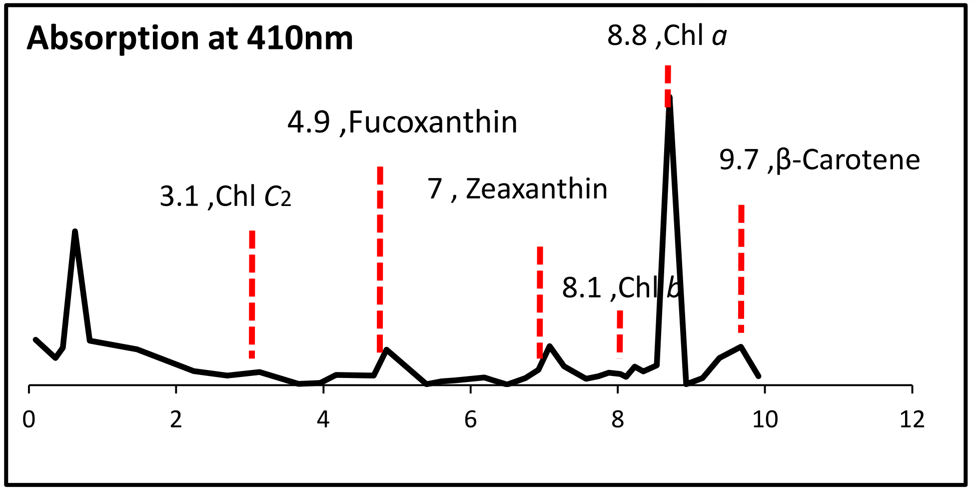
nitrate + nitrite and silicate uptake increased under the HTHP in mangrove and seagrass sediment

Lagoonal sediment release ammonium under ATHP and HTHP

* and ** indicate significant differences at P < 0.01 and P < 0.001 based on the least significant difference test (pot-hoc Tukey's test) depending on habitats (mangrove, seagrass and coral reef lagoon). Lack of significance is indicated by ns.

Sultana et al. (2016). Front. Mar. Sci. 3:100.

Pigments and photosynthetic community



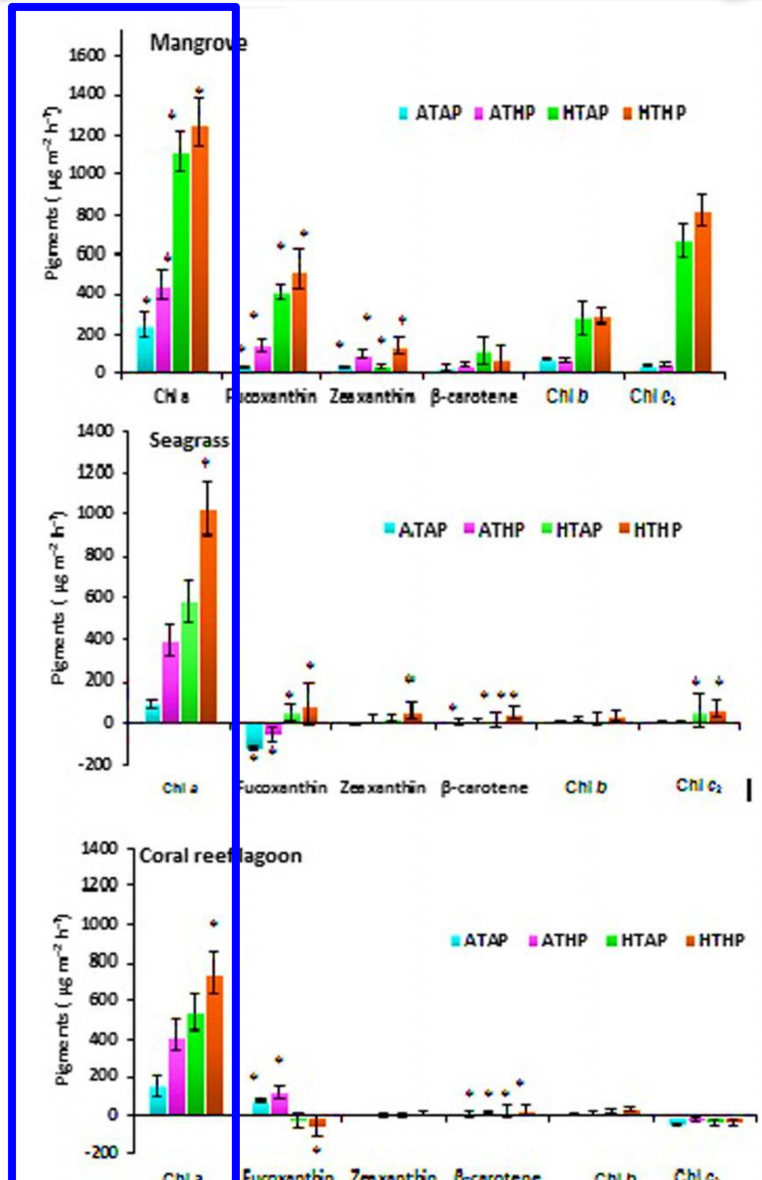
-Under HTHP, increased **chlorophyll *a*** represented the bulk of the photosynthetic community in mangrove and seagrass incubations

