Water Quality Control in RAS:
The importance of an anaerobic treatment stage for removing nitrate, phosphate, and off-flavor compounds

Jaap van Rijn
The Robert H. Smith Faculty of Agriculture, Food and Environment
The Hebrew University of Jerusalem

Topics:

- Water quality control in conventional fish ponds
- Water quality control in RAS
- Anaerobic treatment in RAS
  - Organic matter degradation
  - Nitrate removal
  - Phosphate removal
  - pH and alkalinity
  - Off-flavor
  - Humic acids and Fish health

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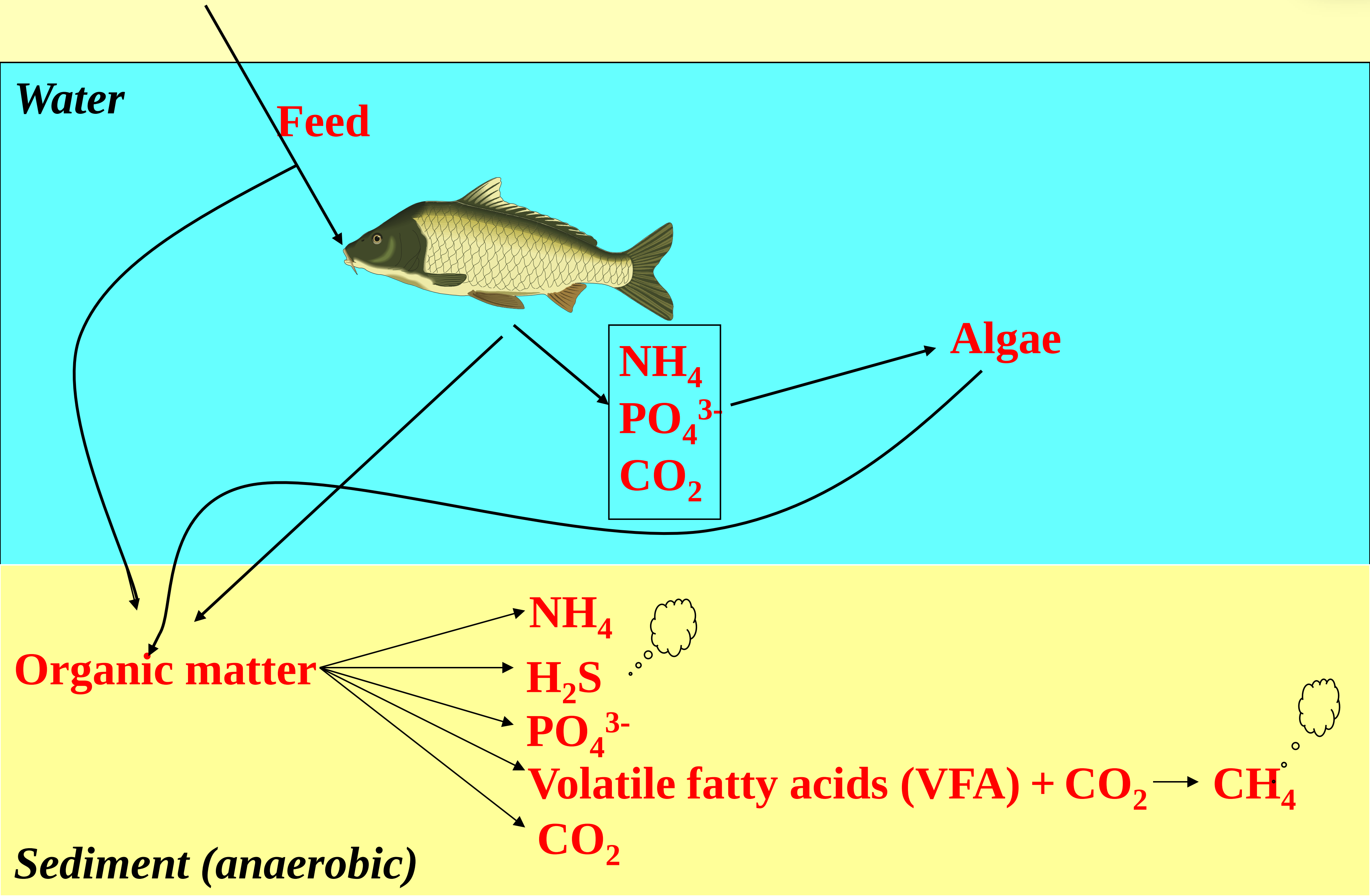
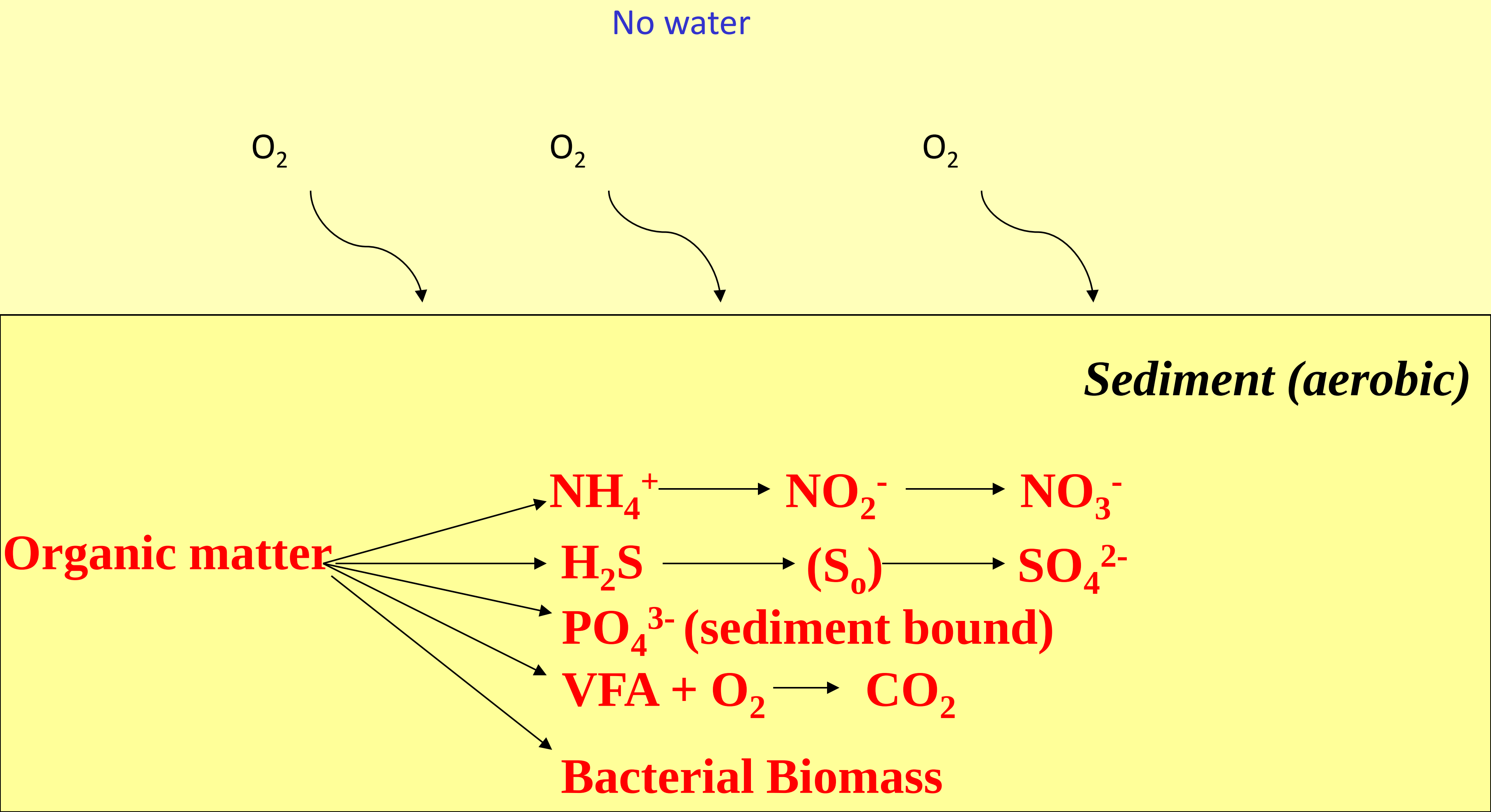
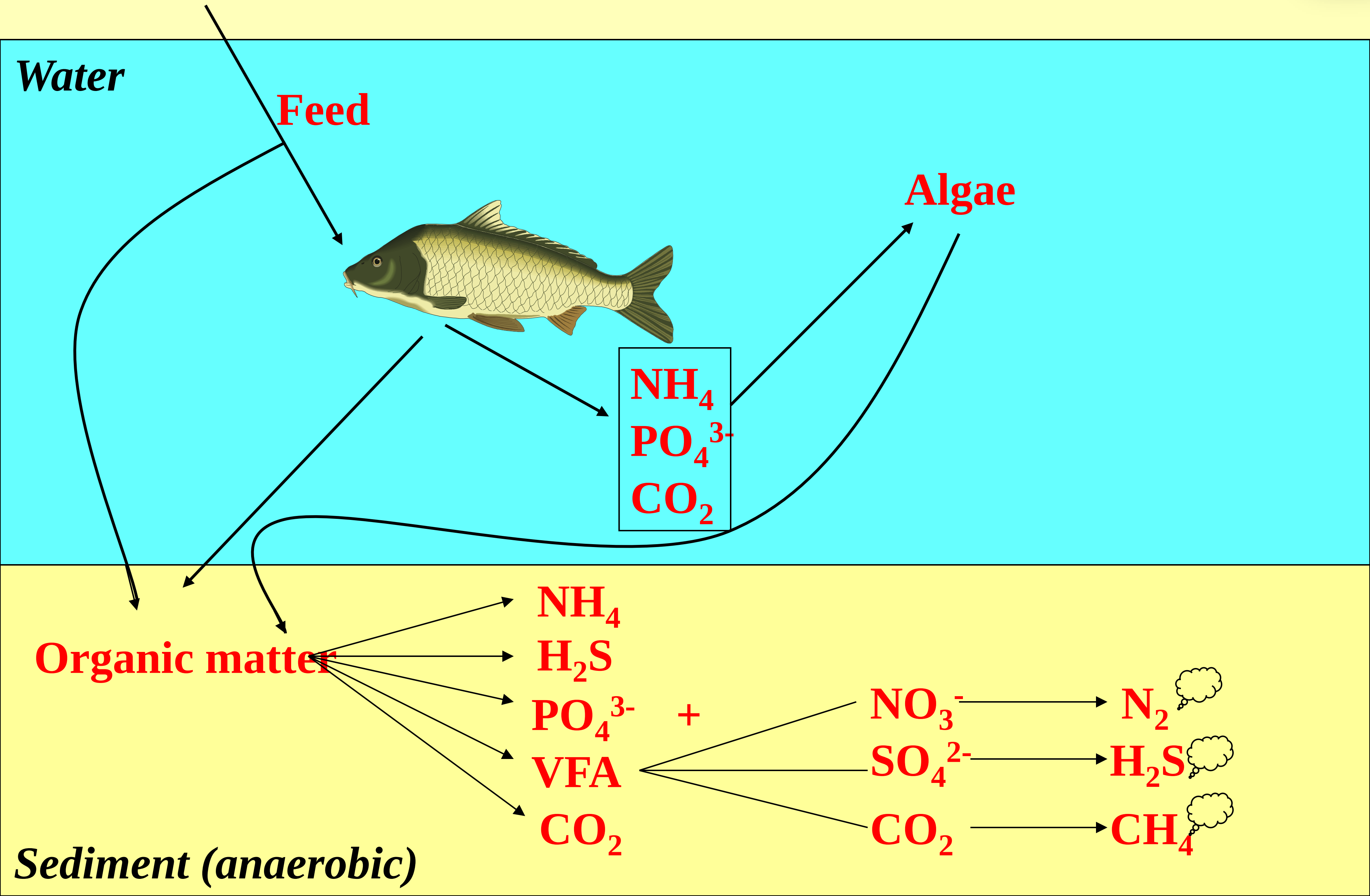
Growing season



