# Bacterioplankton Abundance and Production in Different Regions of the Indian Ocean

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# How & why are bacteria relevant in biogeochemistry?

Ubiquitous

Bags of enzymes

Nutritionally versatile

Patient but fast to respond

Assimilate D O M

Highly diverse

NIO

# Decomposition by Bacteria Pivotal

Marine photosynthesis

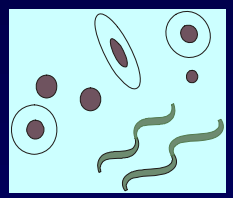
↓

Organic Biomass

↓

Dead Organic Matter

↓



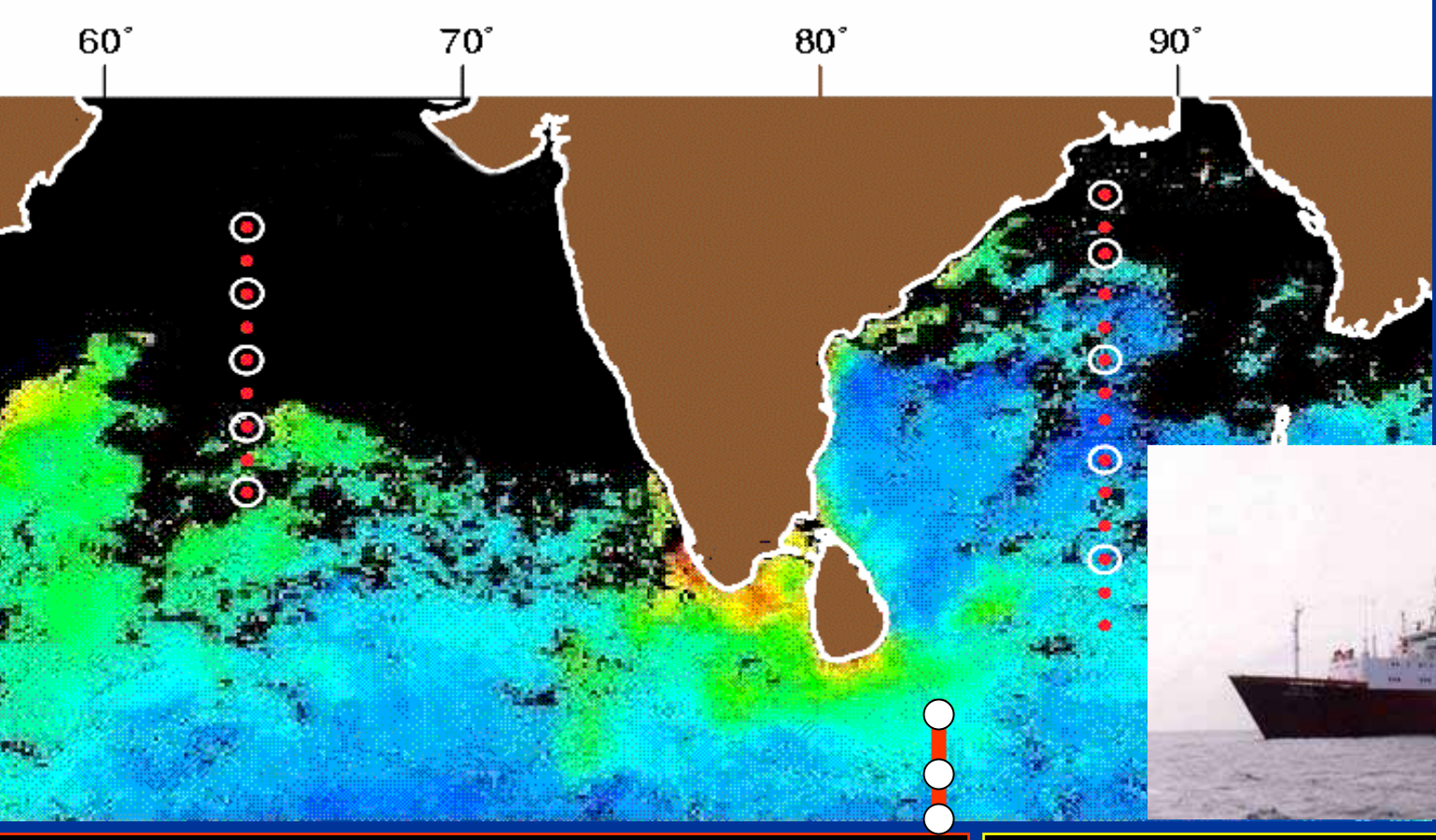
**DECAY BACTERIA**

↓

Inorganic Dissolved Nutrients

$NO_3$; $PO_4$; $SiO_3$; $CO_2$; $H_2S$

Marine Chemosynthesis




JGOFS
BOBPS
CCEIO:
Hbac
abn;pdn

## Arabian Sea:

- Semi annual wind reversals
- Offshore upwelling, winter cooling
- Higher biological productivity
- Intense OMZ & DNZ (200-1200m)
- Invariant MLD mesozoopl biomass

## Bay of Bengal:

- Large freshwater influx
- Mediocre, coastal upwelling
- Warm pool; cloud cover
- Autotr. production lower
- Fish landings up to 35%

# Hbac abundance (no X $10^9$ $L^{-1}$) in different oceans

US DATA SETS (www1.whoi.edu)

| | Sur-50 | <100 | <150 | ~200 |
|---|---|---|---|---|
| **Atlantic (NABE, 1989)** | | | | |
| **Mar-May** | 0.05-16 | 0.05-5.0 | 0.05-5.0 | 0.03-4.0 |
| **Pacific (JGOFS, 1992; 140 W; 12N-12S)** | | | | |
| **Feb-Mar** | 0.05-0.07 | 0.03-0.06 | 0.02-0.05 | 0.02-0.1 |
| **Mar-Apr** | **0.5-0.7** | **0.4-0.5** | **0.2-0.4** | **0.1-0.2** |
| **Aug-Sep** | 0.04-0.1 | 0.02-0.08 | 0.01-0.08 | **--** |
| **Sep-Oct** | **0.6-1.1** | **0.5-0.9** | **0.2-0.6** | **0.2-0.3** |
| **Indian (JGOFS,1995; N; NW)** | | | | |
| **Jan-Feb (NEM)** | 0.07-0.15 | 0.05-0.1 | 0.03-.07 | 0.02-0.04 |
| **Mar-Apr (SIM)** | **0.7-2.5** | **0.5-1.5** | **0.3-0.7** | **0.09-0.1** |
| **Jun-Jul (SWM)** | 0.3-1.7 | 0.1-1.7 | 0.1-0.4 | 0.01-0.05 |
| **Sep-Oct (FIM)** | **0.5-1.7** | **0.3-0.8** | **0.2-0.6** | **0.02-0.05** |

JGOFS-India data; along 64E; India coast

| | | | | |
|---|---|---|---|---|
| **'94 Apr-May (SIM)** | **0.3 - 1.0** | **0.2-0.9** | **0.1-0.6** | **0.1-0.4** |
| **'95 Jan-Feb (NEM)** | 0.05 - 0.1 | 0.03-0.09 | 0.03-0.07 | 0.02-0.07 |
| **'96 Jul-Aug (SWM)** | 0.2 - 0.9 | 0.1-0.6 | 0.09-0.3 | 0.08-0.1 . |

# $^{3}$H Thymidine incorporation rates (pM $L^{-1}$ $h^{-1}$)

**US DATA SETS www1.whoi.edu**

| | Sur-50 | <100 | <150 | ~200 |
|---|---|---|---|---|
| **Atlantic (NABE, 1989)** | | | | |
| **Mar-May** | **1-8** | **0.5-1.5** | **0.5-0.6** | **0.1-0.4** |
| **Pacific (JGOFS, 1992; 140 W; 12N-12S)** | | | | |
| **Feb-Mar** | 0.8-1.5 | 0.1-1.5 | 0.06-0.4 | 0.03-0.1 |
| **Aug-Sep** | 0.3-2.5 | 0.05-2.5 | 0.1-0.9 | 0.1-1.0 |
| **Sep-Oct** | **1.8-3.0** | **0.1-2.0** | **0.1-0.5** | **0.07-0.1** |
| **Indian (JGOFS,1995; N; NW)** | | | | |
| **Jan-Feb (NEM)** | 1-11 | 0.3-8 | 0.3-7 | 0.2-5 |
| **Mar-Apr (SIM)** | **2.5-101** | **0.5-55** | **0.3-100** | **0.9-3.0** |
| **Jun-Jul (SWM)** | 2.3-17 | 0.4-3 | 0.4-2 | 0.5-2 |
| **Sep-Oct (FIM)** | **0.5-12** | **0.2-8** | **0-3** | **0.01-3** |

**JGOFS-India data; along 64E; India coast**

| | | | | |
|---|---|---|---|---|
| **'94 Apr-May (SIM)** | **25 - 50** | **14-29** | **13-16** | **1-4** |
| **'95 Jan-Feb (NEM)** | 0.5 – 1.9 | 0.3-0.9 | 0.3-0.7 | -- |
| **'96 Jul-Aug (SWM)** | 0.9 – 3.0 | 0.2-3.0 | 0.1-0.3 | 0.06-0.1 |

# Annual variability of Bacterioplankton abundance in the Arabian Sea surface waters is of two orders

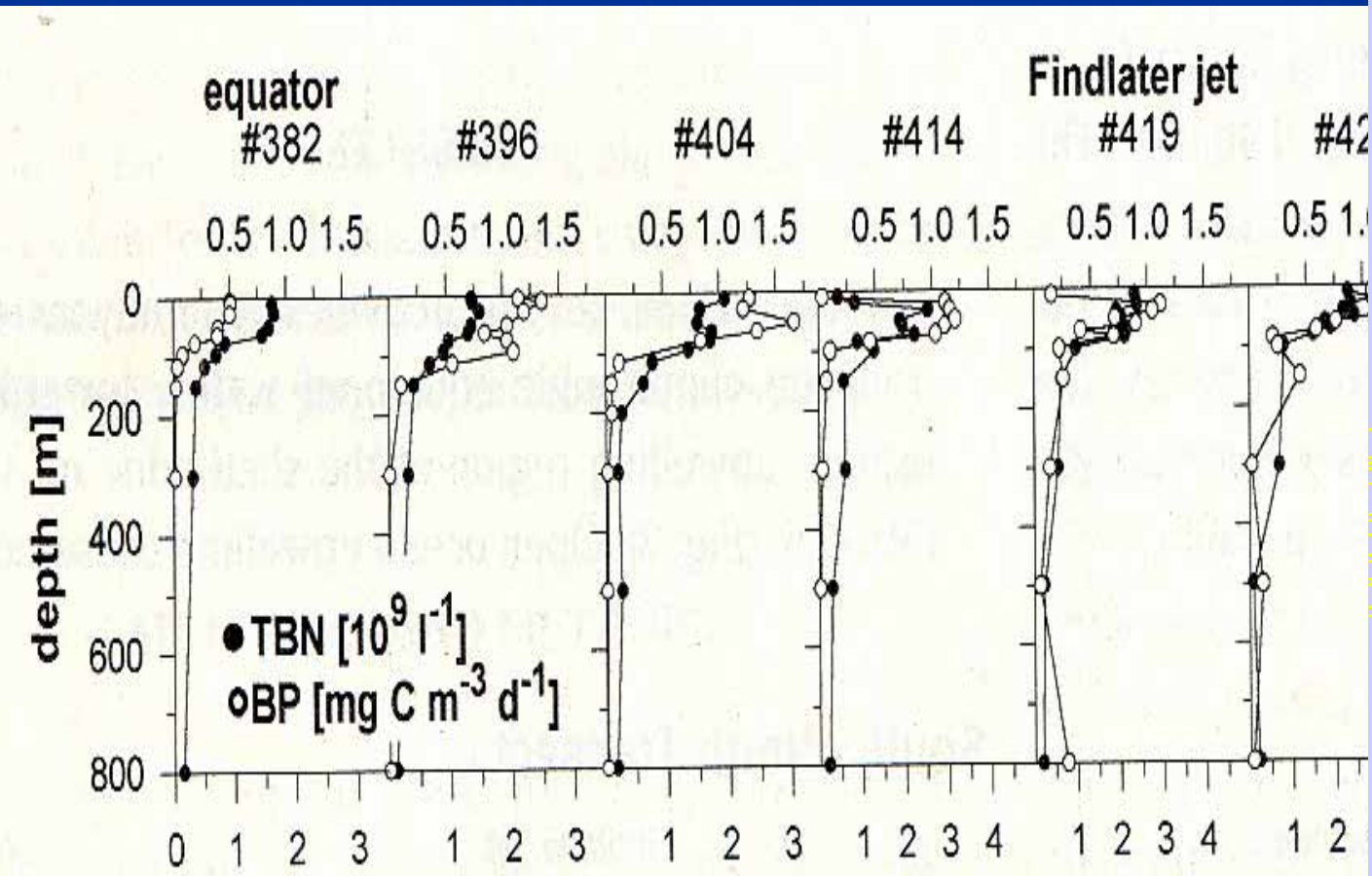
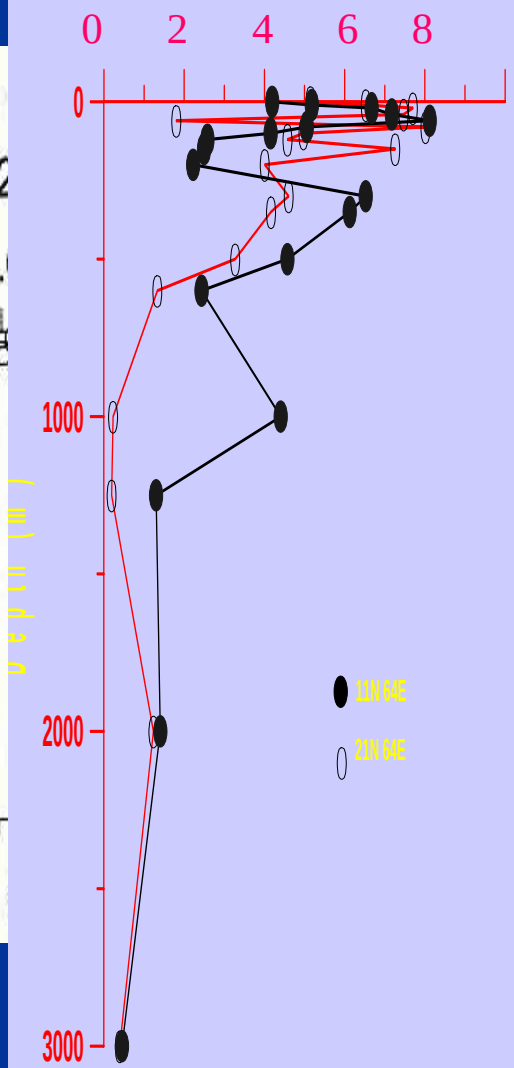
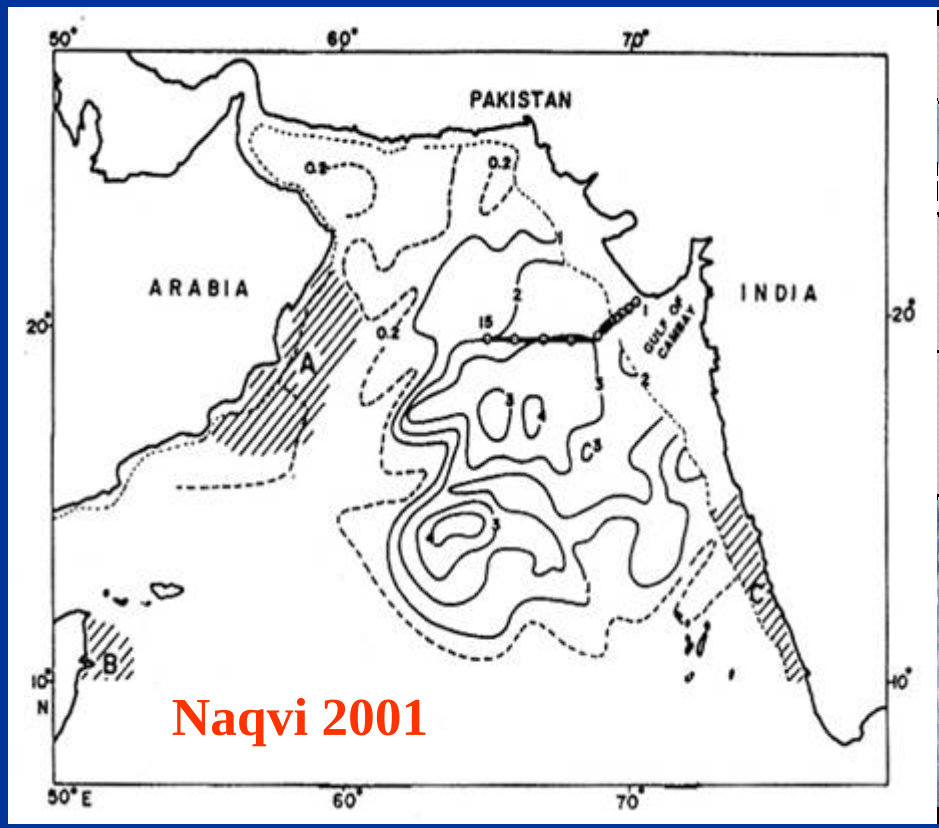