-Dominancy of **pennate diatoms** in mangrove and seagrass

-Prominence of **naviculoids** and Many tiny diatoms

-**Filamentic cyanobacteria** and

- Occasional presence of **flagelletes**



* and ** indicate significant differences at $P < 0.05$ and $P < 0.01$ determined using least significant difference tests (post-hoc Tukey's test) depending on incubation conditions (ATAP, ATHP, HTAP and HTHP) and habitats (mangrove, seagrass and coral reef lagoon)

Sultana et al. (2016). Front. Mar. Sci. 3:100.

Benthic microalgae

5–20 µm sized benthic diatoms, especially naviculoids, were frequently found in all sediments

< 5 µm sized tiny diatoms were abundant in mangrove and seagrass sediments

Changes in sediment-surface chlorophyll *a*

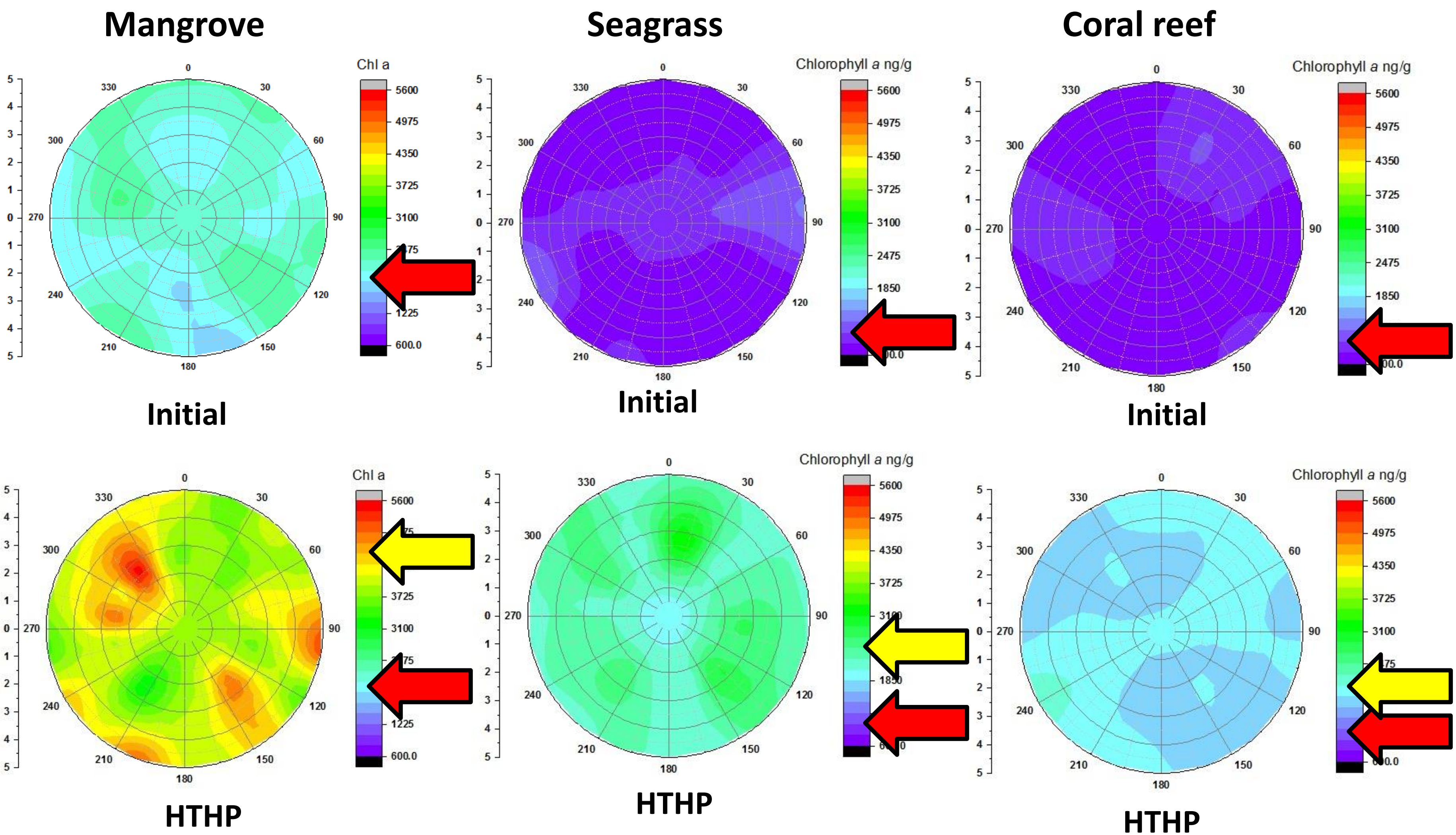
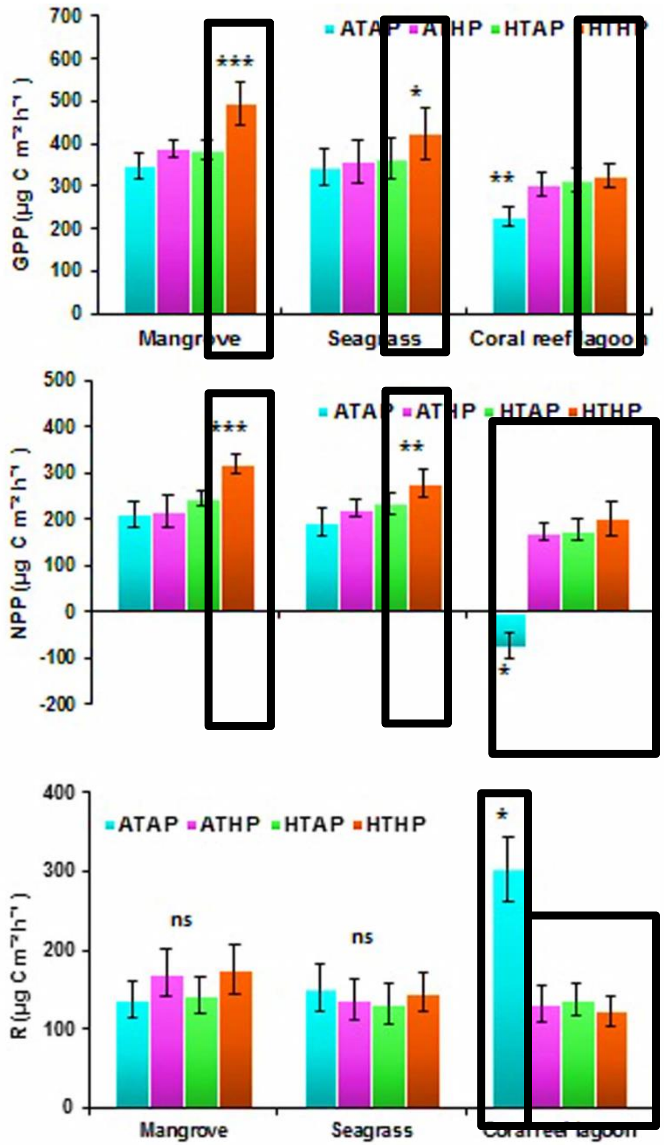