After drainage



After refilling



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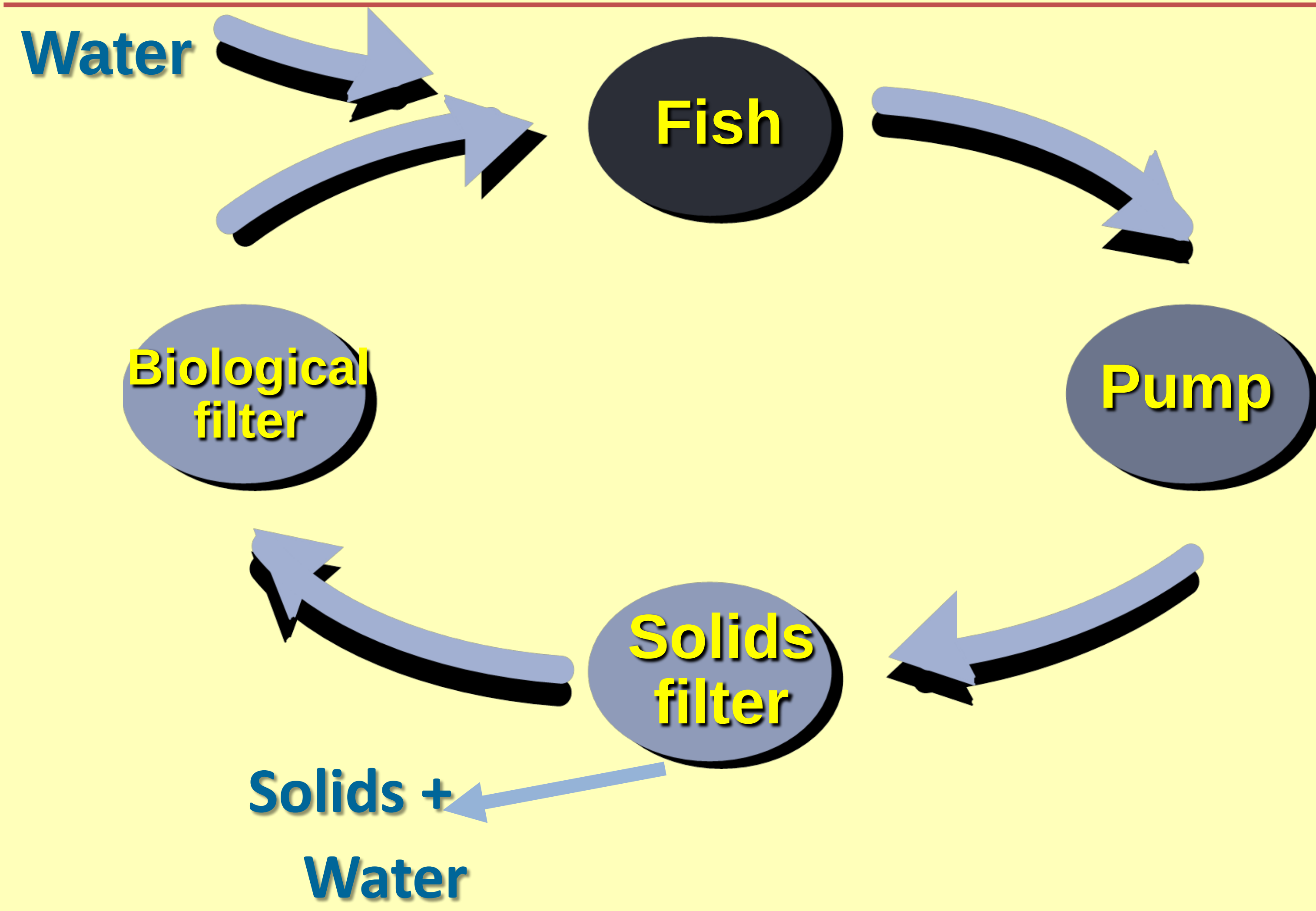
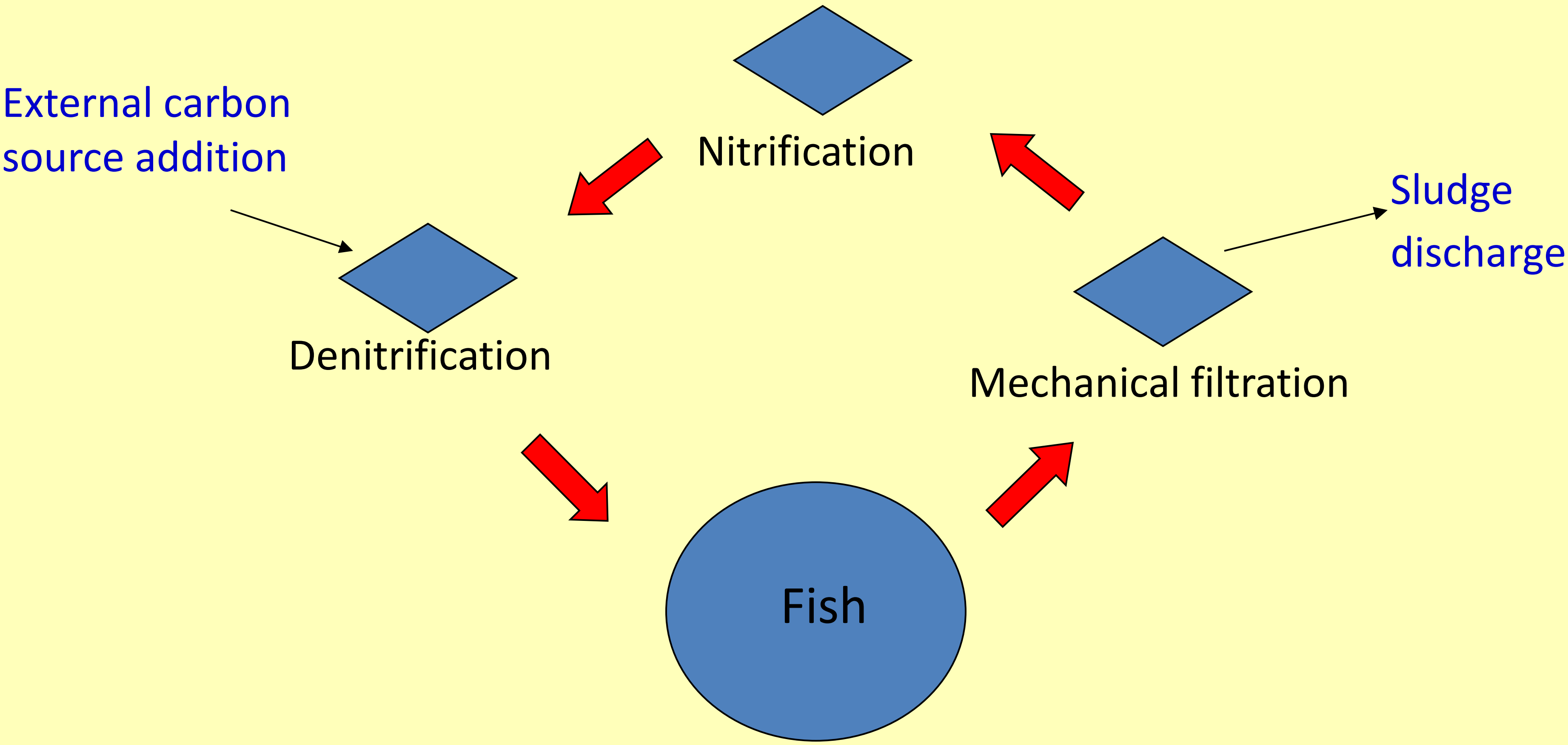
Conventional Recirculating Systems