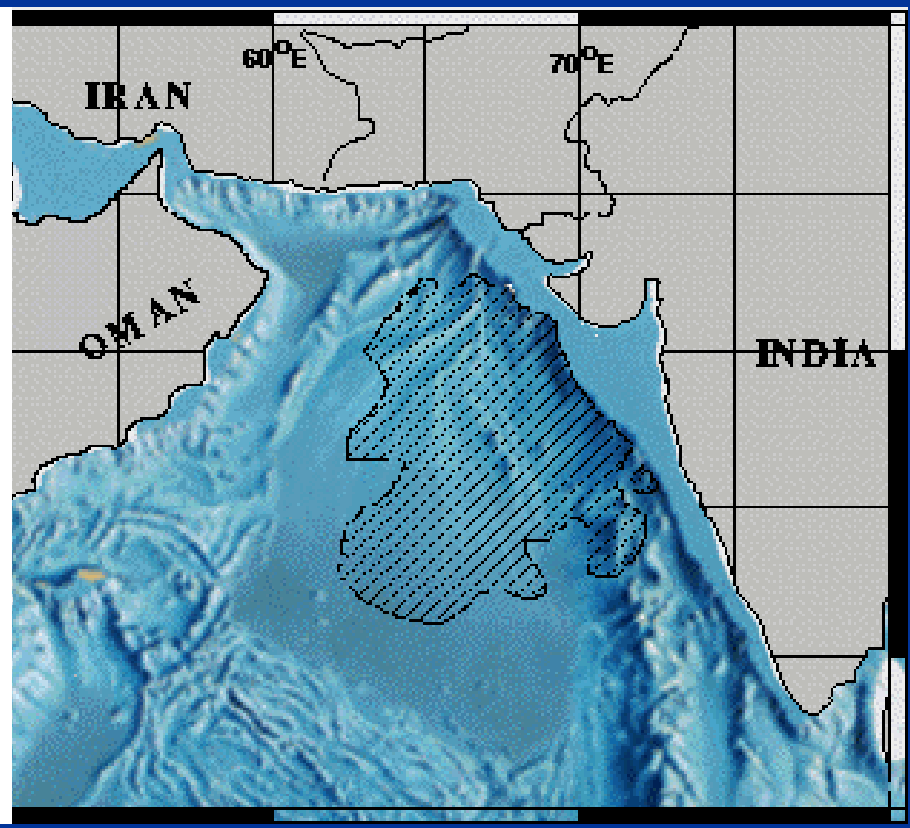

Figure from Hoppe & Ullrich, 1999

**Su:1.8-8.2X10$^{8}$l$^{-1}$**
**Dp: 4.5-9X10$^{7}$l$^{-1}$**



# AS Dentrification is predominantly Hbac mediated




A third of the global-marine denitrification happens in a small area in the Arabian Sea

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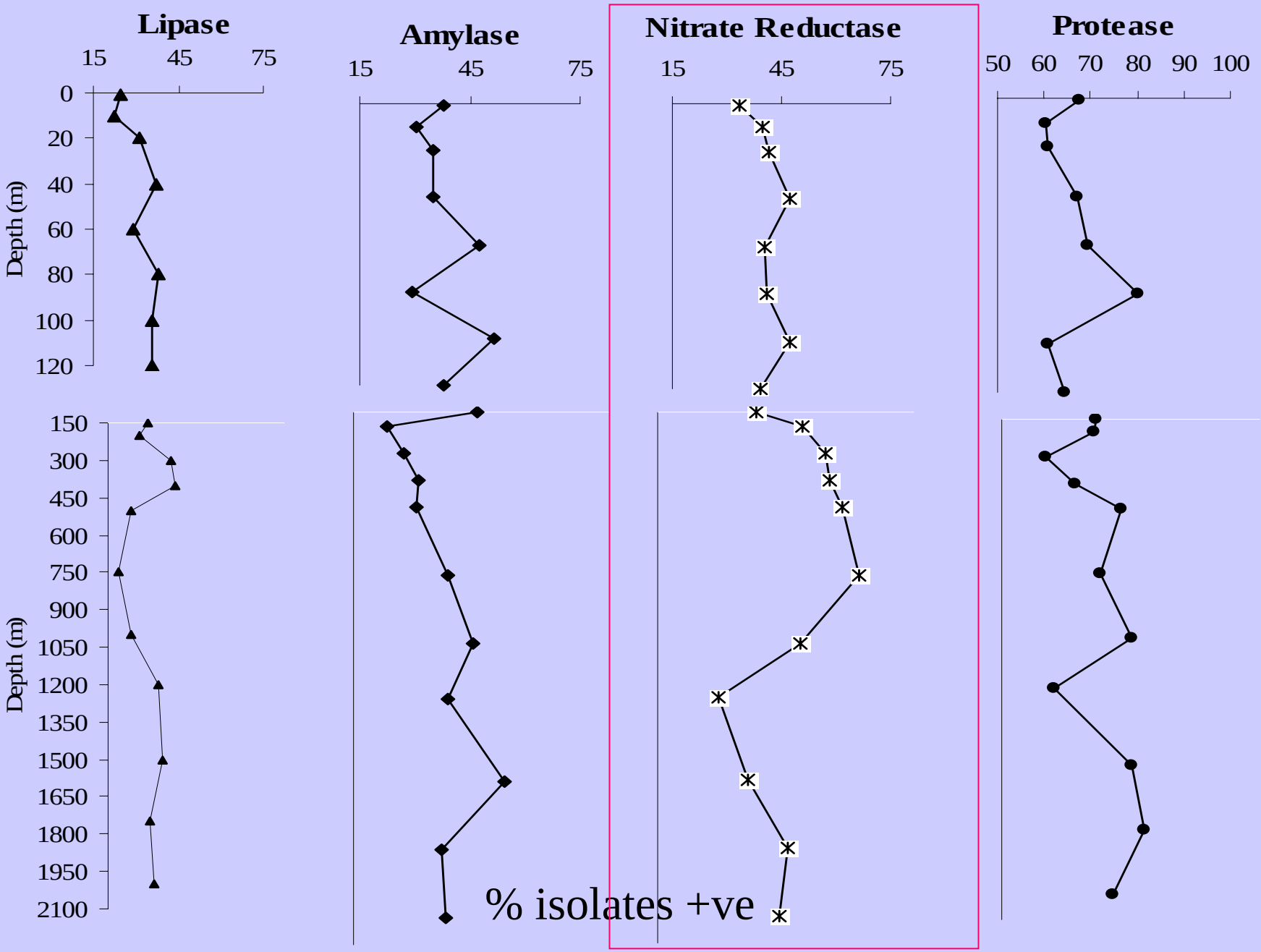
# Hbac thrive through oligotrophic situations

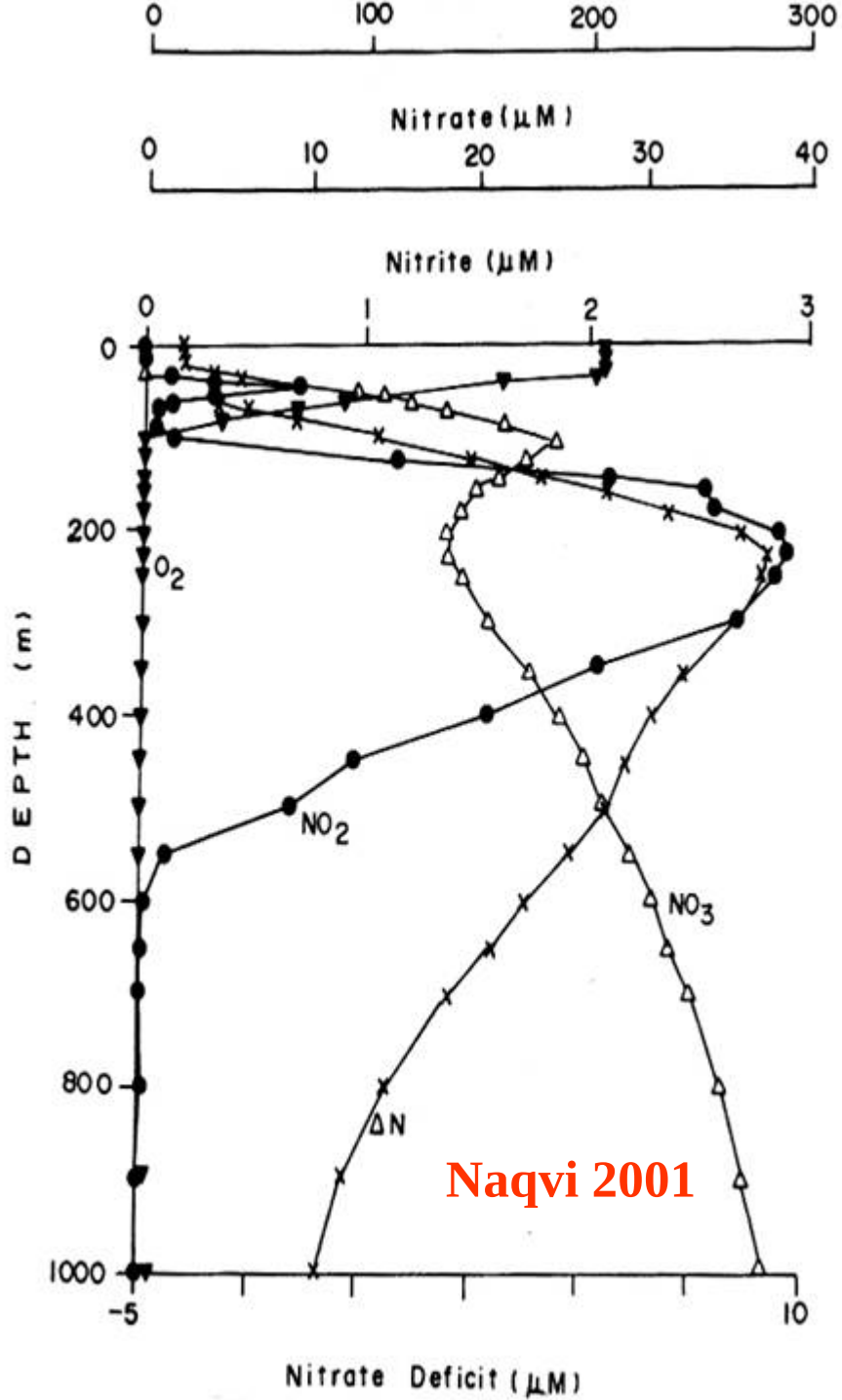
| Depth zone | 1sNA (Plte cnts x $l^{-1}$) | (% of plate counts *vis a vis* 1sNA) 0.5sNA | 0.2sNA | 0.1sNA |
|---|---|---|---|---|
| MLD | 2969-9466 | 108-139 | 138-202 | 119-202 |
| OMZ | 907-1711 | 165-206 | 202-250 | 129-174 |
| !OMZ | 211-1303 | 176-218 | 194-233 | 119-163 |

Adaptation to grow in low nutrient conditions has several ecological advantages. Oligotrophs endure ‘feast ↔famine’ situations better; Miniaturize; Double sensibly; Probably better equipped for ecological adversities

# Hydrolytic Enzymes of culturable Arabian Sea Hbac



# $NO_3$, $NO_2$ profiles and NR




Naqvi 2001

- % NR+Hbac more in Arabian Sea Denitrification Zone
- ~75% DNZ isolates reduce $NO_3$ beyond nitrite
- Rapid denitrfication due to Hbac communities adapted to OMZ

NIO

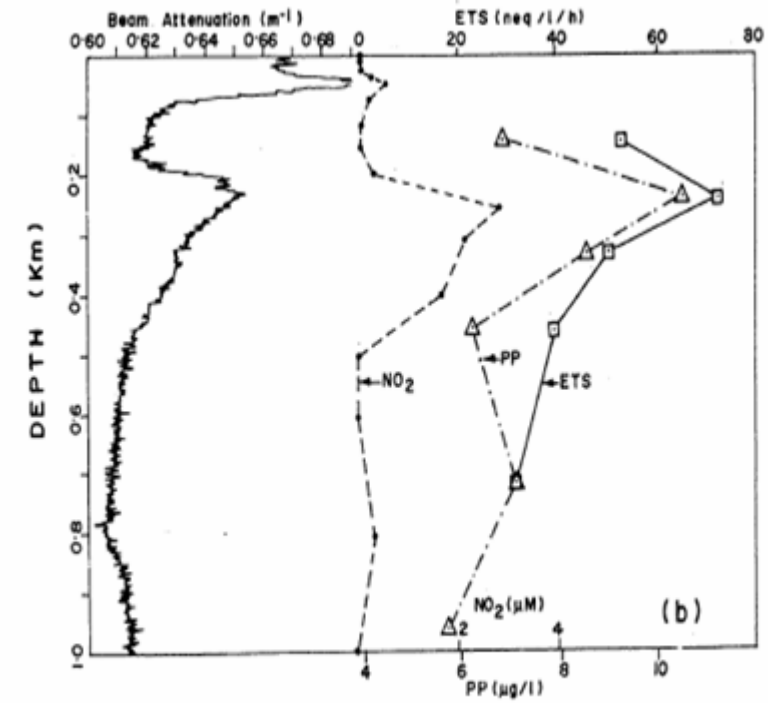
# High Microbial Respiration Rates; NRA in Arabian Sea

"….seem to suggest a major role for dissolved and/or suspended organic matter in fuelling oxygen consumption and denitrification."