Figure 4.4:. HTHP means (high temperature and high pCO_2) condition . The graph was derived from r (radius of the incubation chamber), θ (angles of sediment samples collection), and z (chlorophyll *a* concentration) data. Chlorophyll *a* concentrations in the incubation chambers' sediment surface are shown with colors.

Sultana et al. (2016). Front. Mar. Sci. 3:100.

Primary production



ATAP = ambient temperature and ambient pCO_2, ATHP = ambient temperature and high pCO_2, HTAP = high temperature and ambient pCO_2, and HTHP = high temperature and high pCO_2.

GPP increased synergistically under HTHP in mangrove and seagrass

Neither high temperature nor high pCO_2 alone had a significant impact

Lagoonal sediment showed higher respiration under ATAP and antagonism under HTHP

Stress in lagoonal incubations caused a shift from heterotrophy to autotrophy

Gross primary production (GPP), net primary production (NPP), and respiration (R). *, **and *** indicate significant differences at $P < 0.05$, $P < 0.01$, and $P < 0.001$ determined using least significant difference tests (post-hoc Tukey's test) depending on incubation conditions (ATAP, ATHP, HTAP and HTHP). Lack of significance is indicated by ns.

Sultana et al. (2016). Front. Mar. Sci. 3:100.

Changes in bacterial abundance

Additive increase in sediment and seawater noticed under HTHP

In mangrove seawater and sediments, the impacts of temp. were greater than that of *p*CO_2

ATAP = ambient temperature and ambient *p*CO_2, **ATHP** = ambient temperature and high *p*CO_2, **HTAP** = high temperature and ambient *p*CO_2, and **HTHP** = high temperature and high *p*CO_2