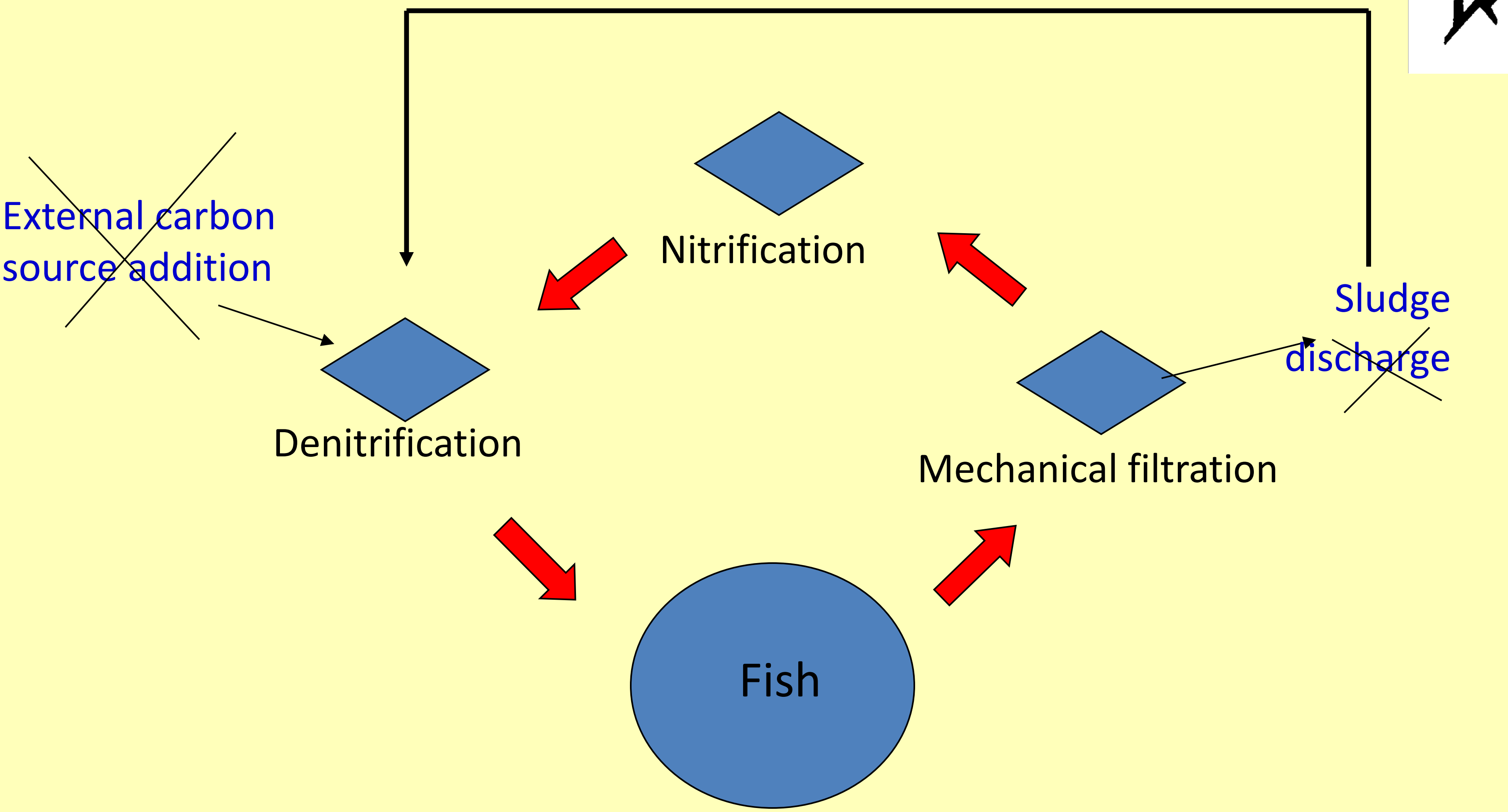


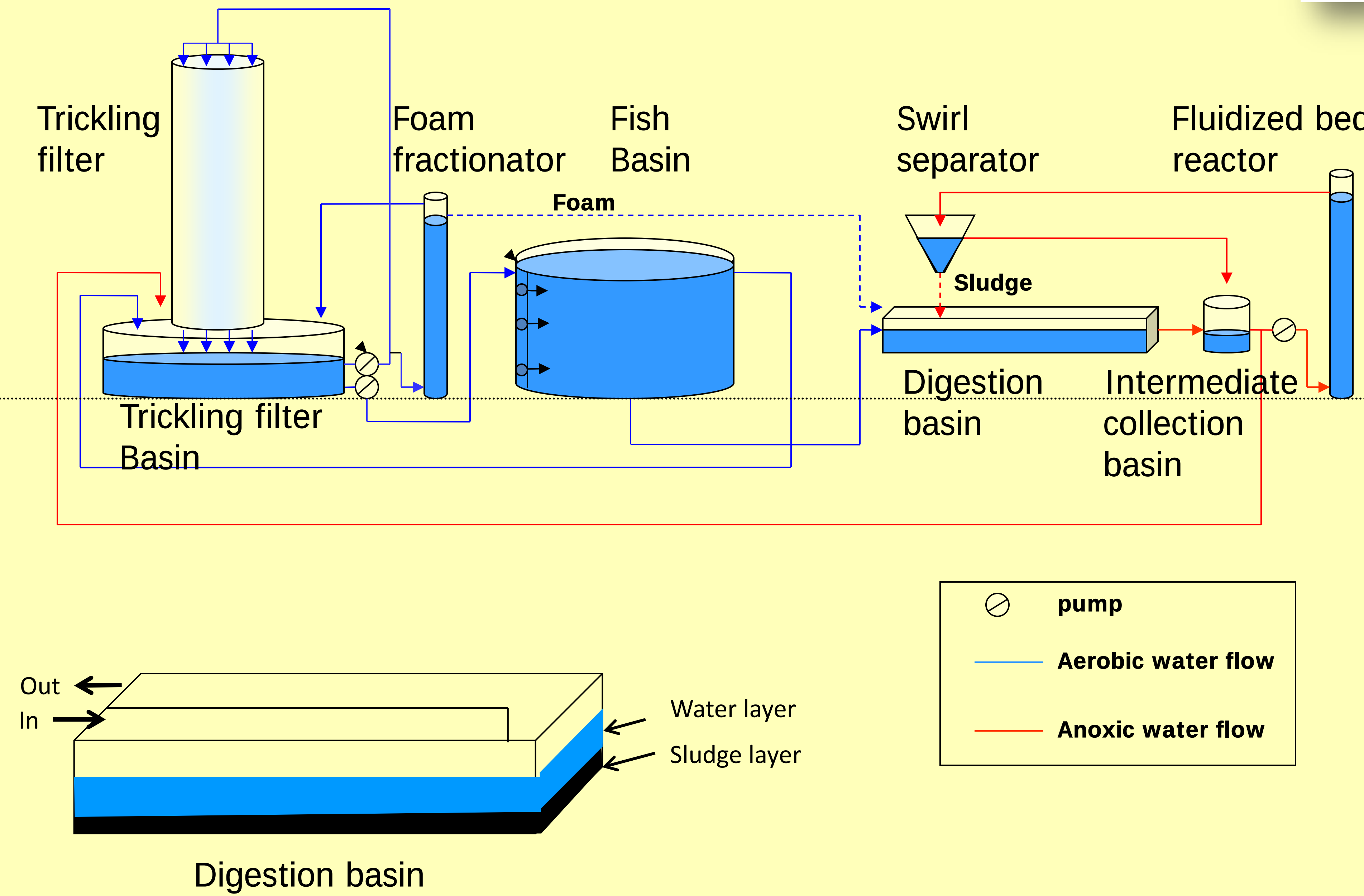
Disadvantages of conventional recirculating systems

* Sludge production
* Nitrate accumulation
* Phosphate accumulation

RAS systems with denitrification step




External carbon source addition
Nitrification
Denitrification
Sludge discharge
Mechanical filtration
Fish


Trickling filter
Foam fractionator
Fish Basin
Swirl separator
Fluidized bed reactor
Foam
Sludge
Trickling filter Basin
Digestion basin