Average number and activity of bacteria

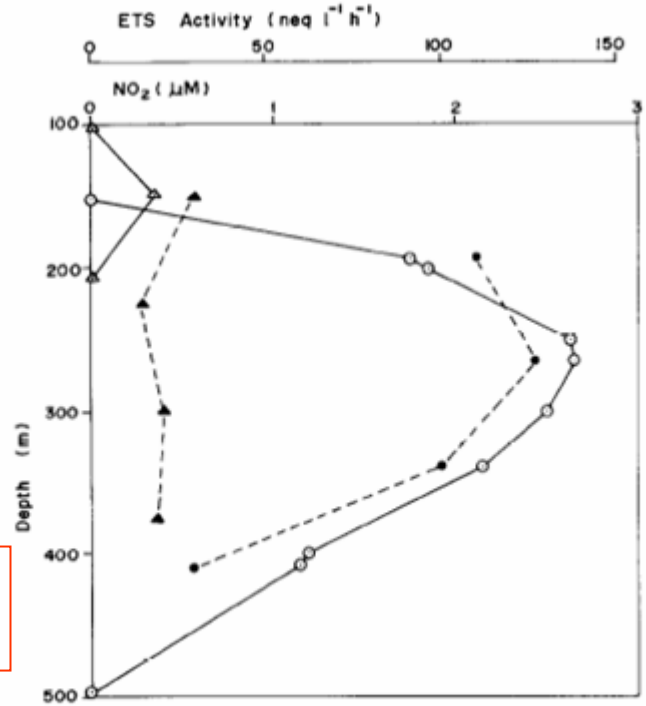
| Depth (m) | NRB ($\times 10^3$/ml) | | | | NRA (µg at $NO_2$-N/ml/hr) | | | |
|---|---|---|---|---|---|---|---|---|
| Stations | 25 | 50 | 100 | 200 | 25 | 50 | 100 | 200 |
| Offshore | 2.2 | 3.7 | 3.1 | 2.1 | 5.1 | 4.2 | 3.0 | 15.3 |
| Nearshore | 0.8 | 0.7 | 0.7 | 1.1 | 7.5 | 5.7 | 1.5 | 16.2 |
| Total | 1.6 | 2.8 | 2.2 | 1.9 | 6.0 | 4.8 | 2.4 | 15.6 |
| | SRB ($\times 10^3$/ml) | | | | SRA (ug at $S^{=}$-S/ml/hr) | | | |
| Offshore | 5.9 | 2.9 | 2.9 | 6.5 | 0.15 | 0.10 | 0.11 | 0.05 |
| Nearshore | 1.5 | 3.2 | 1.2 | 3.8 | 0.18 | 0.13 | 0.08 | 0.01 |
| Total | 4.7 | 3.0 | 2.4 | 5.7 | 0.16 | 0.11 | 0.10 | 0.03 |

**Lokabharathi et al 1993**




. Depthwise distributions of nitrite, electron transport system (ETS) activity, and particulate protein (PP) in relation to beam attenuation at stations (*a*) 2492, (*b*) 2496, (*c*) 2498, (*d*) 2509, (*e*) 2514, and (*f*) 2515 (PP data only at 2496 and 2498).

**Naqvi et al 1993; 1996**



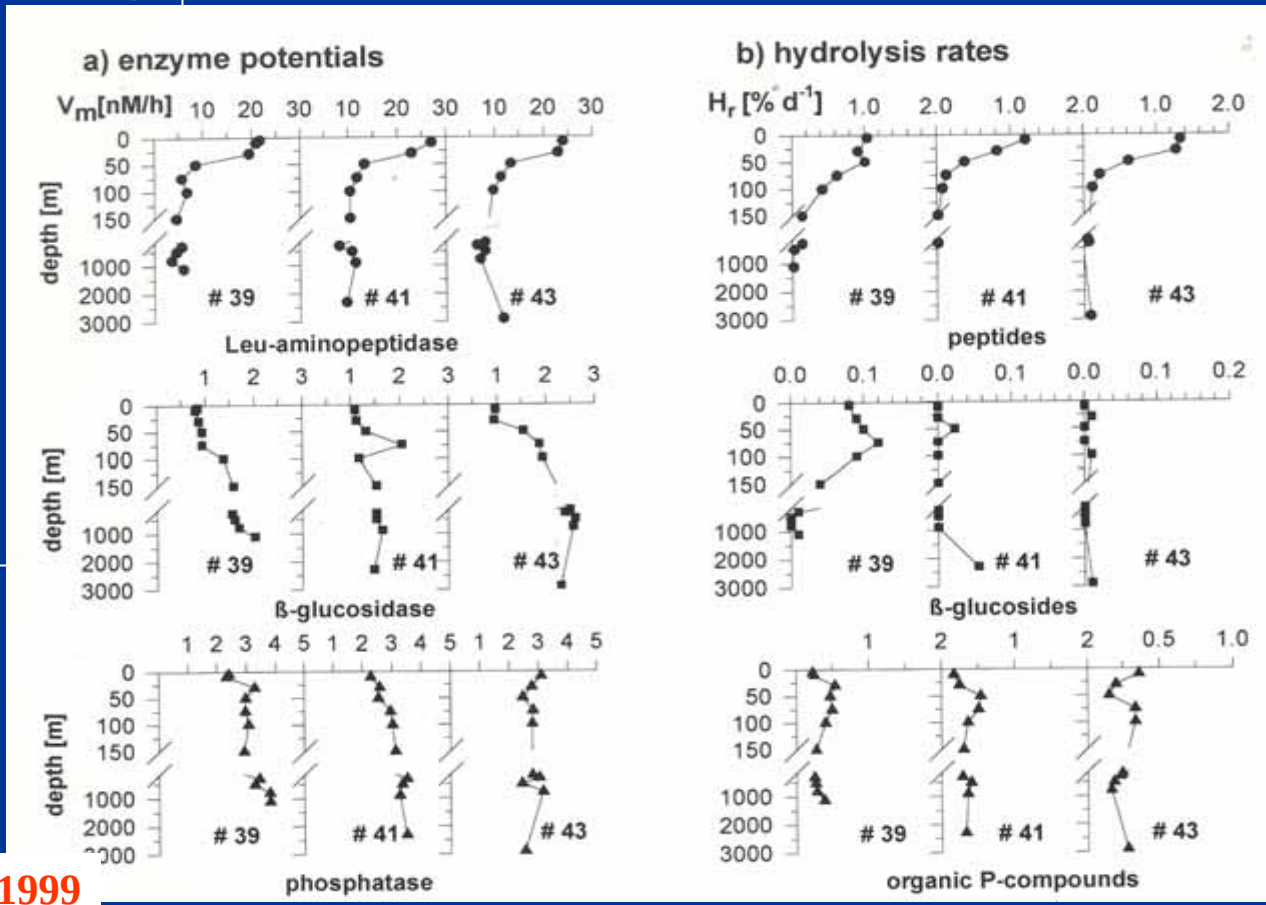

Depth profiles of ETS activity (solid symbols) and nitrite (open symbols) at two stations located at the periphery (Z1; triangles) and close to the centre (L13; circles) of the denitrification zone.

# Enzyme activities in AS

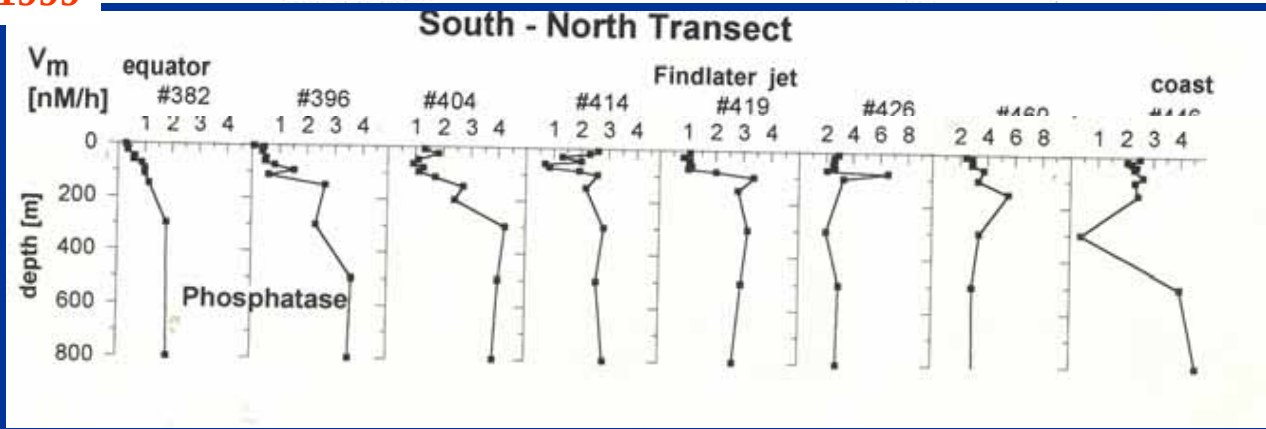
**Faster in surface waters**

**Peptide turnover times quite akin to some reported from estuaries**

**Elevated P-ase activity in mesopelagic zone**




**Figures from Hoppe and Ullrich, 1999**



# High conc of TEP meet deep sea Hbac C

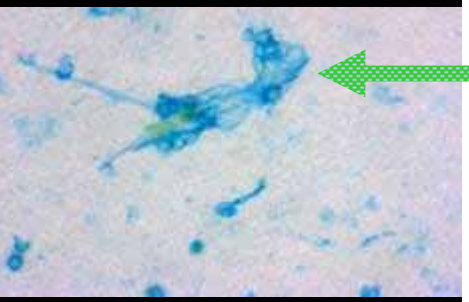
## Arabian Sea:

Large sized; >200 mu

Conc 2-3 times of BoB

Bloom-region highs

Sur Av 60mg AA eqL $^{-1}$



## Bay of Bengal:

Smaller sized; <100mu

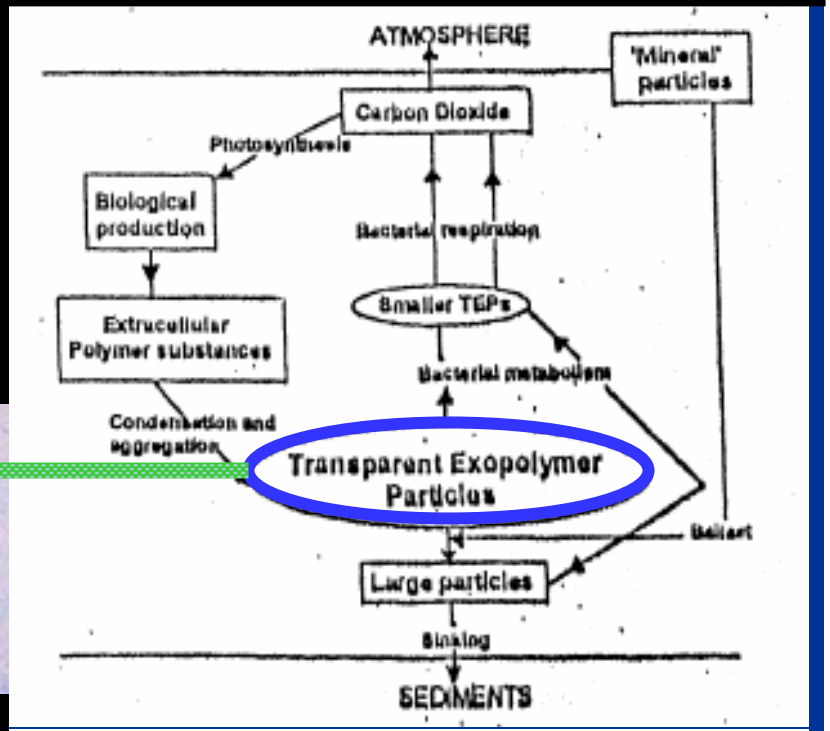
Higher numbers ml$^{-1}$

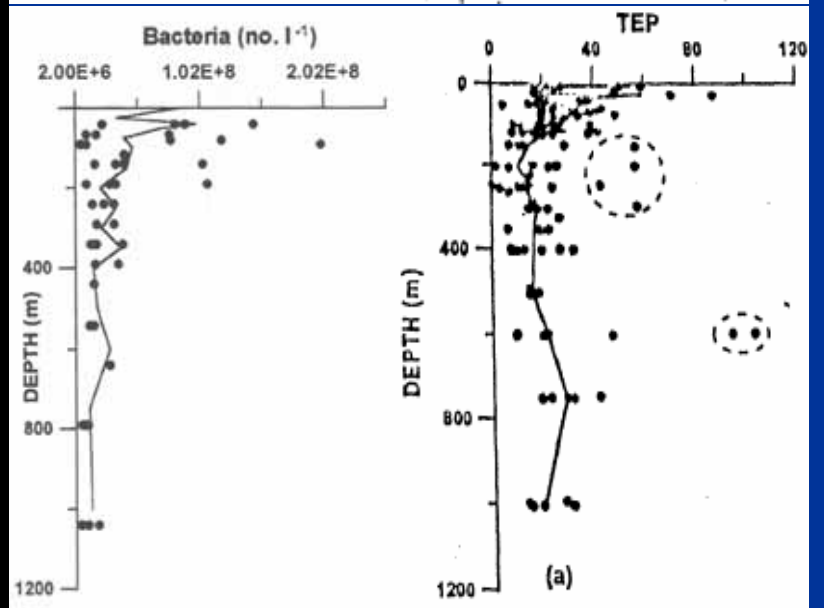
High % with min prtcls

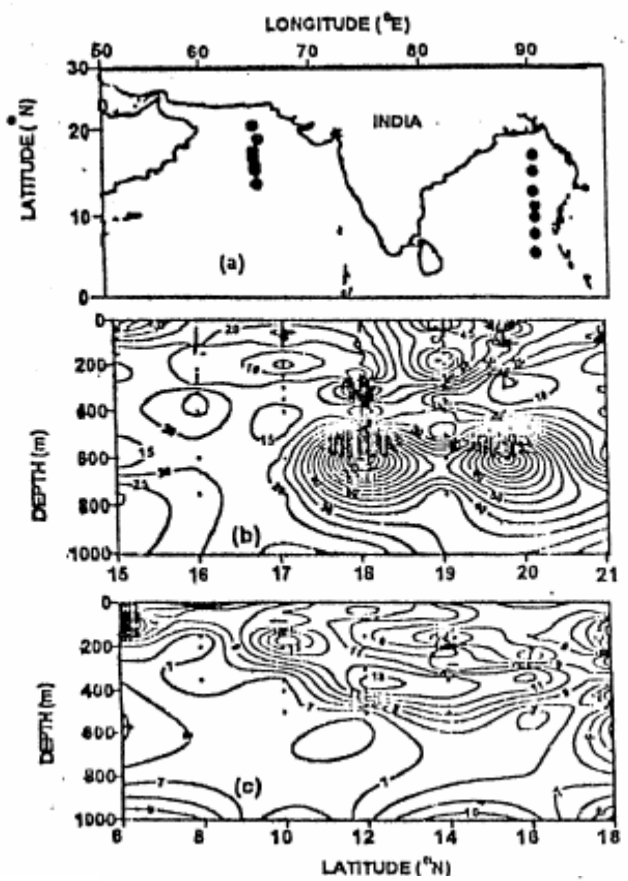
Aid ballasting Org C?

Aid high Hbac in deep!

Sur Av 25mg AA eqL $^{-1}$



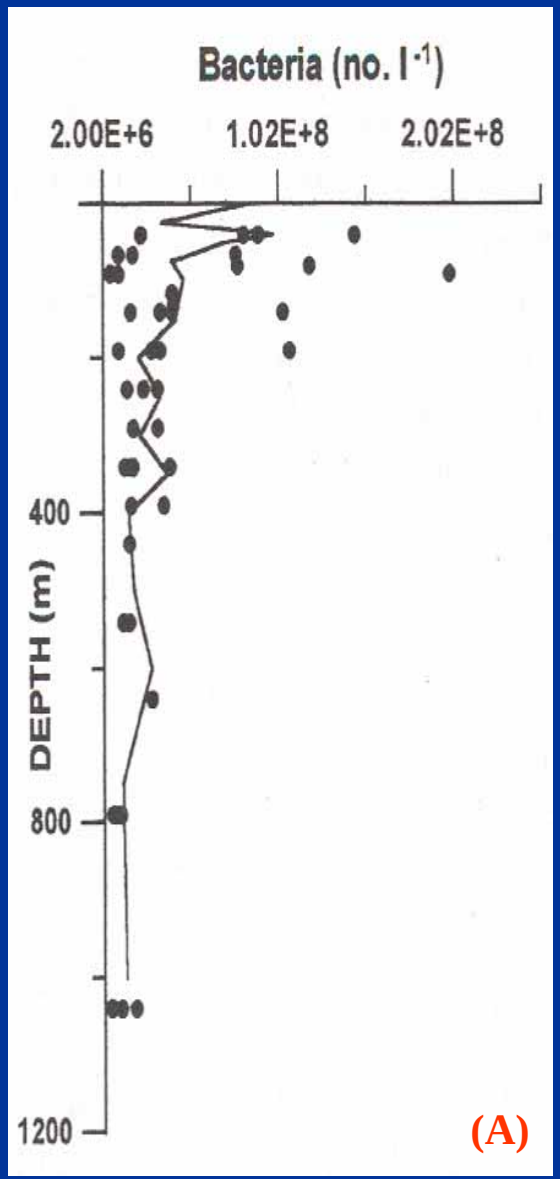



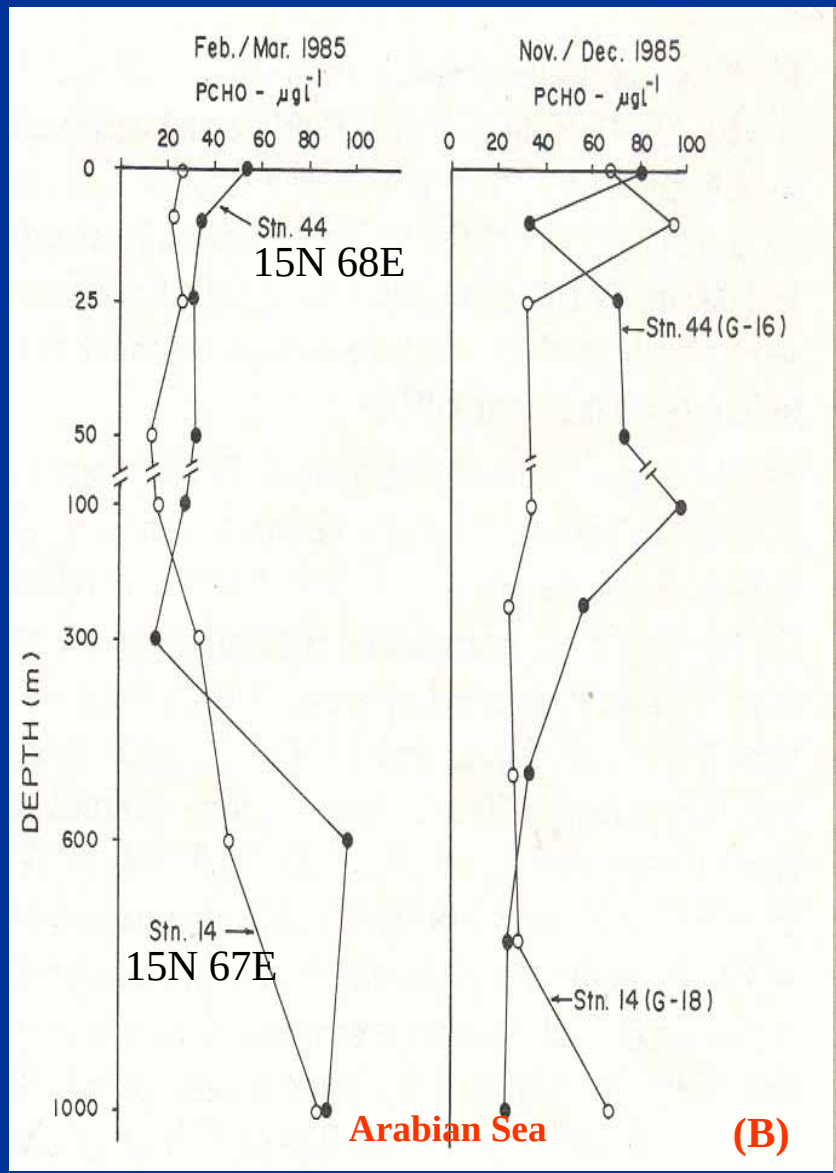

Transparent Exopolymer Particle Characteristics and Bacterial Counts at Mid-depth in the North Indian Ocean

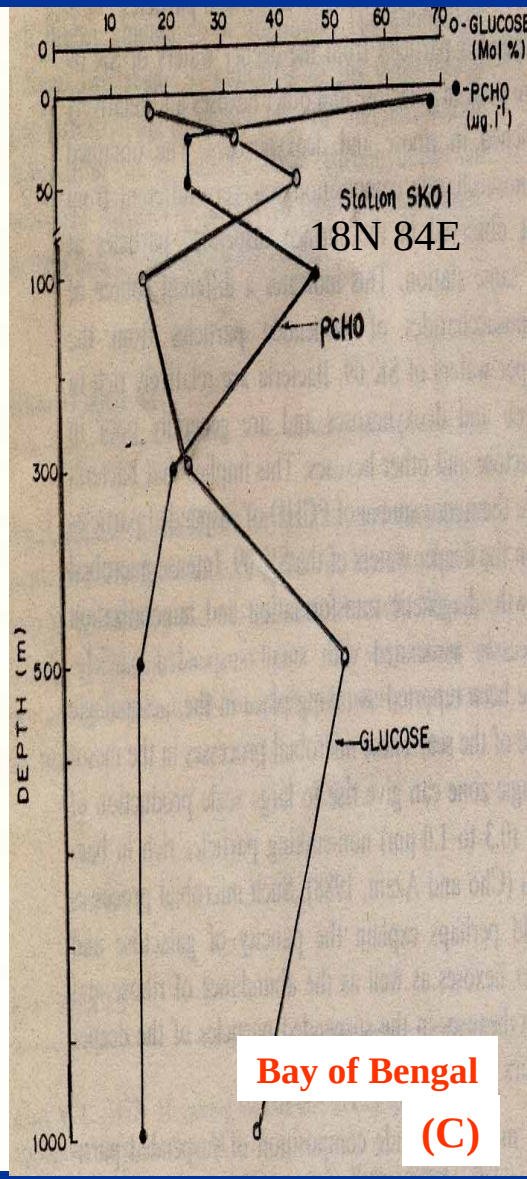
| Lat. (°N) | Long. (°E) | Depth (m) | Bacteria counts[a] (per ml) | TEP mean length[b] (μm) | TEP total counts (per ml) | TEP with mineral particles (%) | TEP without mineral particles (%) |
|---|---|---|---|---|---|---|---|
| | | | Arabian Sea | | | | |
| 15 | 64 | 600 | 2.94 | 37±42 | 260 | 46 | 54 |
| 17 | 64 | 500 | 1.64 | 92±97 | 130 | 46 | 54 |
| 19 | 64 | 500 | 1.29 | 21±23 | 330 | 38 | 62 |
| 21 | 64 | 500 | 3.40 | 42±67 | 350 | 33 | 67 |
| | | | Bay of Bengal | | | | |
| 8 | 90 | 500 | 10.45 | 9±10 | 4400 | 84 | 16 |
| 10 | 90 | 500 | 7.41 | 16±18 | 6690 | 75 | 25 |
| 16 | 90 | 500 | 4.28 | 11±18 | 7790 | 80 | 20 |
| 18 | 90 | 500 | 0.94 | 7±12 | 4800 | 86 | 14 |

[a]Bacteria (x10$^6$) and TEP counts were total numbers in seawater.
[b]The lengths of TEP were determined from a minimum of 30 particles.
[c]TEPS associated with and without mineral particles were based on those counted in randomly selected 40 fields on each filter.

# Particulate carbohydrates substantial in deep layers of Indian Ocean



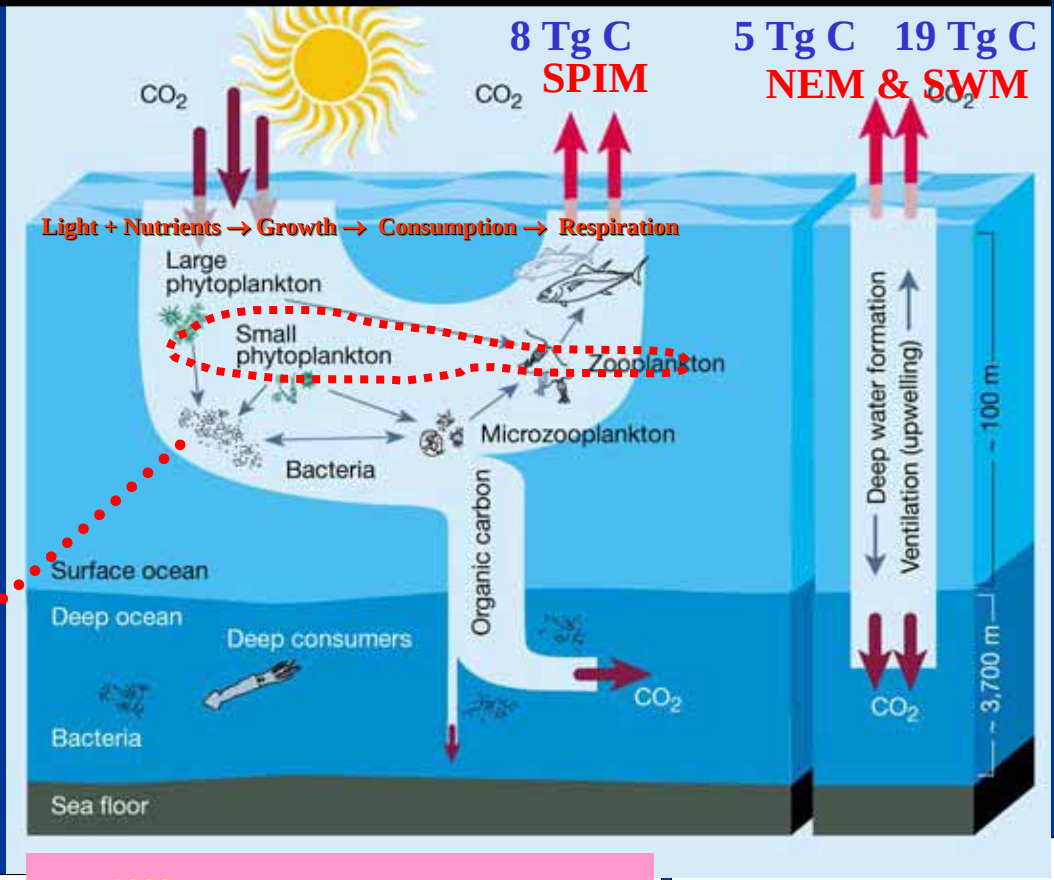

Figures B & C from Bhosle et al 1989; 1992

# Biological Pump in the Eastern Arabian Sea

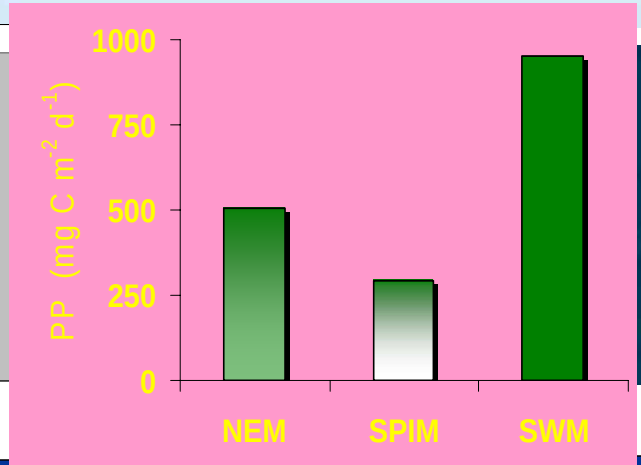
**In the EAS, primary productivity undergoes drastic seasonal variability; lowest during SpIM**