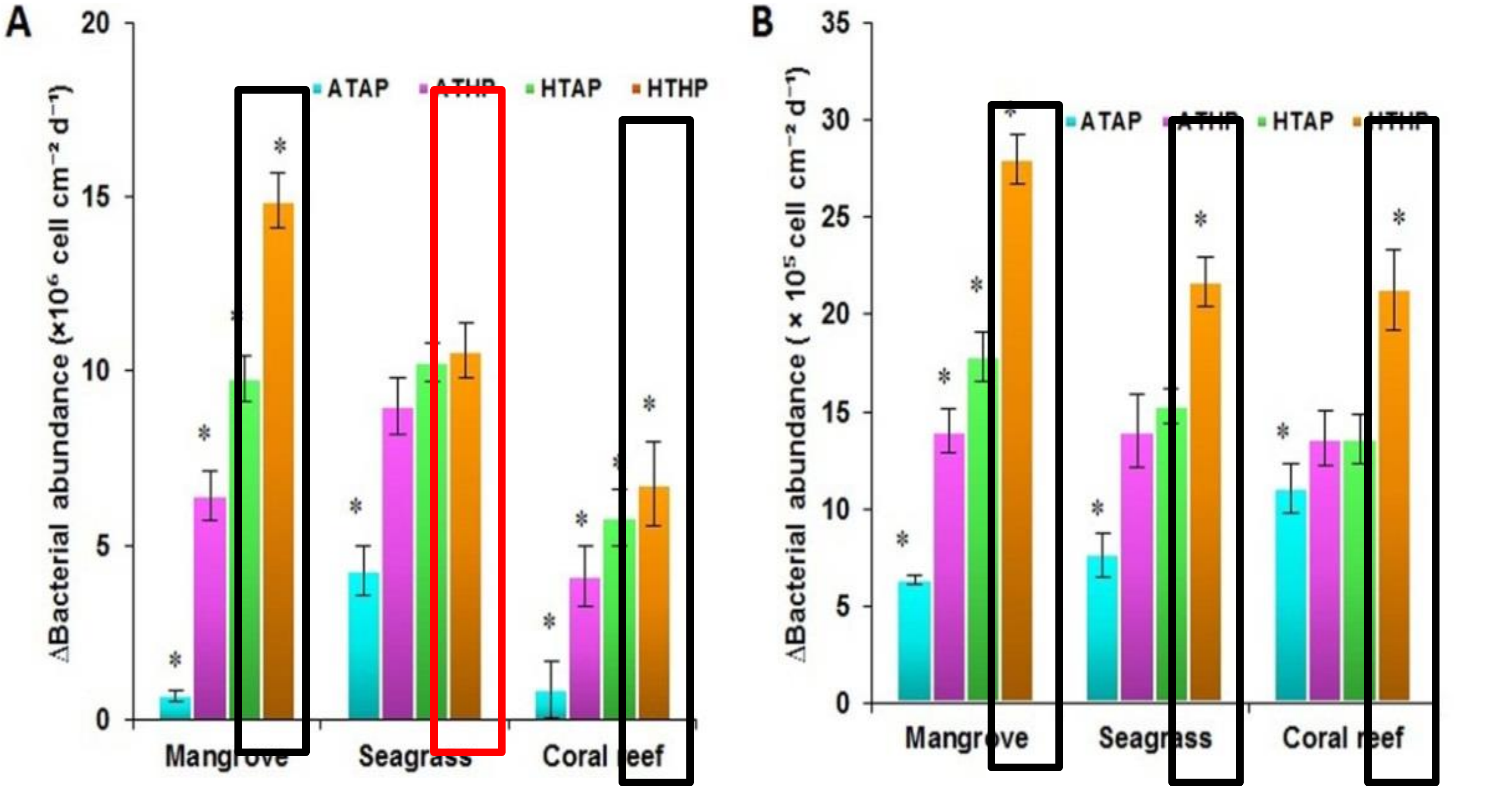