Intermediate collection basin
pump
Aerobic water flow
Anoxic water flow
Out
In
Water layer
Sludge layer
Digestion basin

Marine Beta Plant

Fish Basin

Digestion basin

Fluidized bed reactor

Trickling filter

Swirl separator

Zero-Discharge Closed-System Rehovot, Israel

Herev Le'et (Israel)

Hudson (USA)

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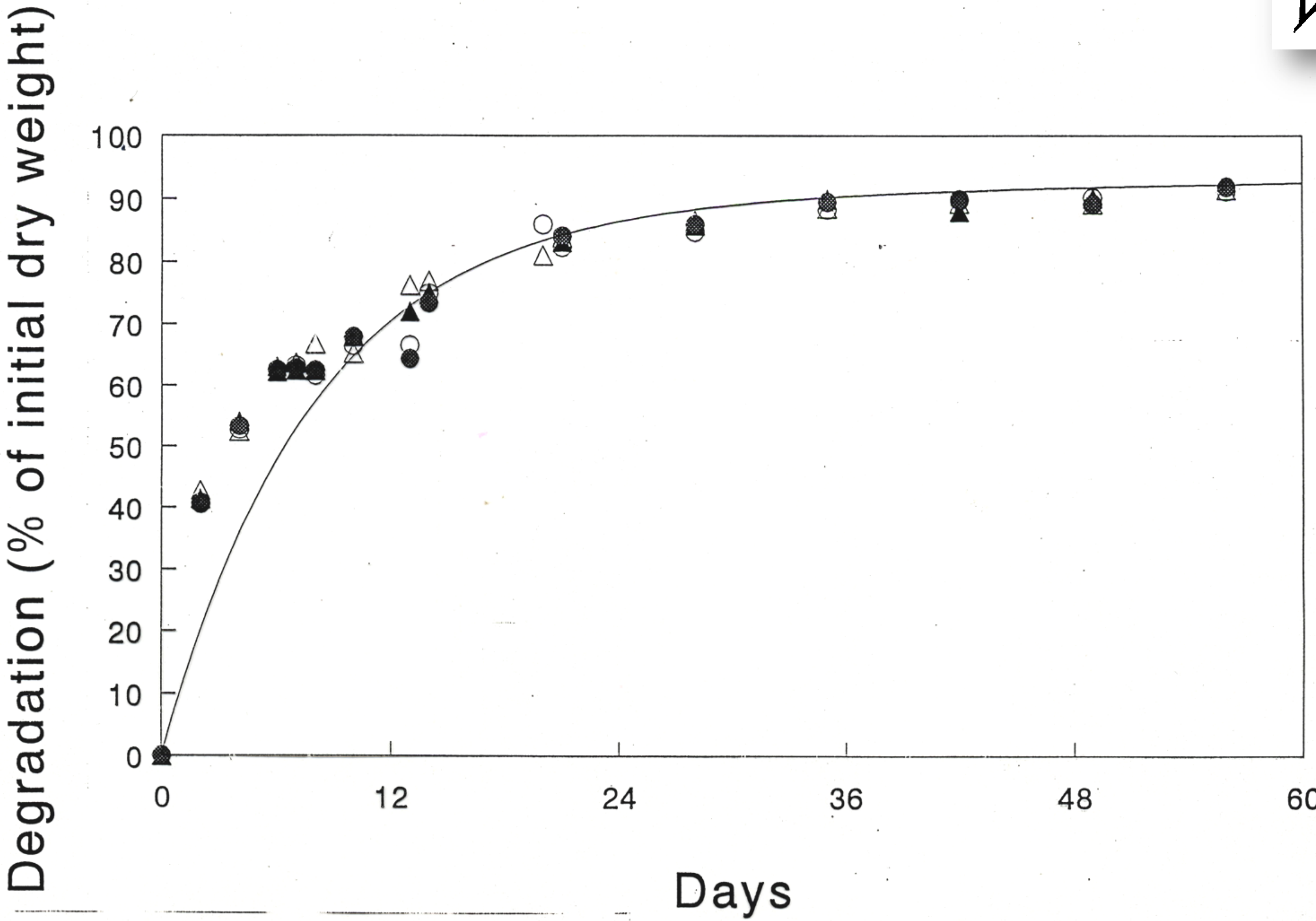
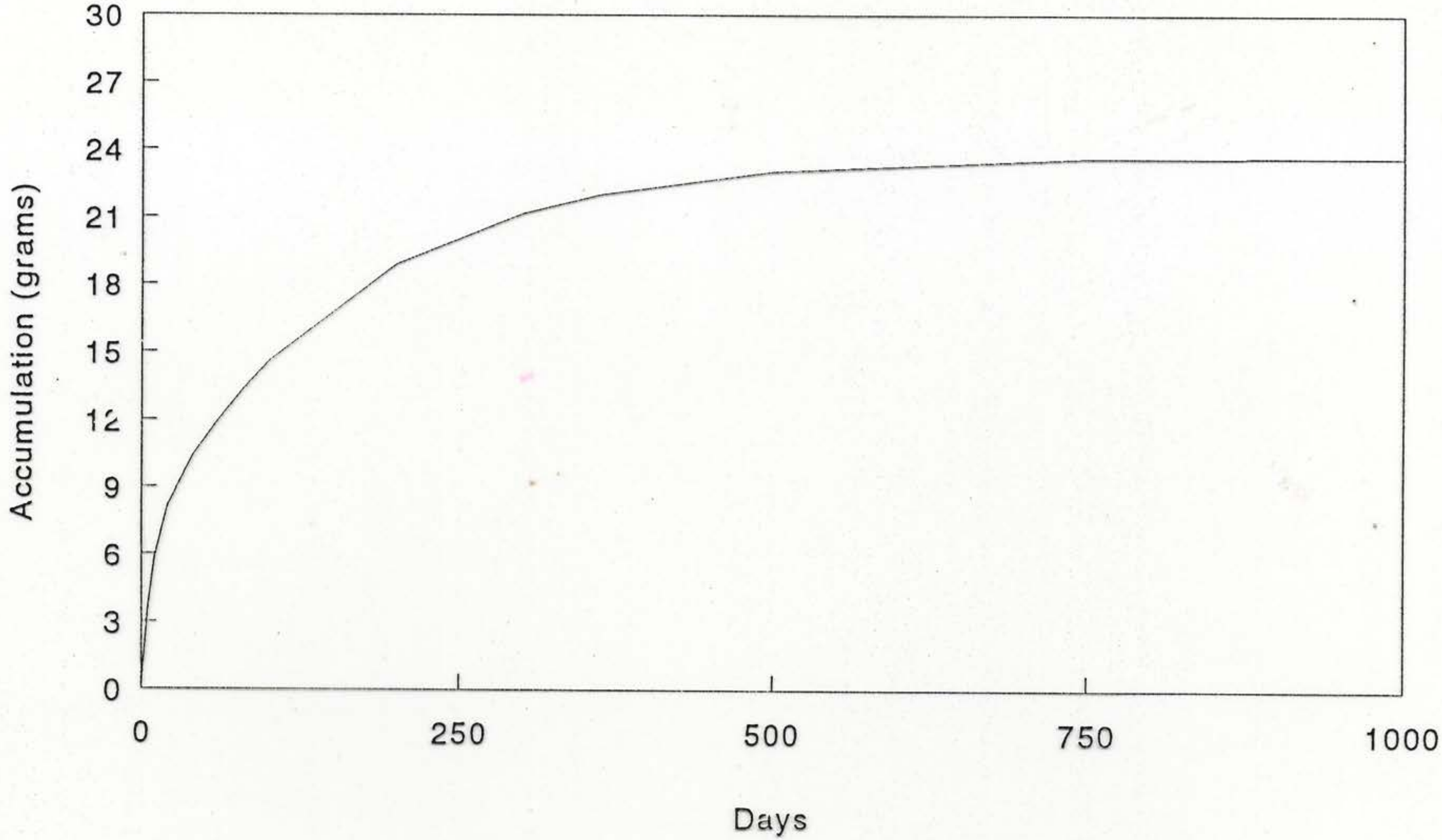
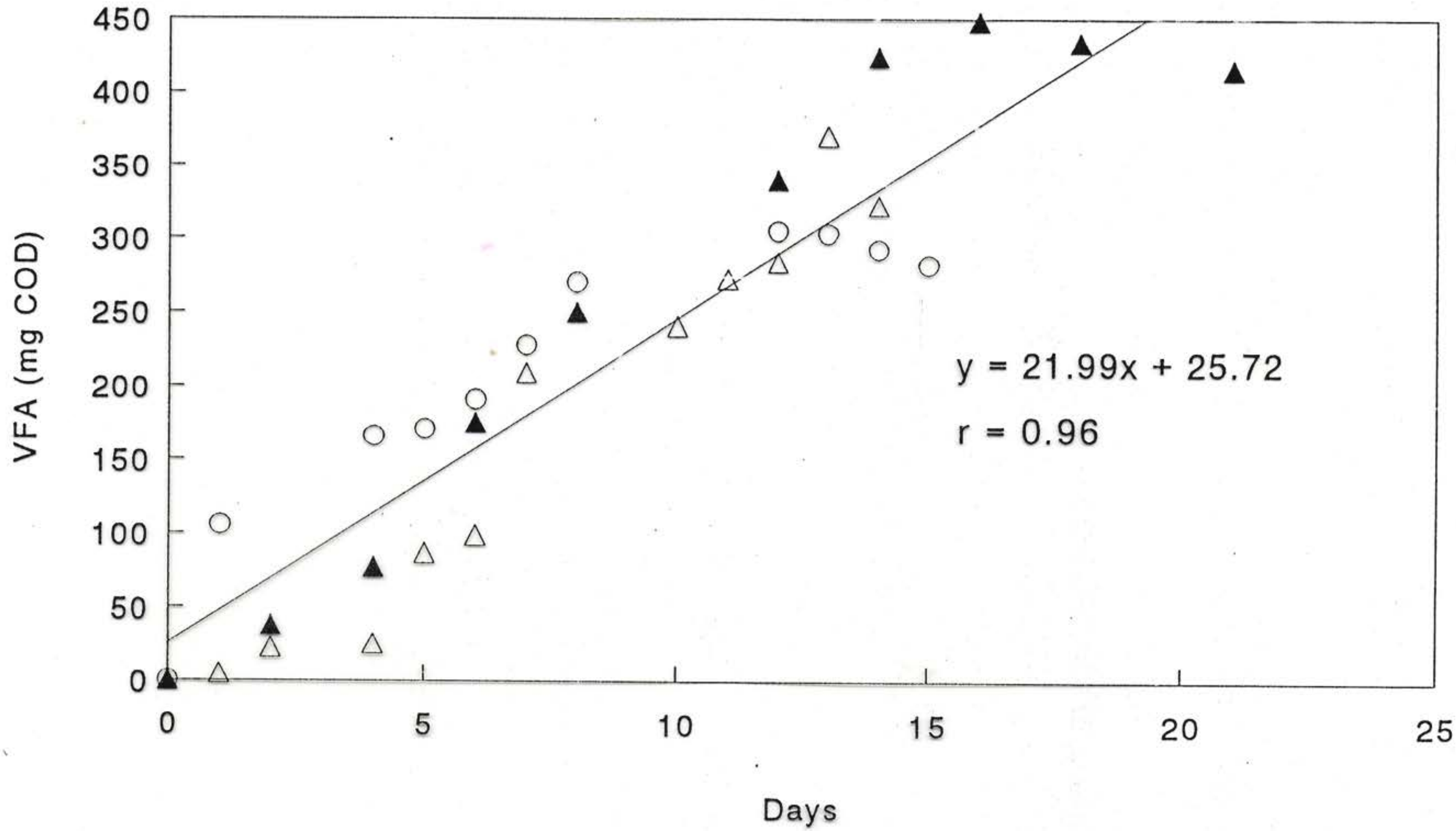