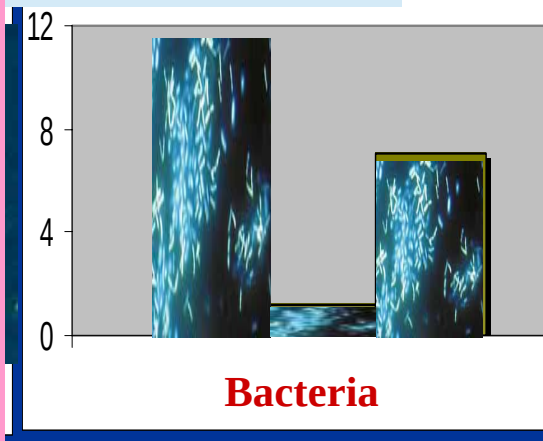
**During SIM, Hbac throug microbial loop sustain micro – and meso- zooplankton; providing for C-flux despite low PP**

**Microbial loop**

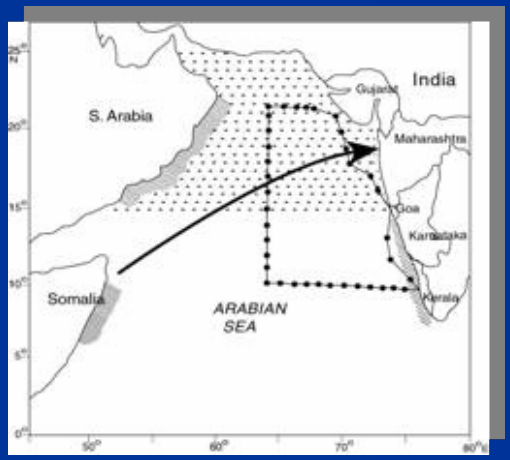


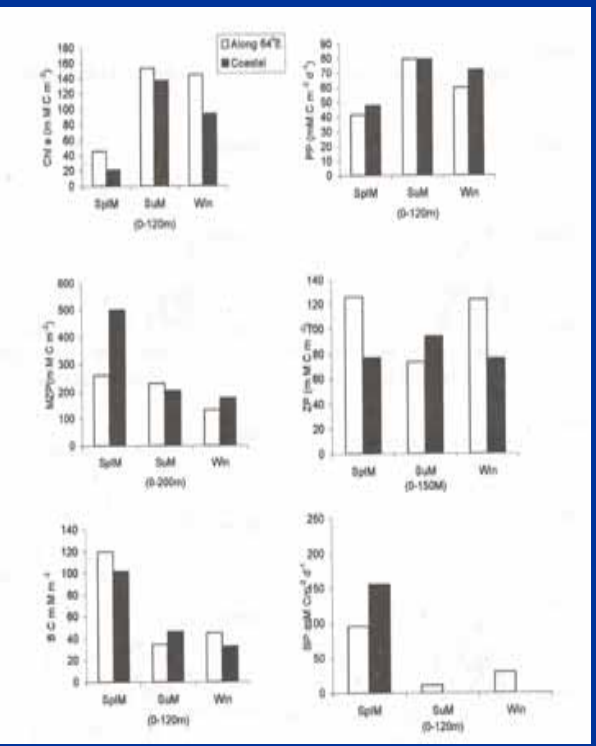


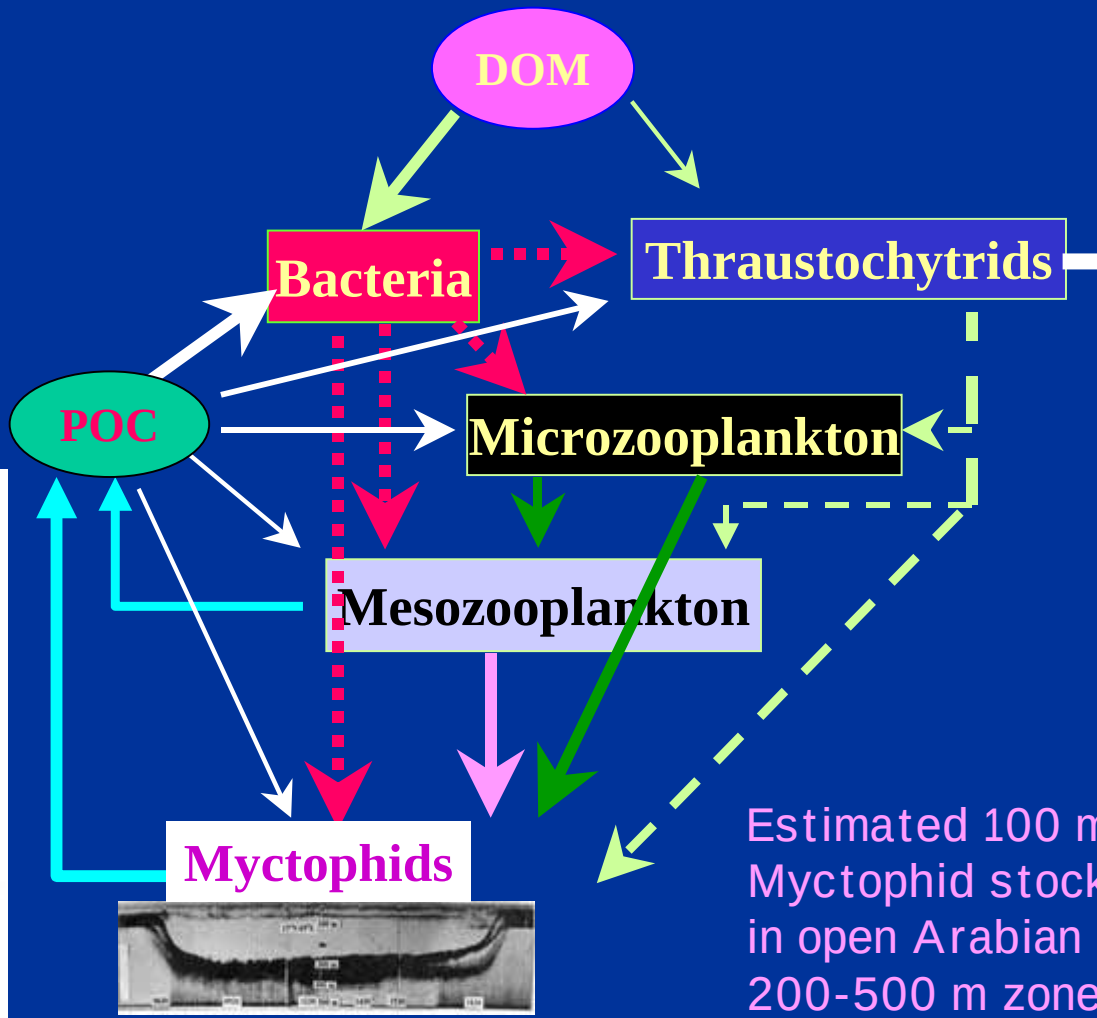


# AS Microbial loop: vital for myctophids?

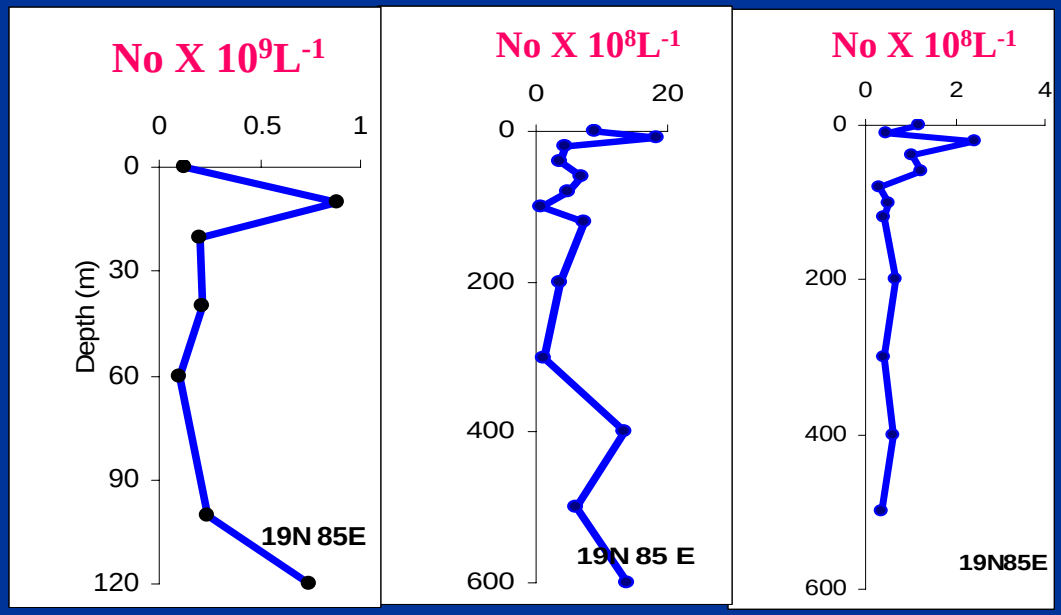


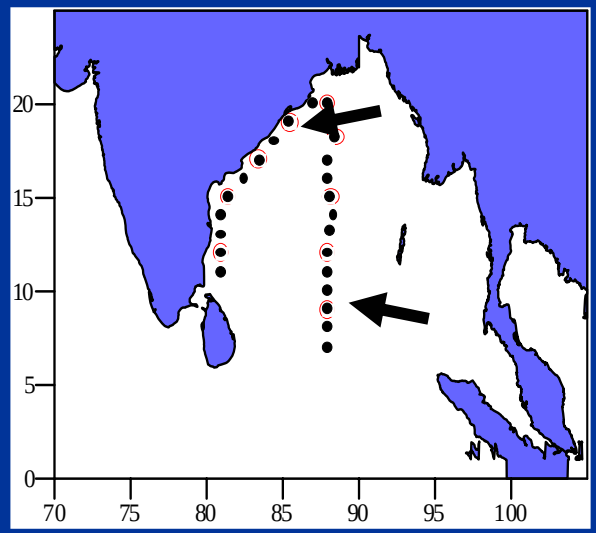


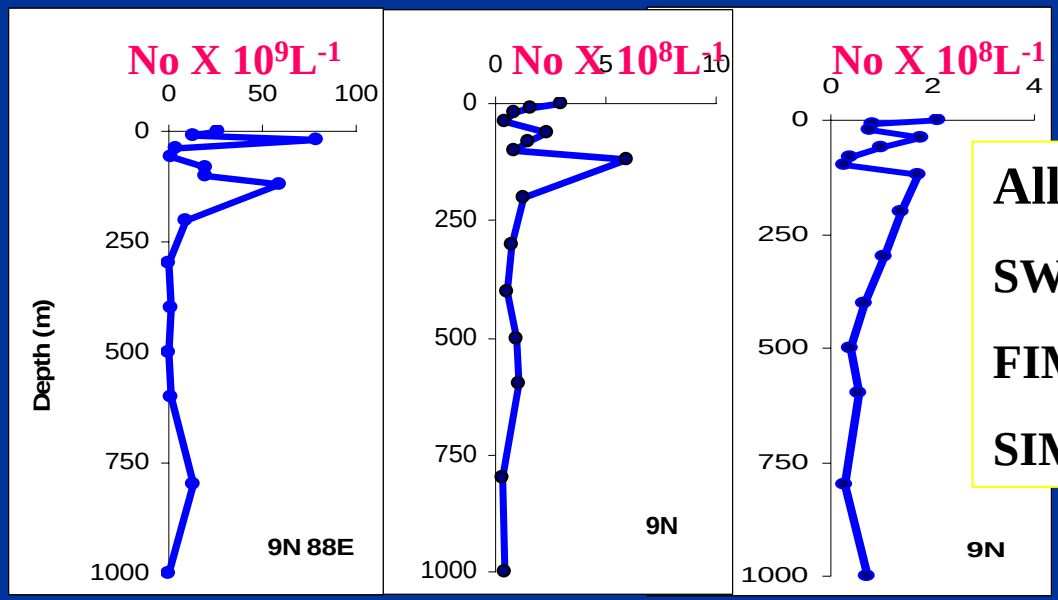

Estimated 100 mmt
Myctophid stock
in open Arabian Sea
200-500 m zone

# HBac abundance more in the eddy regions of the Bay




SWM FIM SIM



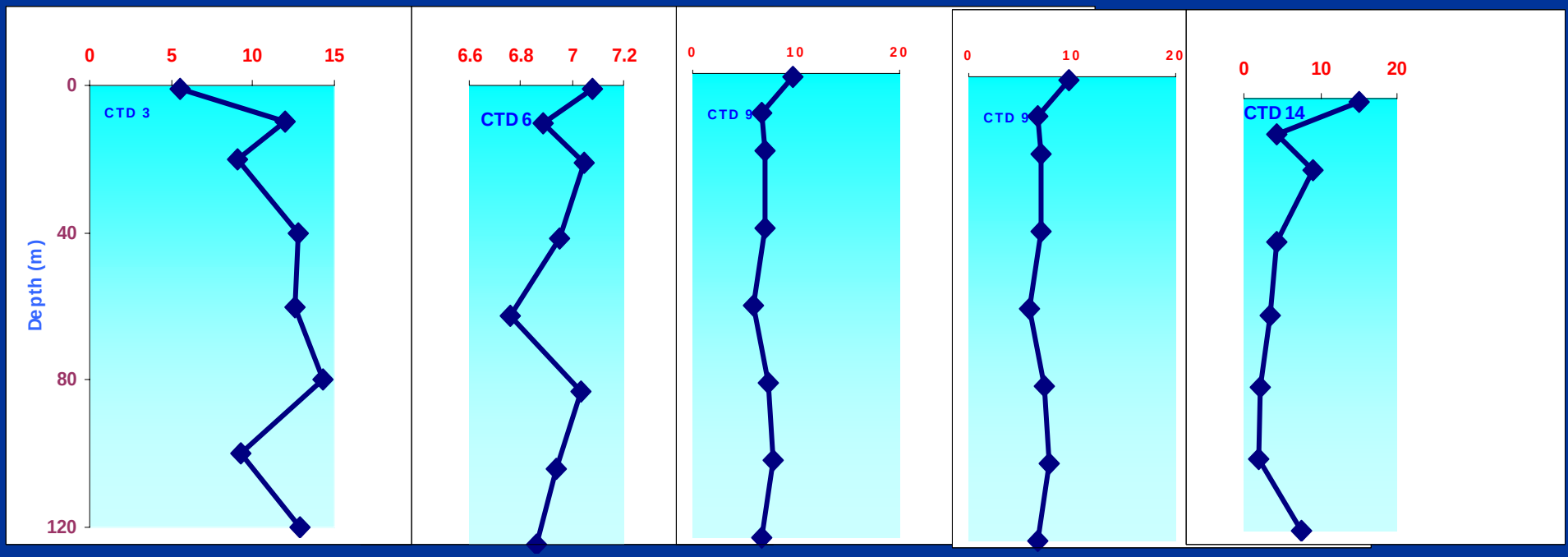

**All seasons ranges ($10^9$ $L^{-1}$)**

**SWM:** 3.8-79.0; 1.5-20; 9.1-60; 0.4-10

**FIM:** 1.1- 2.1; 7.6-9.4; 2.5-5.0; 1.5-2.0

**SIM:** 0.02-0.4; 0.24-0.7; 0.2-0.4; 0.3-0.4

# BCP (mg C $m^{-3}$ $d^{-1}$) along 88 °E



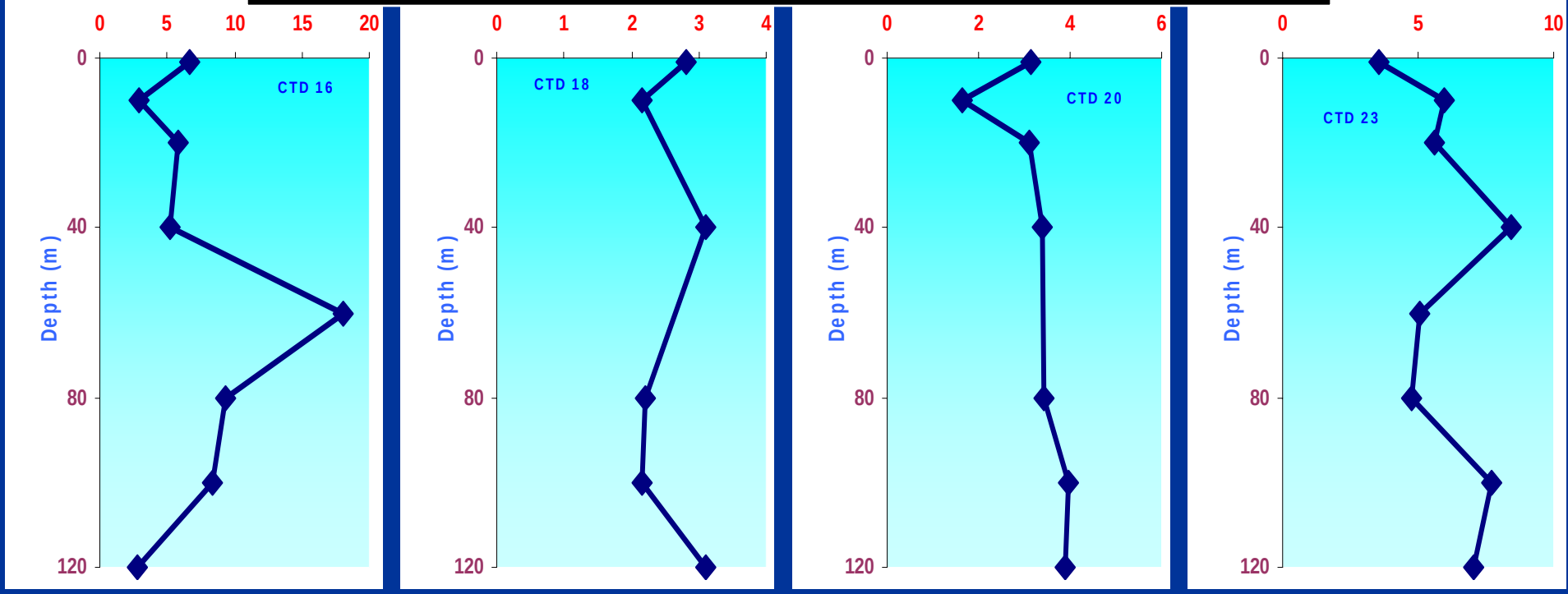