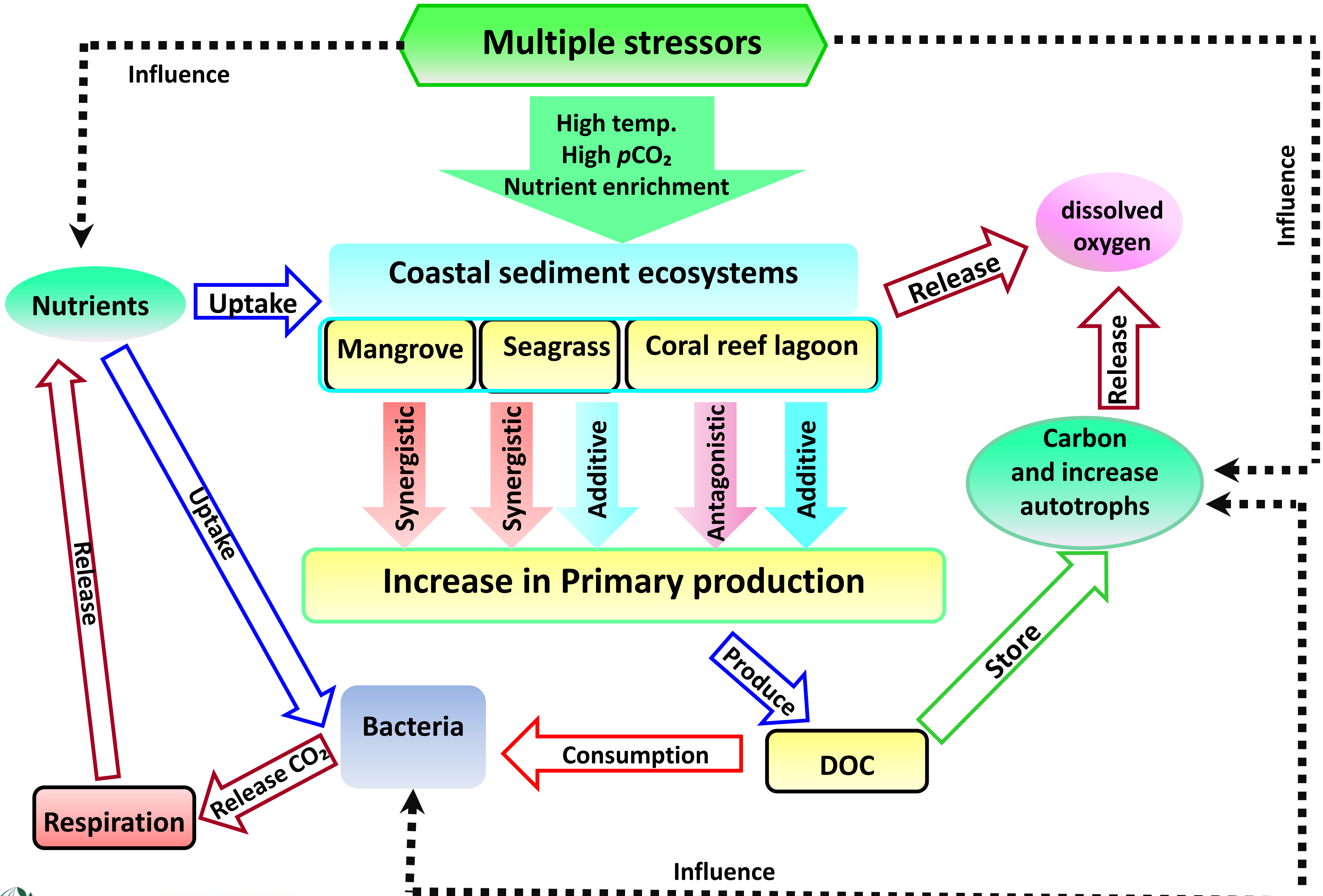