Degradation (% of initial dry weight)
100
90
80
70
60
50
40
30
20
10
0
0
12
24
36
48
60
Days

10

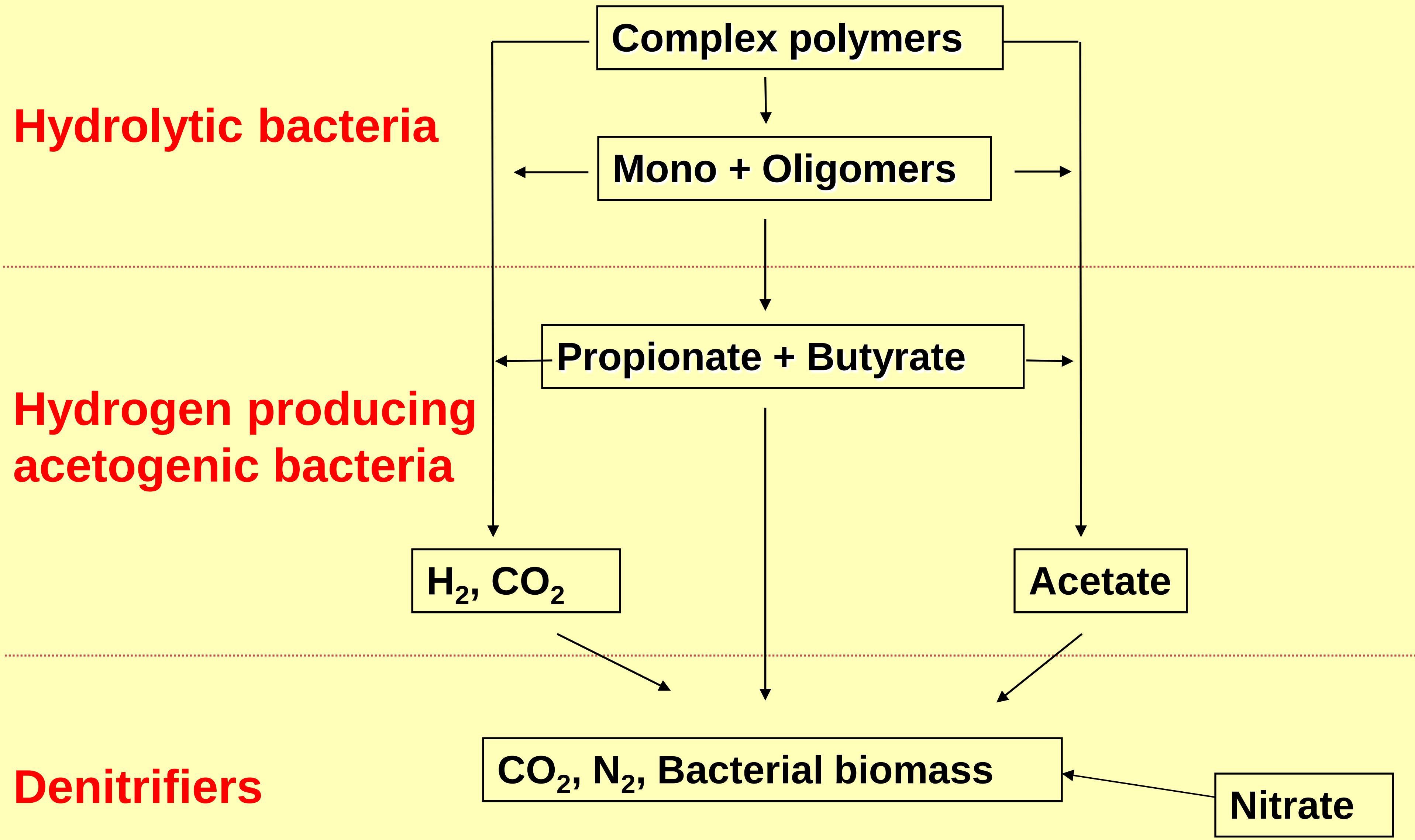
Predicted sludge accumulation



Release of VFA's during anaerobic degradation of fish feed



Anaerobic carbon metabolism with nitrate as terminal electron acceptor



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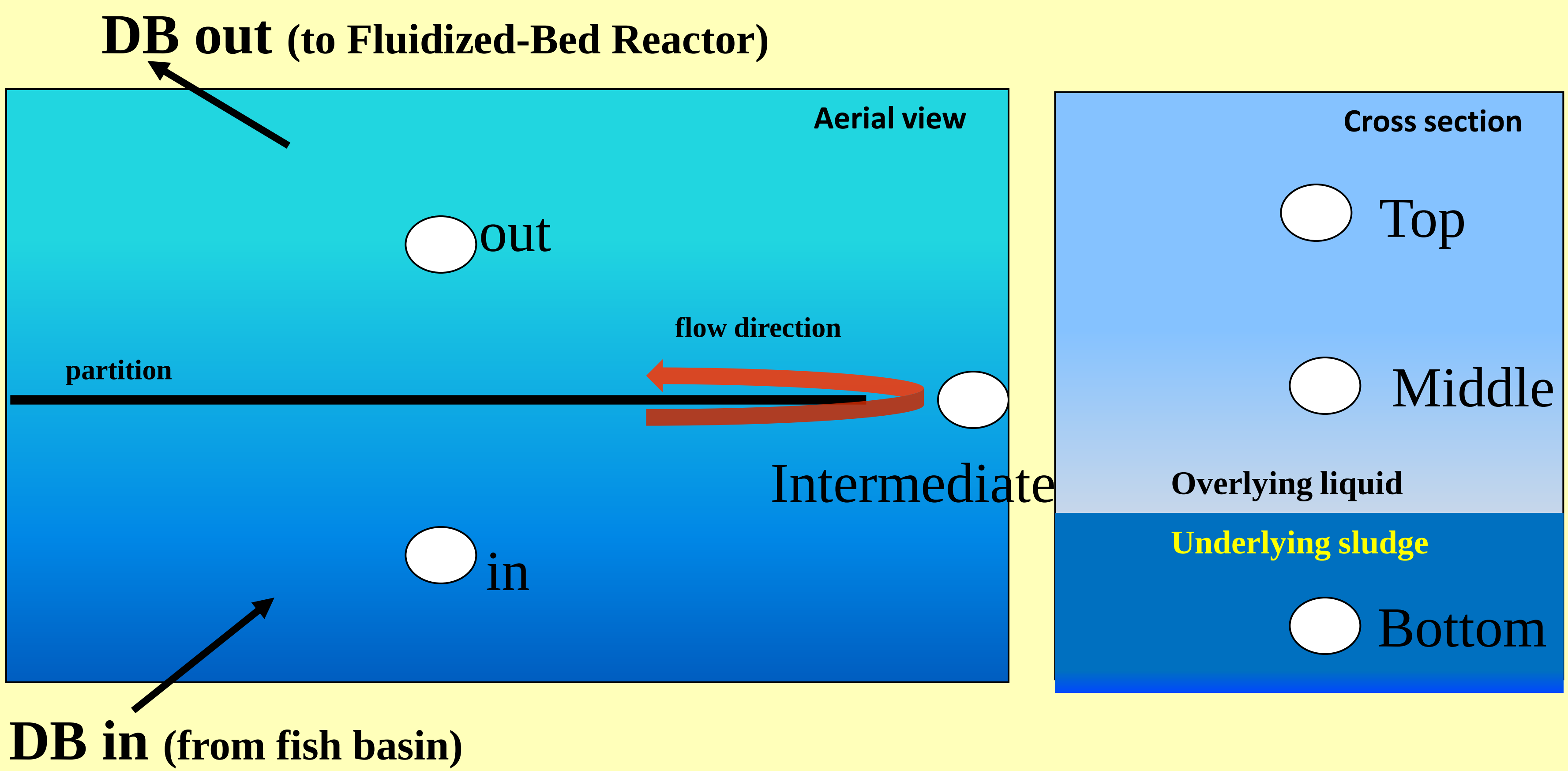
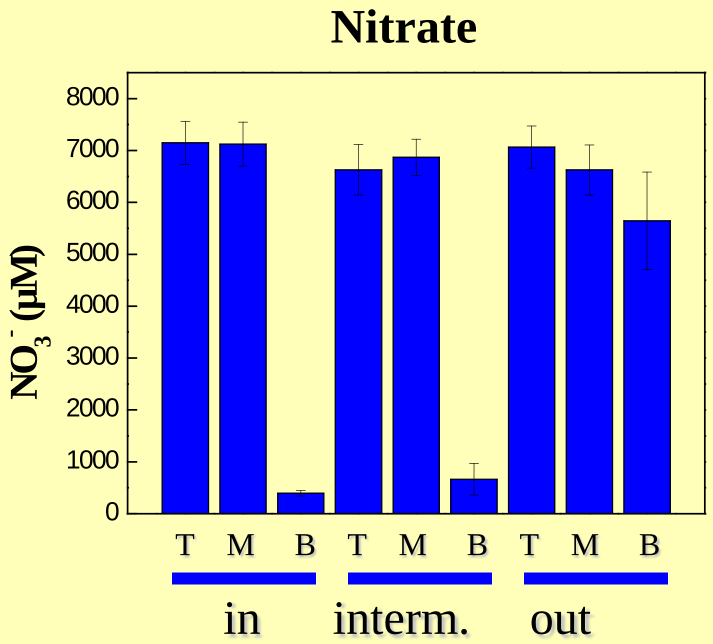
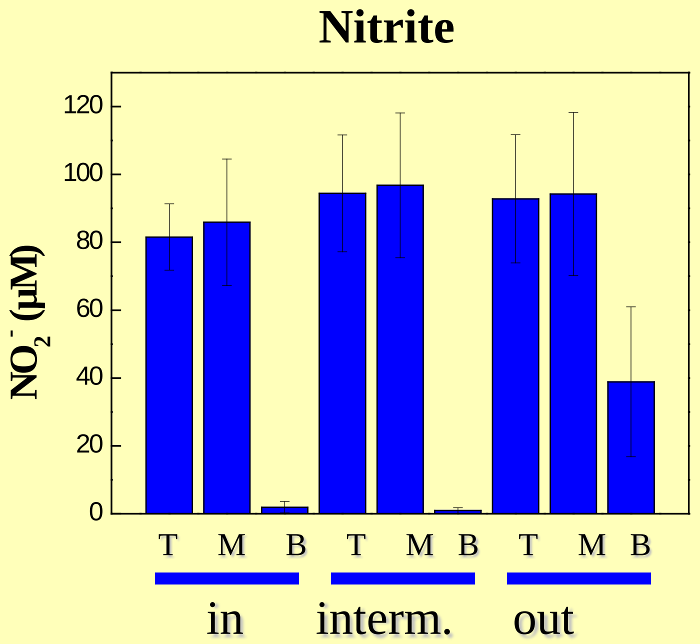
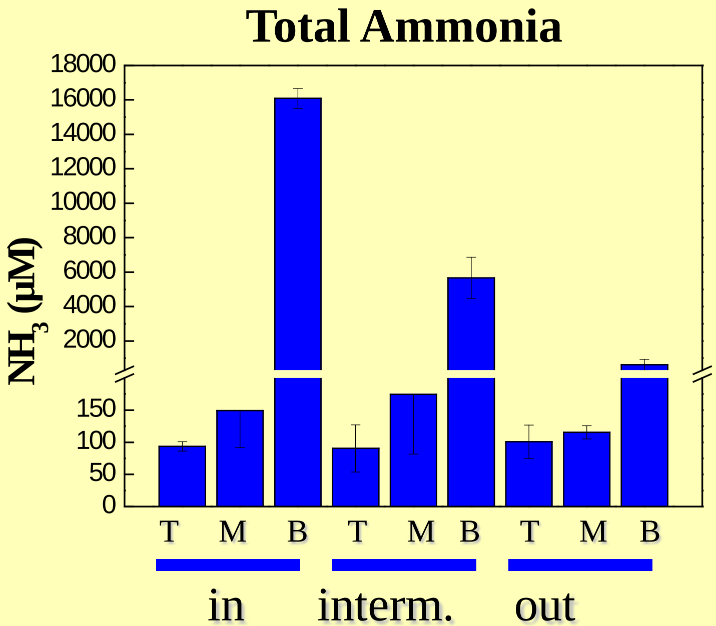
Schematic Diagram of the Digestion Basin (DB)

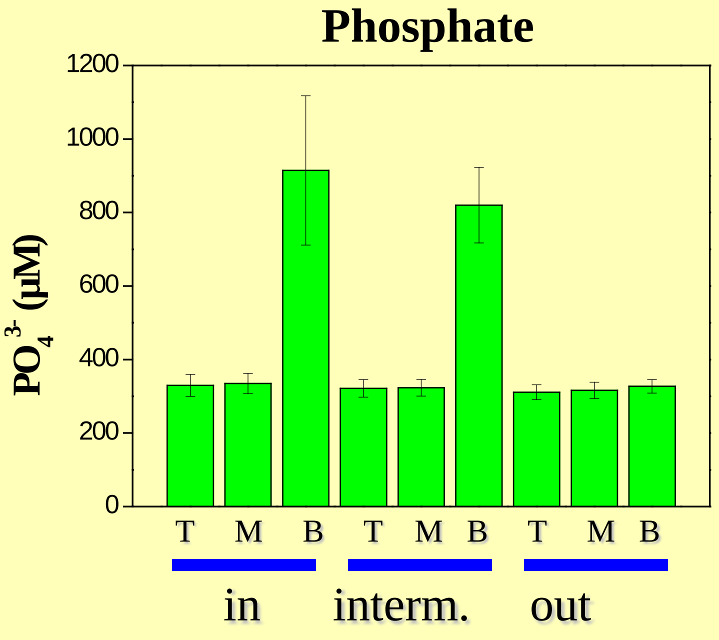


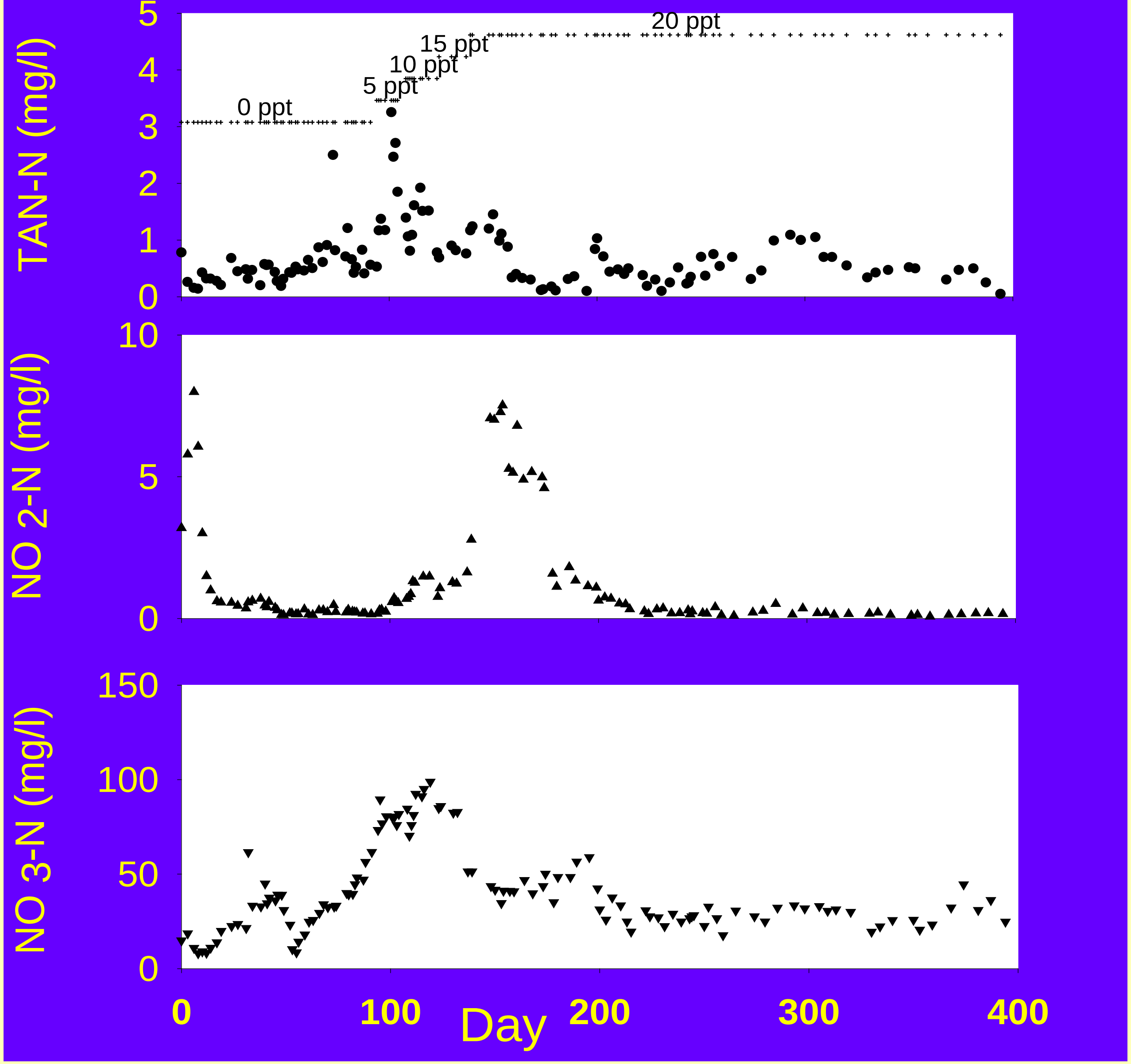
Chemical Parameters - DB











TAN-N (mg/l)
NO 2-N (mg/l)
NO 3-N (mg/l)
0 ppt
5 ppt
10 ppt
15 ppt
20 ppt
0
1
2
3
4
5
10
50
100
150
0
100
200
300
400
Day