## Bacterial Carbon Production ($m^{-3}$ $d^{-1}$ )

BGR Measured through $^{3}H$ uptake determination

1 M $^{3}H$ incorporation produces 2.17 X $10^{18}$ bacterial cells

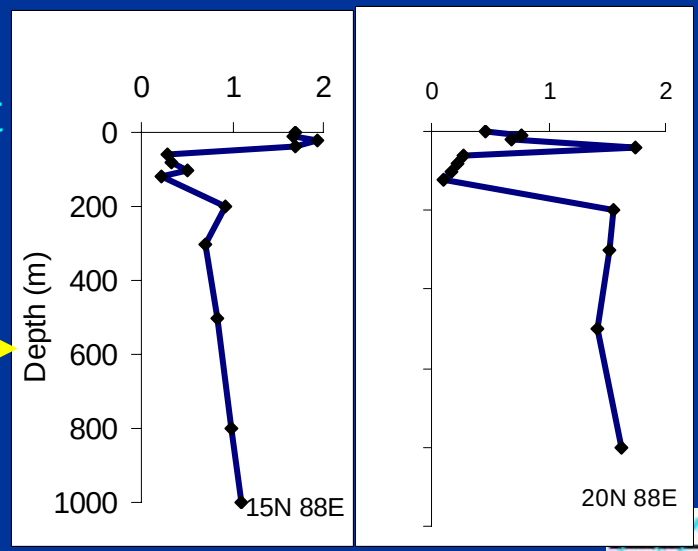
1 bacterial cell has 11 fg C

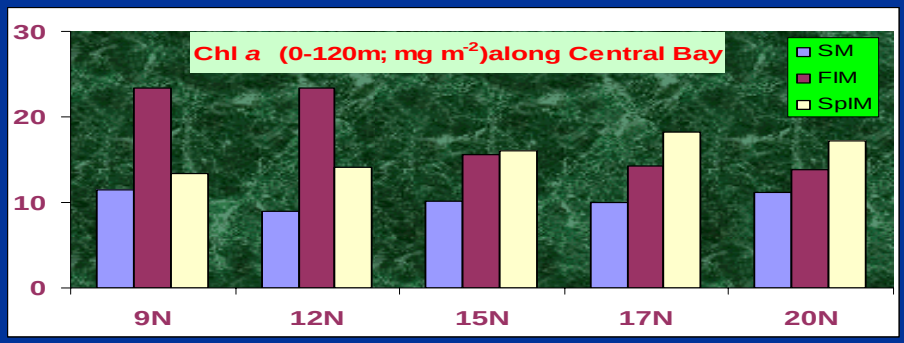
# BCP (mg $m^{-3}$ $d^{-1}$)along Coastal Transect

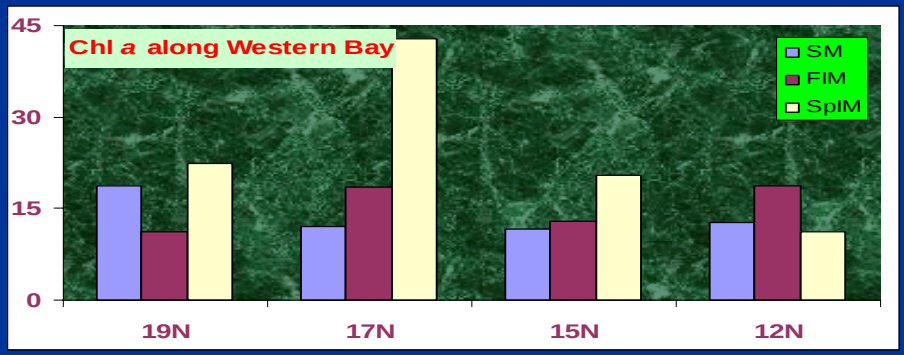


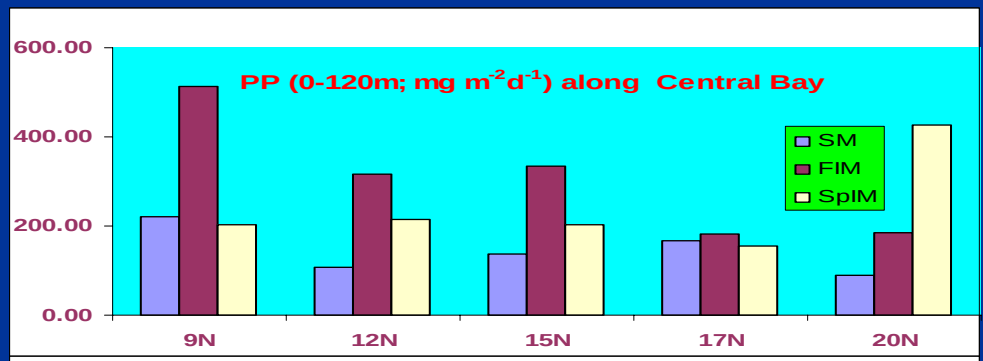

**Coastal BCP generally lower than that in the open ocean; quite surprisingly**

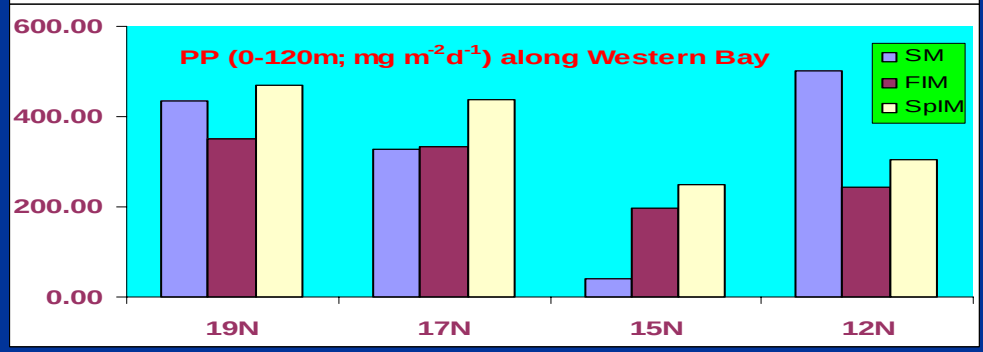
**BCP often higher below 200m!**

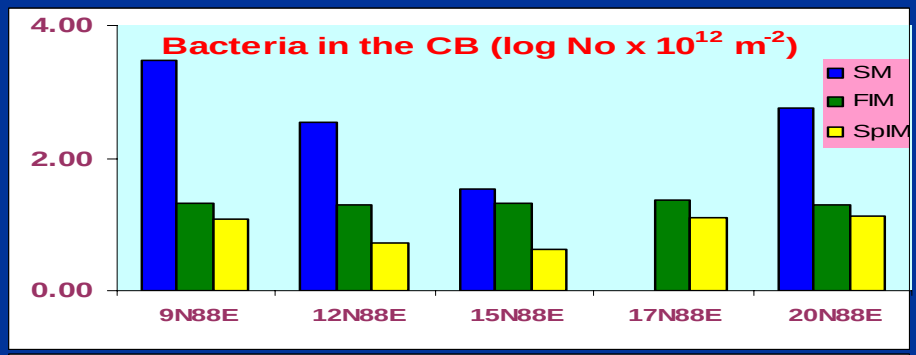


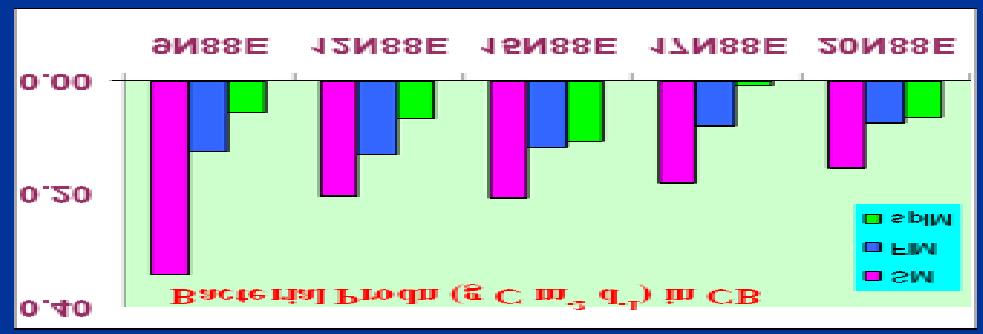

Chl a (0-120m; mg m-2)along Central Bay
SM
FIM
SpIM
30
20
10
0
9N
12N
15N
17N
20N