Figure 4.8: Changes in bacterial abundance in sediment (A) and seawater (B). * indicates a significantly difference at *P* < 0.01 determined using a least significant difference test (post-hoc Tukey's test) depending on incubation conditions

Sultana et al. (2016). Front. Mar. Sci.

Conclusion


Multiple stressors
Influence
High temp.
High pCO_2
Nutrient enrichment
Influence
dissolved oxygen
Nutrients
Uptake
Coastal sediment ecosystems
Release
Mangrove
Seagrass
Coral reef lagoon
Release
Synergistic
Synergistic
Additive
Antagonistic
Additive
Carbon and increase autotrophs
Uptake
Release
Increase in Primary production
Store
Produce
Bacteria
Consumption
DOC
Release CO_2
Respiration
Influence

Conclusion

•The increasing impact of several stressors differs significantly from the impact of the single stressors and can result in nonlinear effects and ecological surprises (Segner et al., 2014). Our result is not an exception to this statement.

•A synergistic increase in sediment primary production was observed under the combination of stressors, except in the coral reef

•In lagoon sediment system turned into autotrophy under stress.

•Activities of microbial community increased but not exceeds that of autotrophic compartments.

•Greater carbon fixation by mangrove sediment and accumulation of organic carbon in our incubations implied a high resilience of Mangrove sediment.

•Similar study in Bangladesh is necessary to determine the potential carbon pool in coastal sediment under Future climate scenario

The increasing impact of several stressors differs significantly from the impact of the single stressors and can result in nonlinear effects and ecological surprises .

Thank you

for your kind attention