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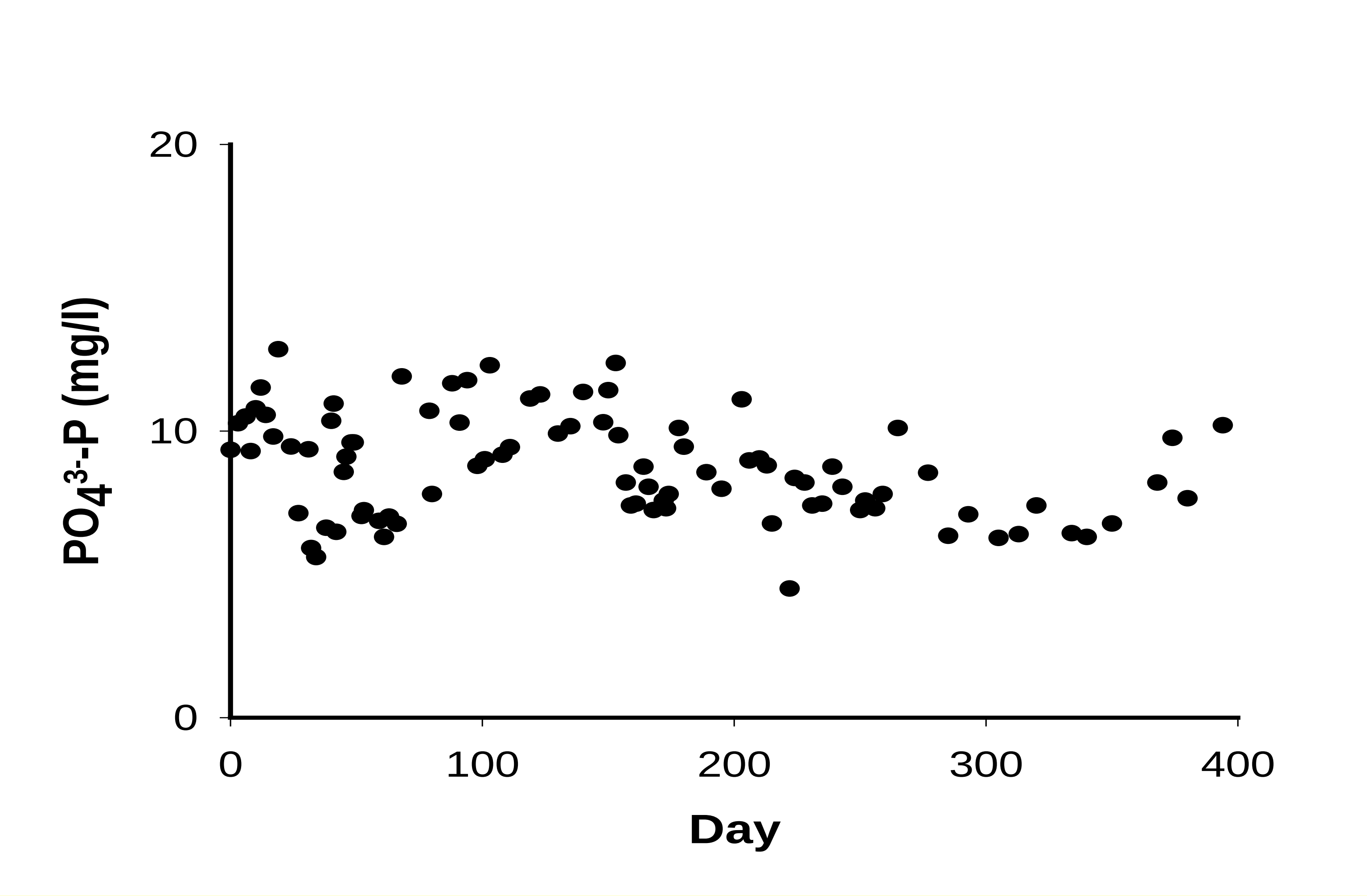
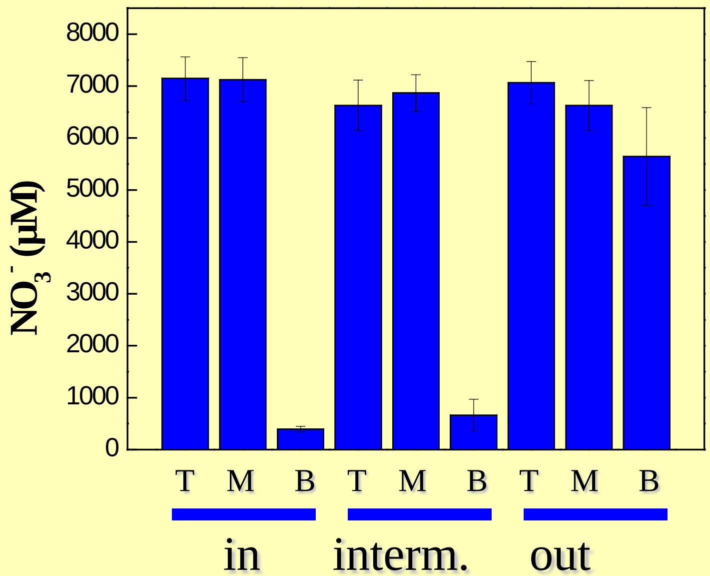
Rehovot: phosphate concentrations in fish basin