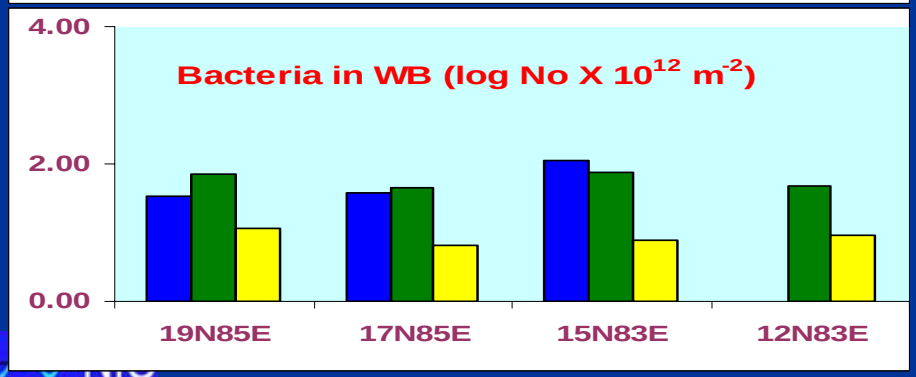

Chl a along Western Bay
SM
FIM
SpIM
45
30
15
0
19N
17N
15N
12N

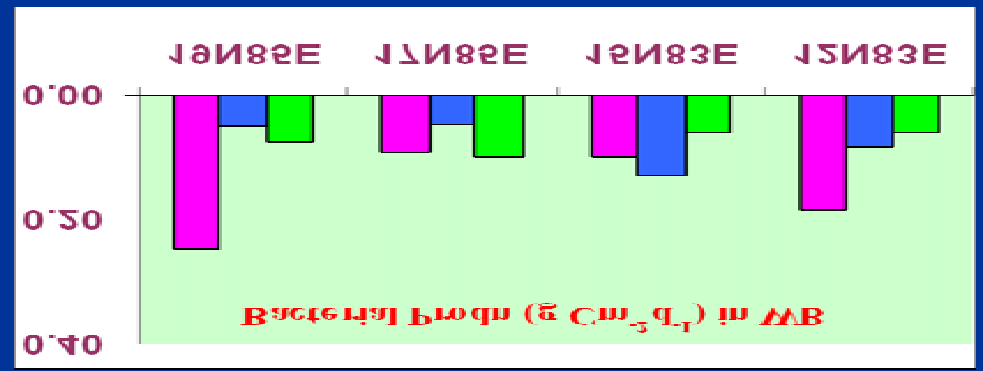

PP (0-120m; mg m-2d-1) along Central Bay
SM
FIM
SpIM
600.00
400.00
200.00
0.00
9N
12N
15N
17N
20N


PP (0-120m; mg m-2d-1) along Western Bay
SM
FIM
SpIM
600.00
400.00
200.00
0.00
19N
17N
15N
12N


Bacteria in the CB (log No x 10^12 m^-2)
SM
FIM
SpIM
4.00
2.00
0.00
9N88E
12N88E
15N88E
17N88E
20N88E

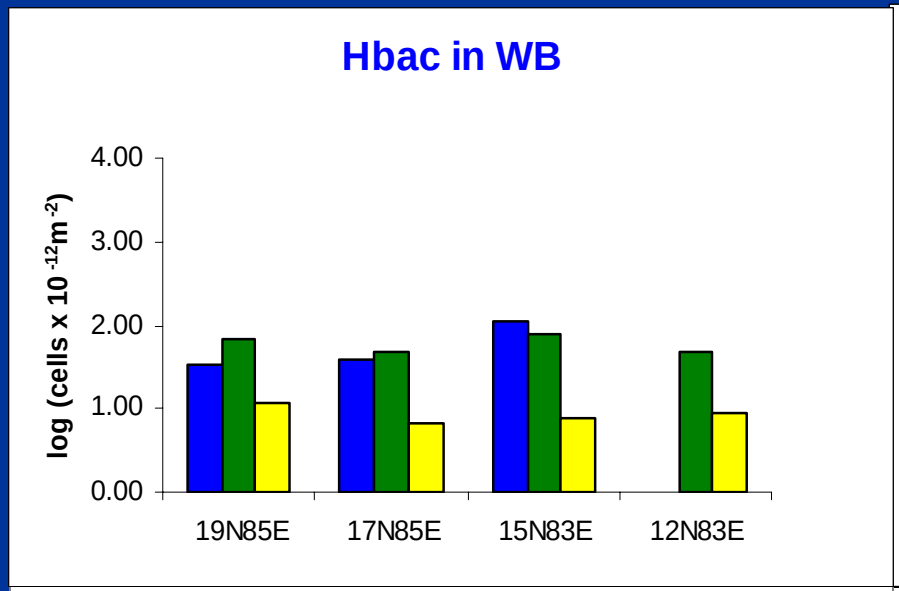


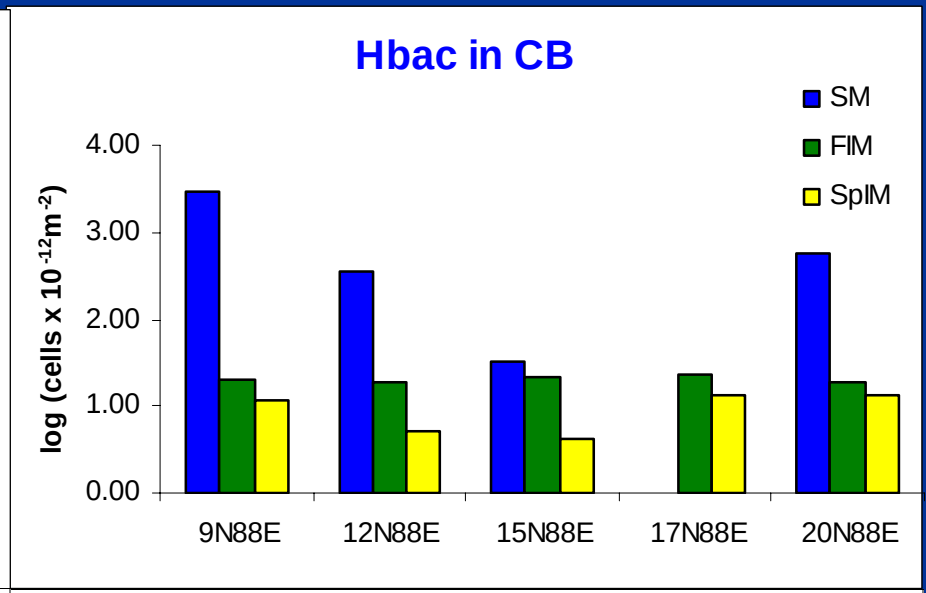

Bacteria in WB (log No X 10^12 m^-2)
4.00
2.00
0.00
19N85E
17N85E
15N83E
12N83E

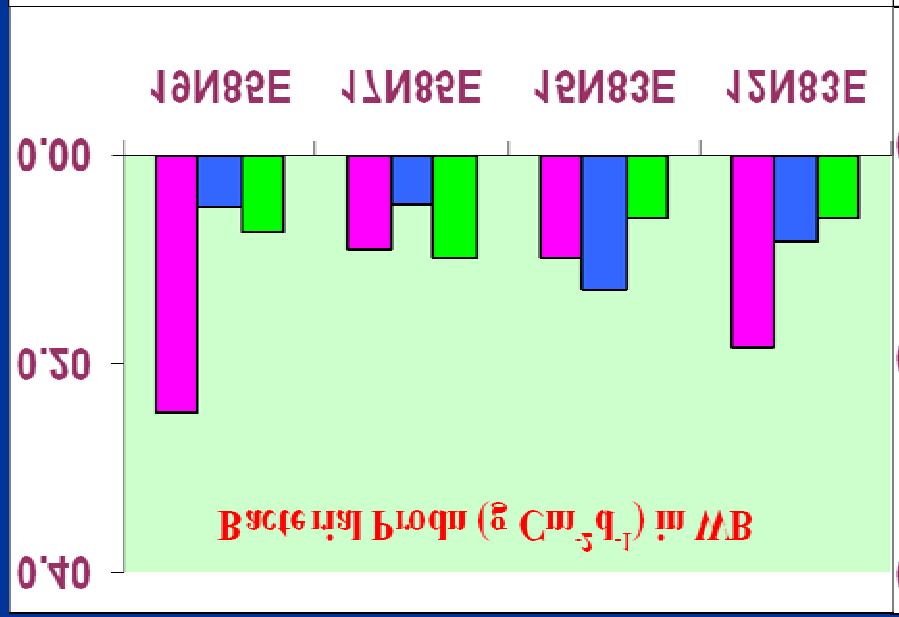


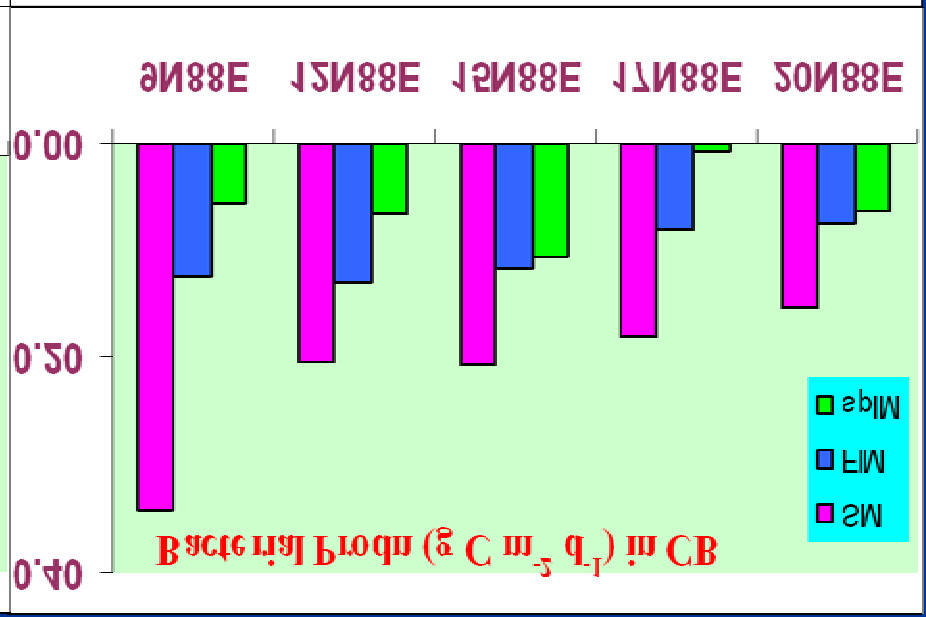
# Contrasting Seasonal differences:

## Unlike in the Arabian Sea, Hbac & BP more during SWM than in SIM/FIM





# Mesozooplankton Biomass (ml $100m^{-3}$) in BoB

| | Coastal | Oceanic |
|---|---|---|
| SWM | 10.2-226.1 | 4.7-807.3 |
| FIM | 27.6-236.4 | 8.4-153.4 |
| SpIM | 7.5-706.4 | 17.5-230.0 |

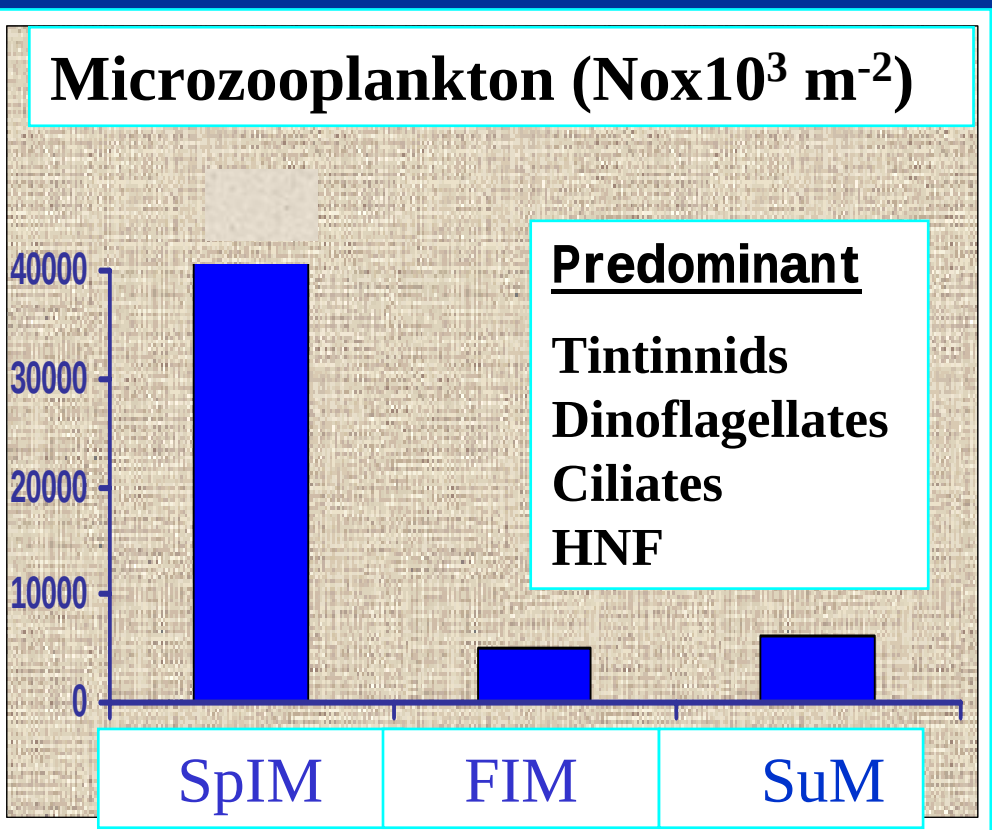
**Mean biomasses comparable to those fm Arabian Sea!!**

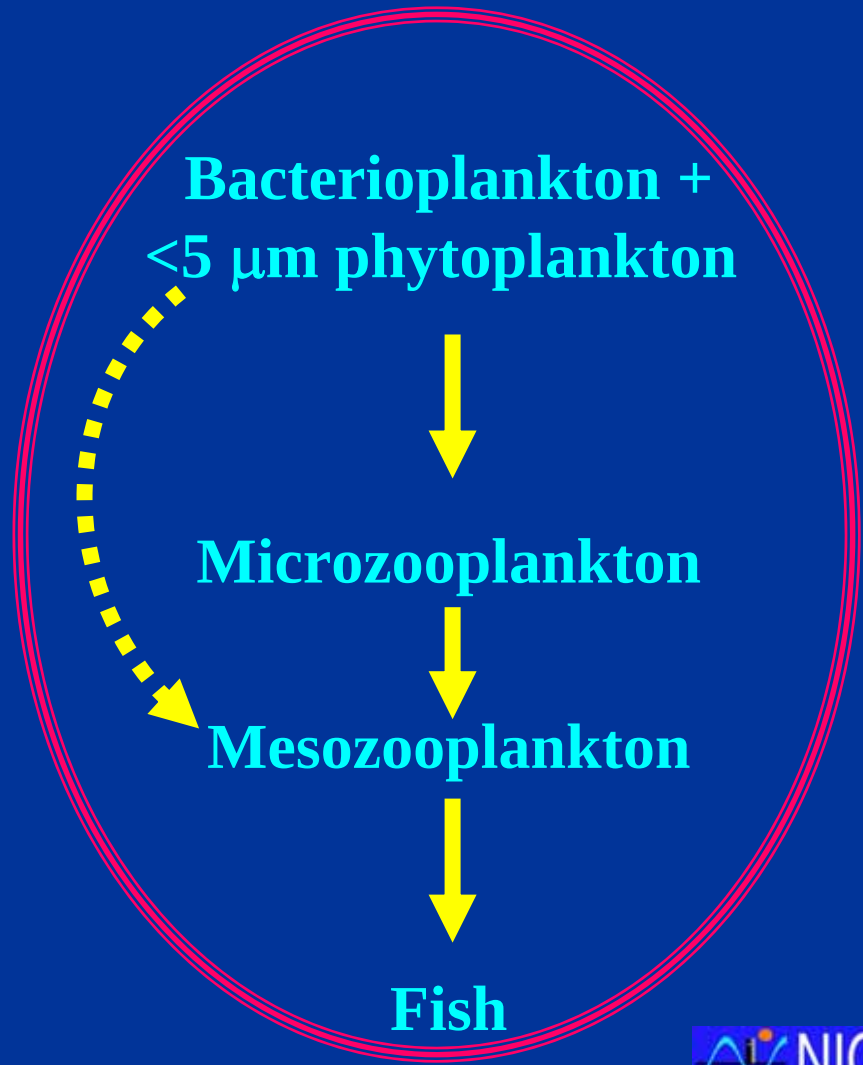
# Too Far Fetched?