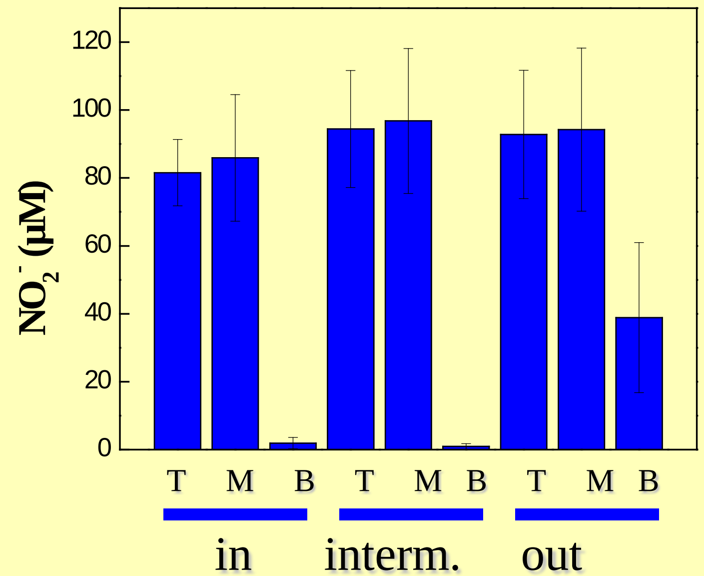


Chemical Parameters - DB

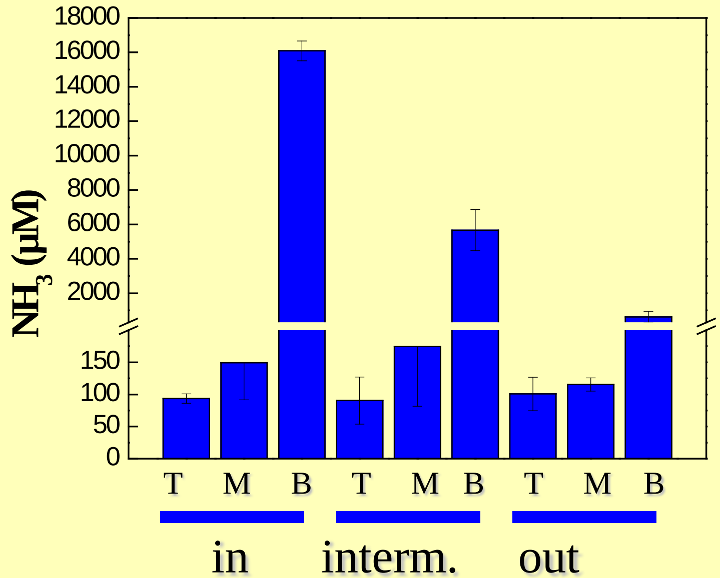
Nitrate



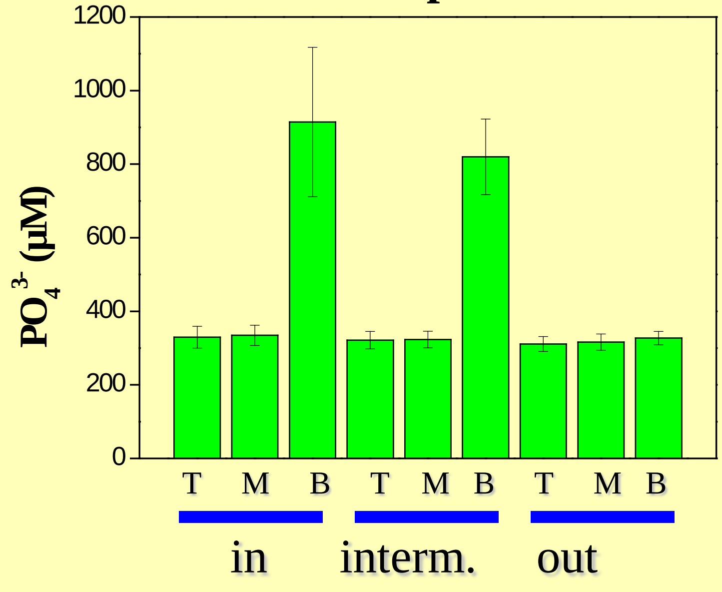
Nitrite



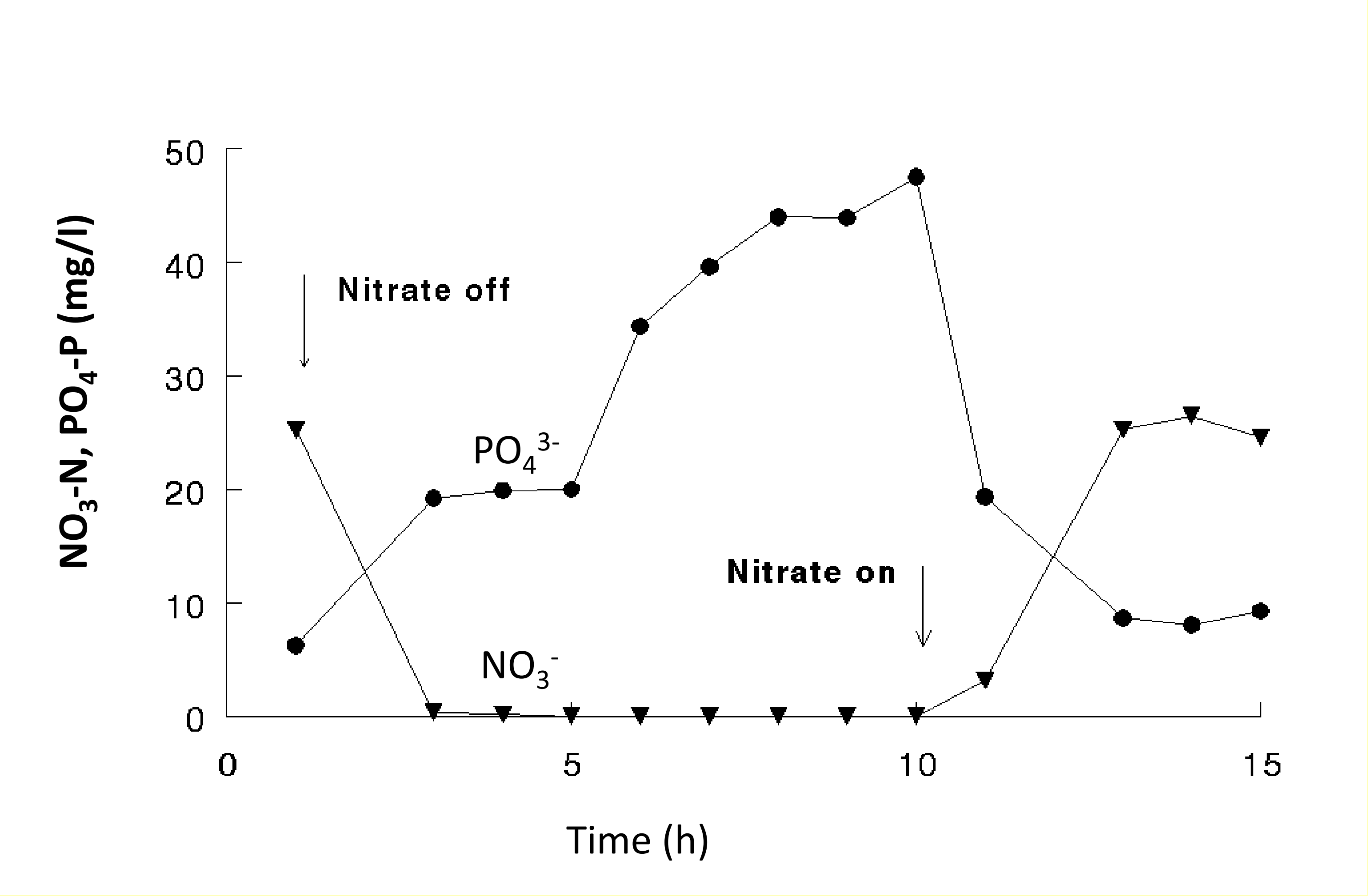
Total Ammonia



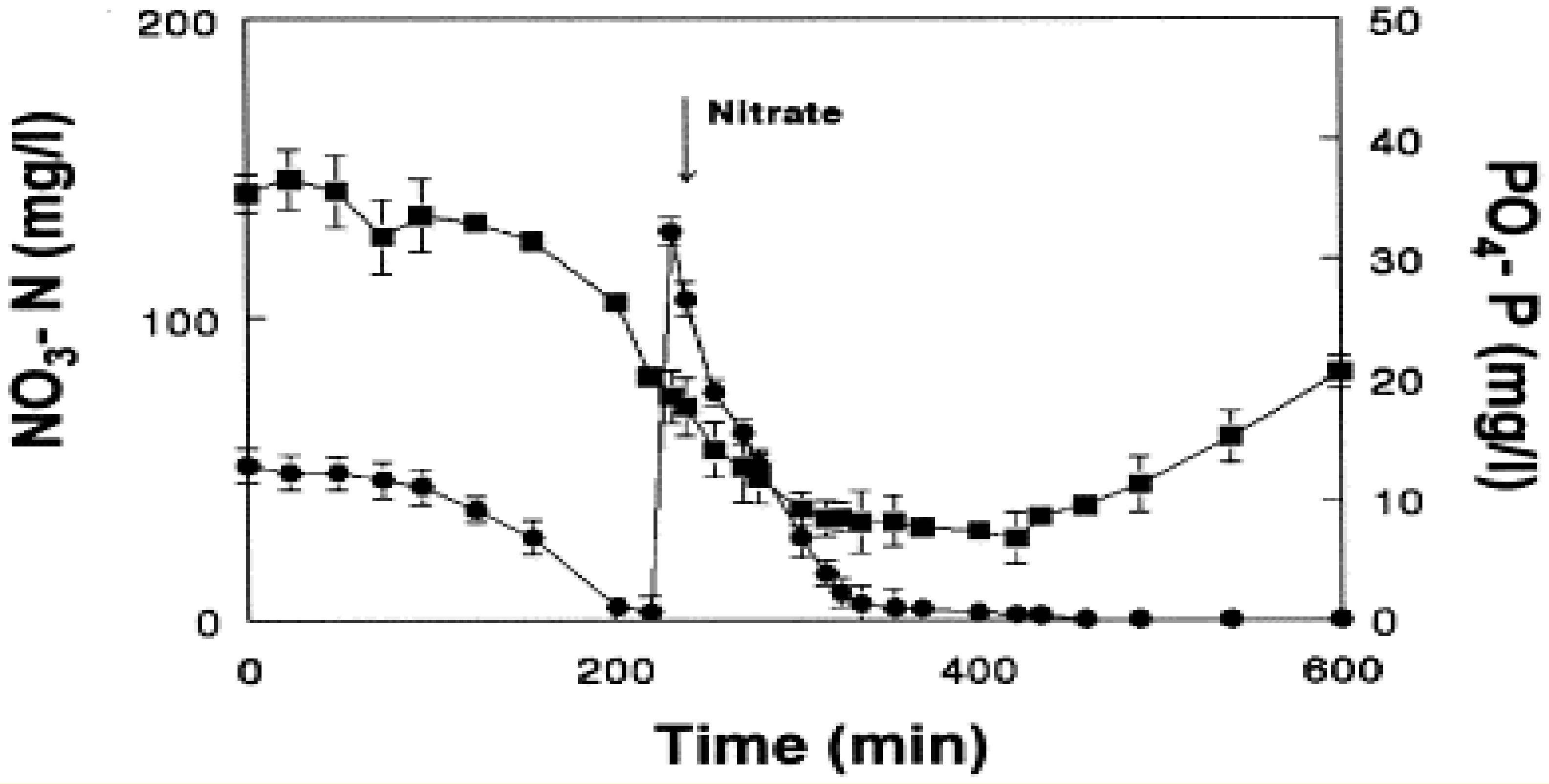
Phosphate



Effect of turning off the nitrate supply to the DB on phosphate concentrations in the overlying water of the DB

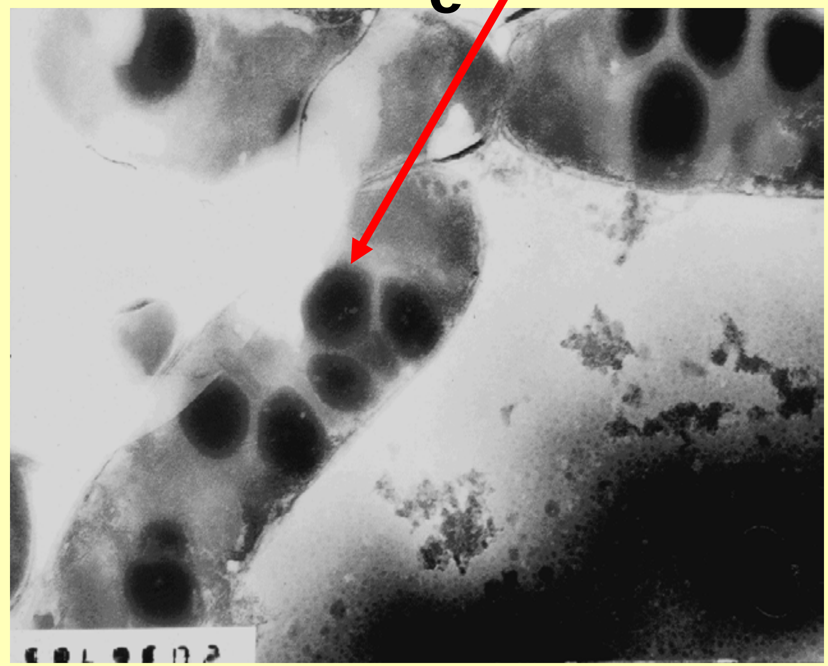


Phosphate removal by a bacterial consortium



Phosphate accumulation in denitrifiers

Before exposure to phosphate



After exposure to phosphate

Calculated degree of saturation of the major minerals most likely to be formed by diagenetic processes in the sedimentation basin sludge. The calculations were carried out using PHREEQC thermodynamic software and the pore water data measured in this study (see text). Note that minerals with a positive SI are oversaturated and potentially able to precipitate depending on the kinetics of precipitation.

Phase	**Saturation Index (SI)**	**Log IAP**	**Log KT**	**Mineral formula**
Anhydrite	-1.16	-5.52	-4.36	$CaSO_4$
Aragonite	1.74	-6.60	-8.34	$CaCO_3$
Calcite	1.88	-6.60	-8.48	$CaCO_3$
Dolomite	4.15	-12.94	-17.09	$CaMg(CO_3)_2$
Gypsum	-0.96	-5.44	-4.58	$CaSO_4 \cdot 2H_2O$
Hydroxyapatite	6.86	3.44	-3.42	$Ca_5(PO_4)_3OH$
Struvite	-1.94	2.72	-13.5	$Mg(NH_4)(PO_4) \cdot H_2O$

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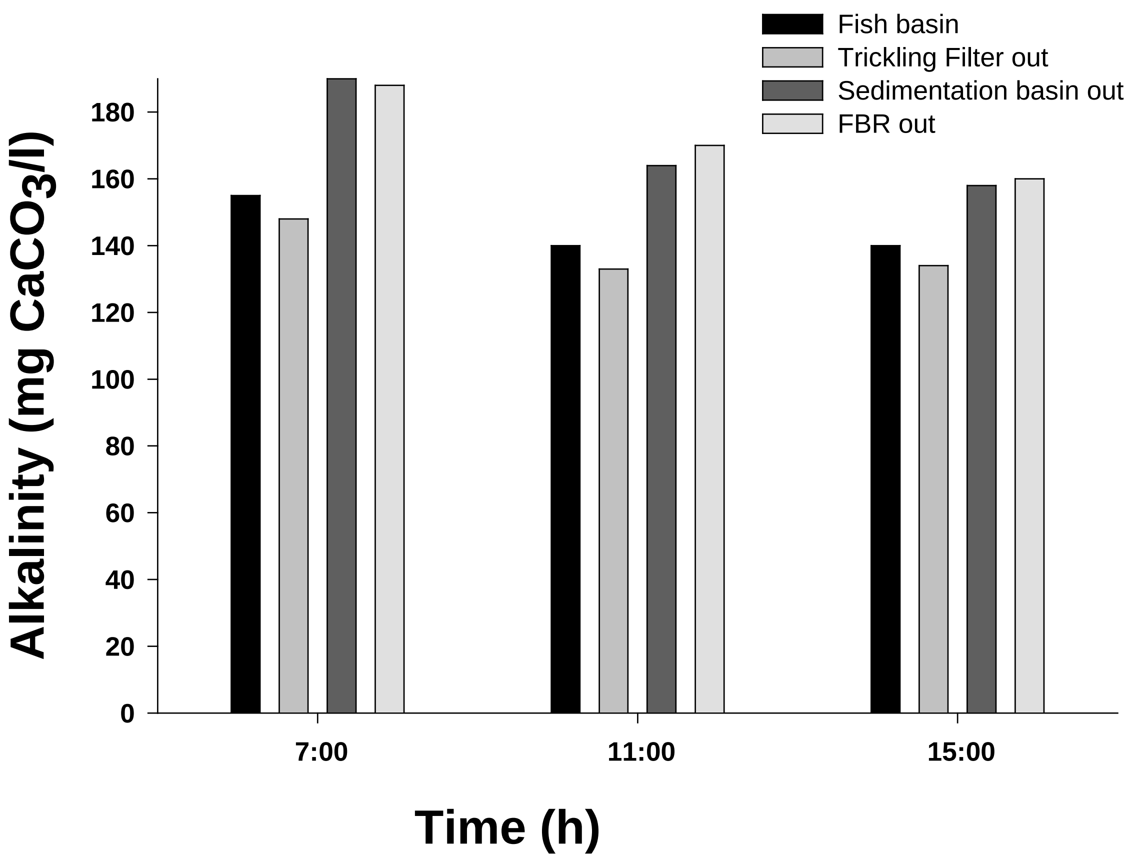

Fish basin
Trickling Filter out
Sedimentation basin out
FBR out
Alkalinity (mg CaCO3/l)
0
20
40
60
80
100
120
140
160
180
7:00
11:00
15:00
Time (h)