**Microzooplankton abundance in the Bay much lower**

**Mesozoo biomass comparable to ones from Arabian Sea**

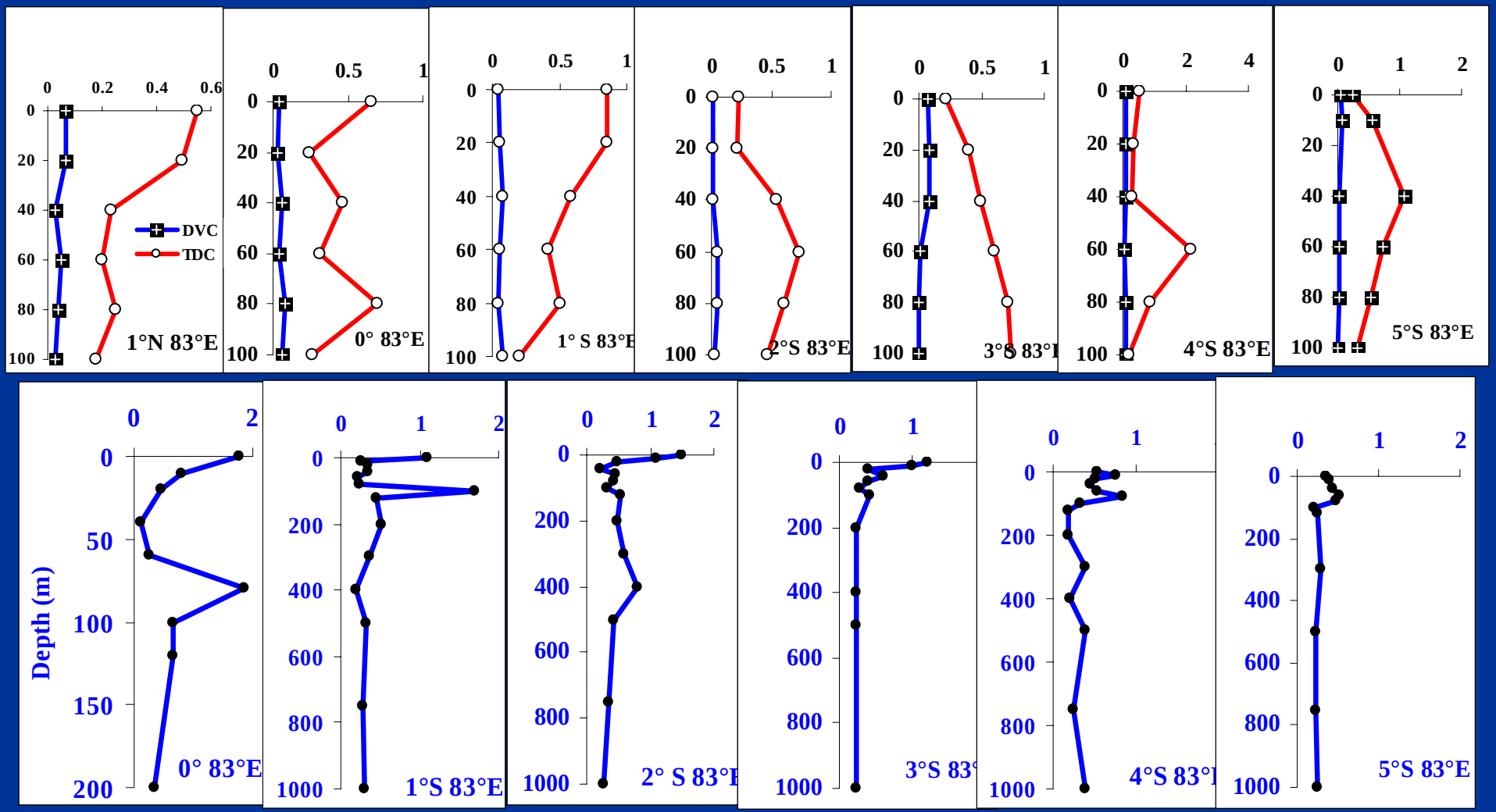
**Mesozoo might be preying on bacteria along with particulates**



# Hbac (No x $10^8$ $L^{-1}$ in Equatorial Indian Ocean along 83°E

- ❖Surface counts higher during July-August
- ❖Primary/Secondary peaks around chl a maxima
- ❖DVC 5-25% of total counts in Feb and July-August

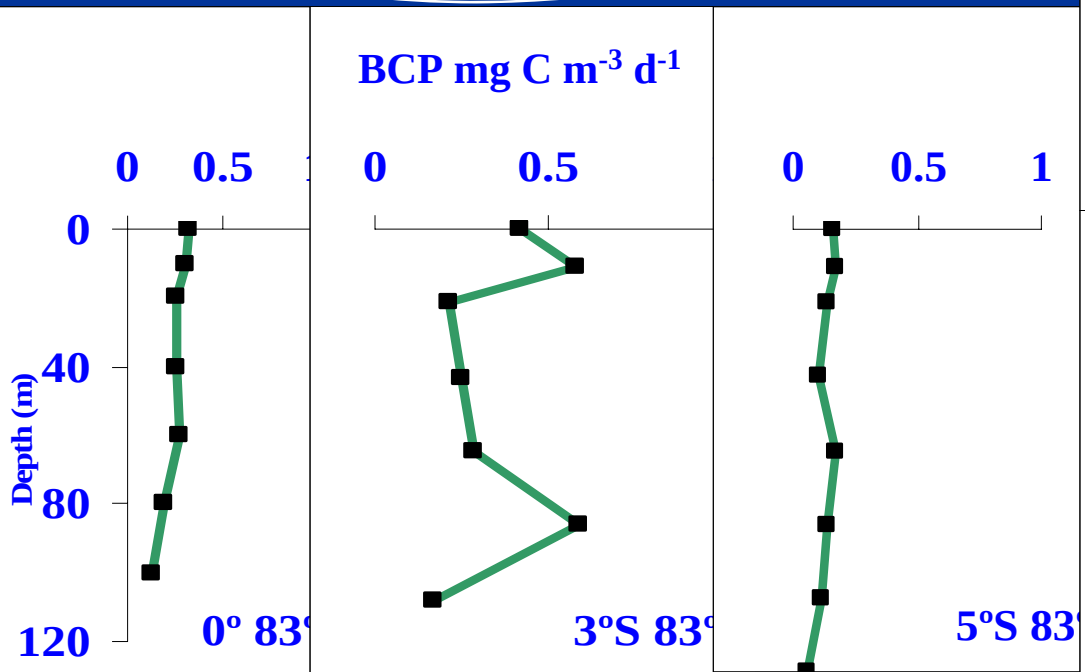


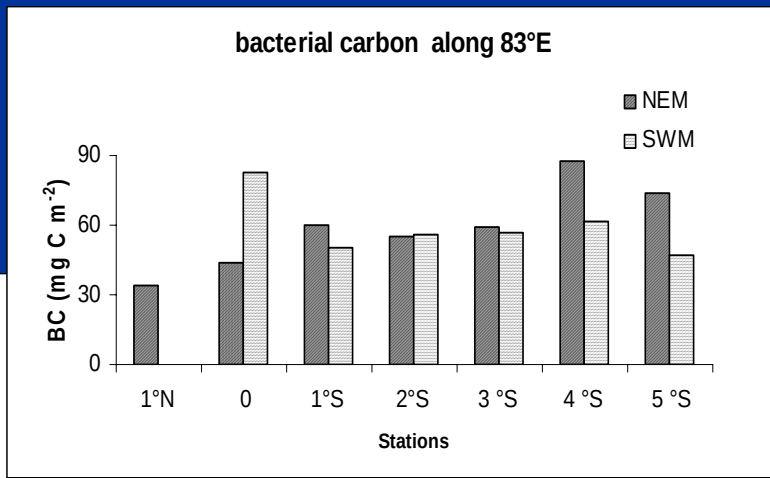
# Hbac C stocks and prodn in oligotrophic EIO

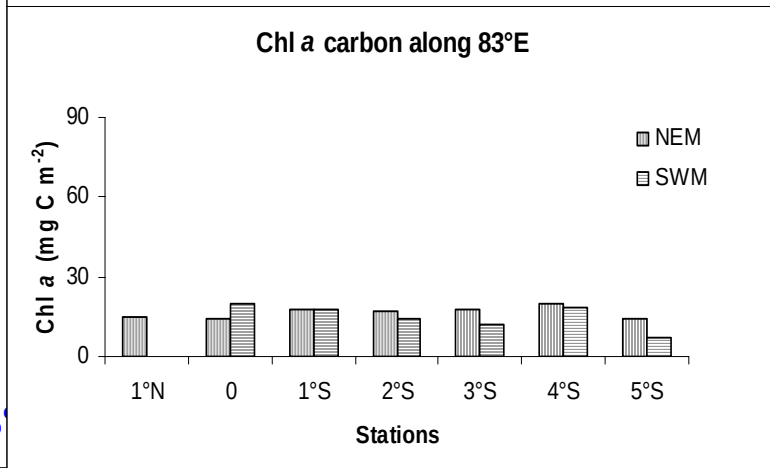
**Hbac- 33-87 mg $m^{-2}$ ; BP: 16-35 mg $m^{-2}$ $d^{-1}$ (0-120m column)**

**Chl *a*- 14-20 mg $m^{-2}$ ; PP: 26-40 mg $m^{-2}$ $d^{-1}$**

***Dinoflagellates* more in surface**

# Hbac (no x $10^9$ $L^{-1}$) in Indian Ocean regions

| | Sur-50 | <100 | <150 | ~200 |
|---|---|---|---|---|
| **JGOFS-India; Eastern Arabian Sea: Seasonal variability very high** | | | | |
| **'94 Apr-May (SIM)** | **0.3 - 1.0** | **0.2-0.9** | **0.1-0.6** | **0.1-0.4** |
| **'95 Jan-Feb (NEM)** | 0.05 - 0.1 | 0.03-0.09 | 0.03-0.07 | 0.02-0.07 |
| **'96 Jul-Aug (SWM)** | 0.2 - 0.9 | 0.1-0.6 | 0.09-0.3 | 0.08-0.1 |
| **BOBPS-India; along 88°E; India east coast: more abundant in deep** | | | | |
| **'01 Jul-Aug (SWM)** | **3.8-79.0** | **1.5-20** | **9.1-60** | **0.4-10** |
| **'02 Sep-Oct (FIM)** | **1.1- 2.17.6-9.4** | **2.5-5.0** | **1.5-2.0** | |
| **'03 Apr-May (SIM)** | **0.02-0.4** | **0.24-0.7** | **0.2-0.4** | **0.3-0.4** |
| **Cobalt-Crust Survey-India; along 83°E; 1N-5S: scarce; yet pivotal?** | | | | |
| **'o3 Feb (NEM)** | 0.01 - 0.18 | 0.03-0.18 | -- | -- |
| **'03 Jul-Aug (SWM)** | 0.02 – 0.2 | 0.03-0.09 | 0.04-0.07 | 0.03-0.08 |

# $^{3}$H Thymidine incorporation rates (pM $L^{-1}$ $h^{-1}$)

| | Sur-50 | <100 | <150 | ~200 |
|---|---|---|---|---|
| **JGOFS-India data; along 64E; India coast: Sometimes exceeded PP** | | | | |
| **'94 Apr-May (SIM)** | **25 - 50** | **14-29** | **13-16** | **1-4** |
| **'95 Jan-Feb (NEM)** | 0.5 – 1.9 | 0.3-0.9 | 0.3-0.7 | -- |
| **'96 Jul-Aug (SWM)** | 0.9 – 3.0 | 0.2-3.0 | 0.1-0.3 | 0.06-0.1 |
| **BOBPS-India; along 88°E; India east coast: generally more than AS** | | | | |
| **'01 Jul-Aug (SWM)** | **16-37** | **17-25** | **0.5-5** | **0.4-6** |
| **'02 Sep-Oct (FIM)** | **5-12** | **7-10** | **5-7** | **0.4-4** |
| **'03 Apr-May (SIM)** | **8-11** | **4-11** | **0.9-11** | **0.3-2** |
| **Cobalt-Crust Survey-India; along 83°E; 1N-5S: Lowest yet >60% of PP** | | | | |
| **'03 Jul-Aug (SWM)** | 0.5-2.0 | 0.6-3.0 | 0.8-3.0 | 0.8-1.8 |

# Bacterioplankton in IO

## Arabian Sea

Decoupled with chl & PP

Seasonal excesses of BP

Sustain microbial loop: IM

Aid MLD-MSZP Biomass

Faster rmnrlzn:$CO_2$ /$N_2O$ efflux

Net hetrotrophy spcly in IMs

## Bay of Bengal

More abundant than in AS

Contribute 15- 66% of PP

^Regional grazing press

Preponderant; ^BP in deep

Extant in regions of eddy

Ballasting adv. to Hbac?

## EIO

Hbac significant to myxotrophs; micrograzers

# Future attention on Indian Ocean Bacterioplankton

✓Phylogenetics and metagenomics for diversity analyses

✓Their role in biotansformation of submicron particles

- ❖Bacterioplankton groups reported to form highly stratified populations in the surface layer
- ❖Their consumption of specific dissolved org. compds reported to differ among various phylogenetic groups
- ❖Their community structure very important in seasonal patterns of DOC accumulation and

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DOD
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Dr V K Banakar

**Plea of a Marine Microbe:**


# *Thank You*

NIO