Nitrification

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$$

(Alkalinity gain= 1 meq of alkalinity per mmole excreted NH_3)

$$NH_4^+ + 2O_2 = NO_3^- + 2H^+ + H_2O$$

(Alkalinity loss = 2 meq of alkalinity per mmole NH_4^+)

Alkalinity loss through NH_3 excretion and subsequent nitrification is 1 meq per mmole of NH_3 excreted by the fish

Heterotrophic denitrification

$$2NO_3^- + [5H_2] + 2H^+ \longrightarrow N_2 + 6H_2O$$

Alkalinity gain = 1 meq of alkalinity per mmole NO_3

Heterotrophic denitrification

$$2NO_3^- + [5H_2] + 2H^+ = N_2 + 6H_2O$$

Alkalinity gain = 1 meq of alkalinity per mmole NO_3

Autotrophic denitrification (on H_2S)

$$5H_2S + 8NO_3^- \longrightarrow 5SO_4^{2-} + 4N_2 + 4H_2O + 2H^+$$

*(Alkalinity **loss** = 2 meq per 8 mmole NO_3^-)*

$$5SO_4^{2-} + [20H_2] + 10H^+ \longrightarrow 5H_2S + 20H_2O$$

*(Alkalinity **gain** = 10 meq per 5 mmole SO_4^{2-})*

Alkalinity gain = 1 meq of alkalinity per mmole NO_3

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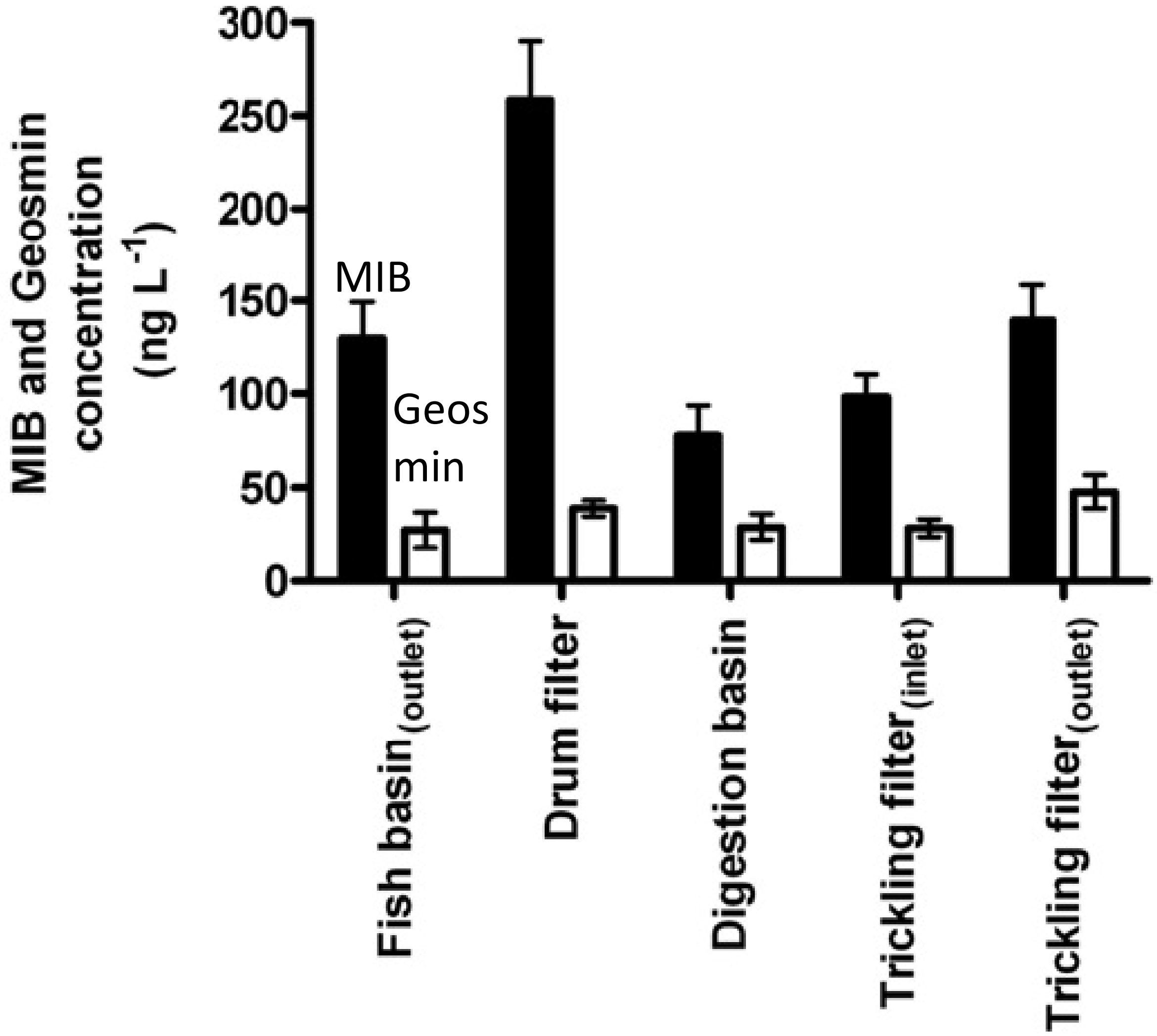
Geosmin and MIB in RAS components



Geosmin and MIB uptake by sludge

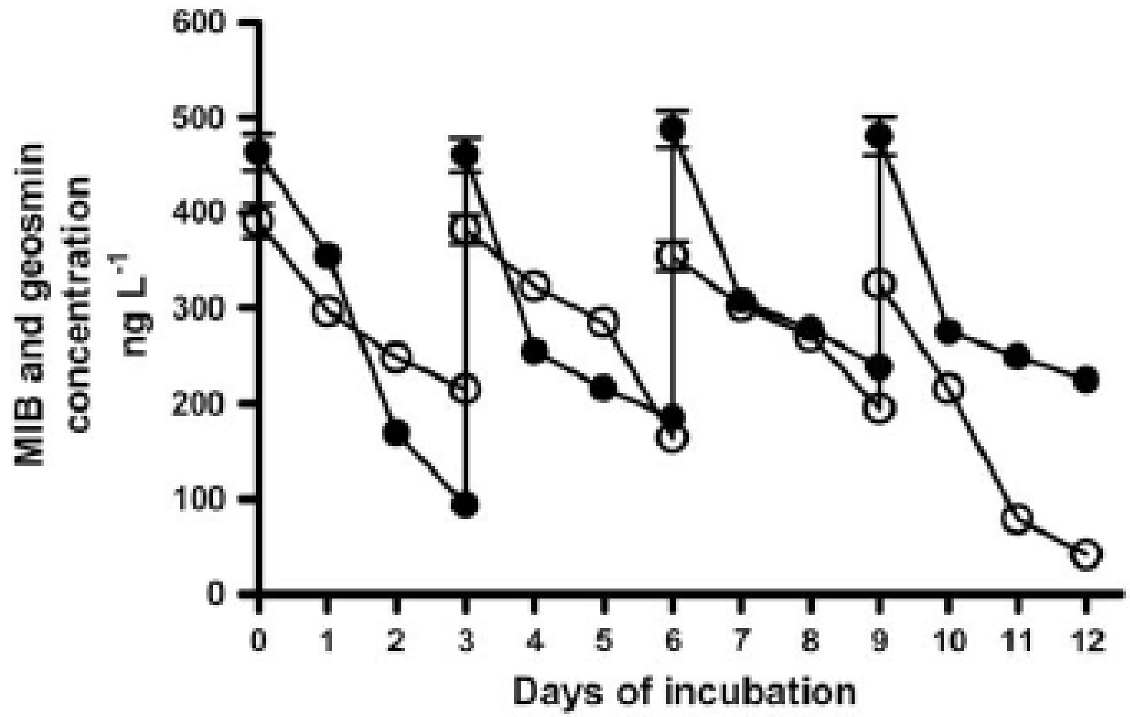


Fig. 1 – MIB (•) and geosmin (○) concentrations in the water phase of vials incubated with sludge derived from the anaerobic digestion basin of a mariculture recirculating system. Samples were spiked with MIB and geosmin every three days. The values are average concentrations, error bars represent standard deviations (*n* = 3). For data points lacking error bars, the standard deviation was less than 5% of the mean value.

Geosmin and MIB uptake by sludge

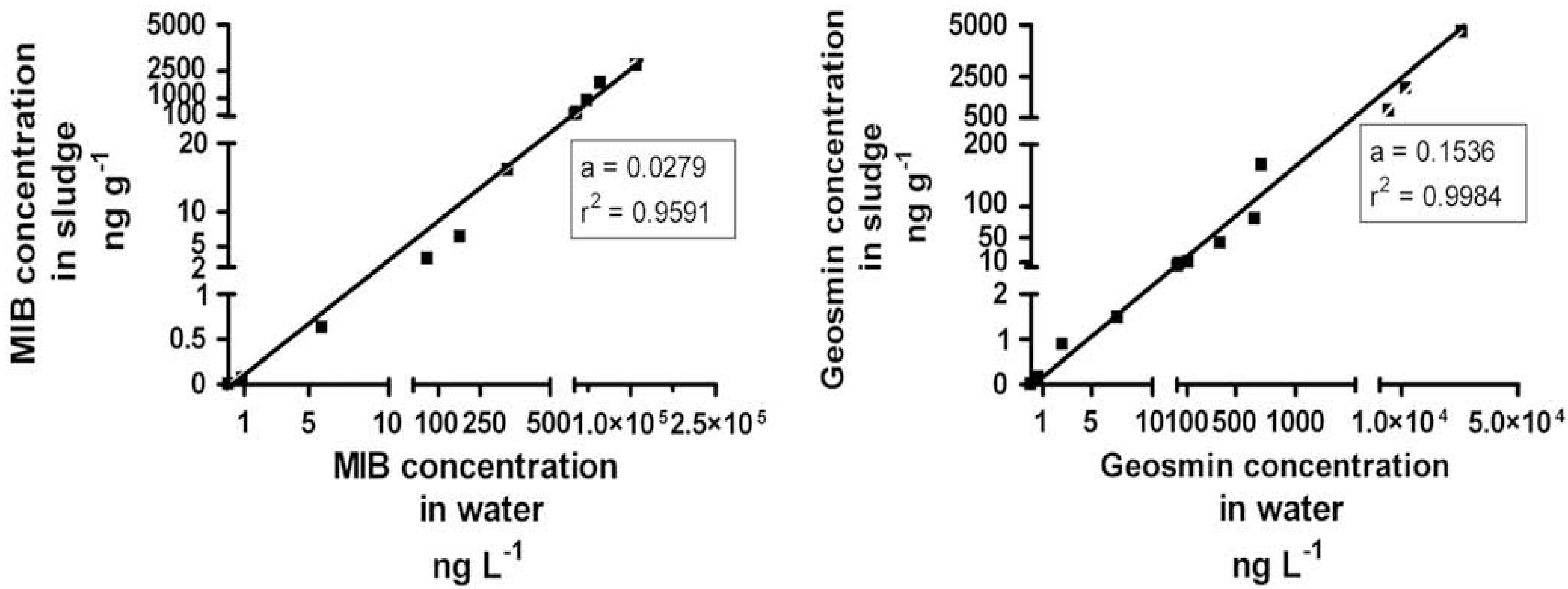


Fig. 2 – MIB (left) and geosmin (right) concentrations in the water and sludge phases at equilibrium. Values are average values (*n* = 2). When the differences between the duplicates exceeded 5%, a third replicate was analyzed so that the average values were based on a total of three replicates. The standard deviation was less than 5% of the mean value.

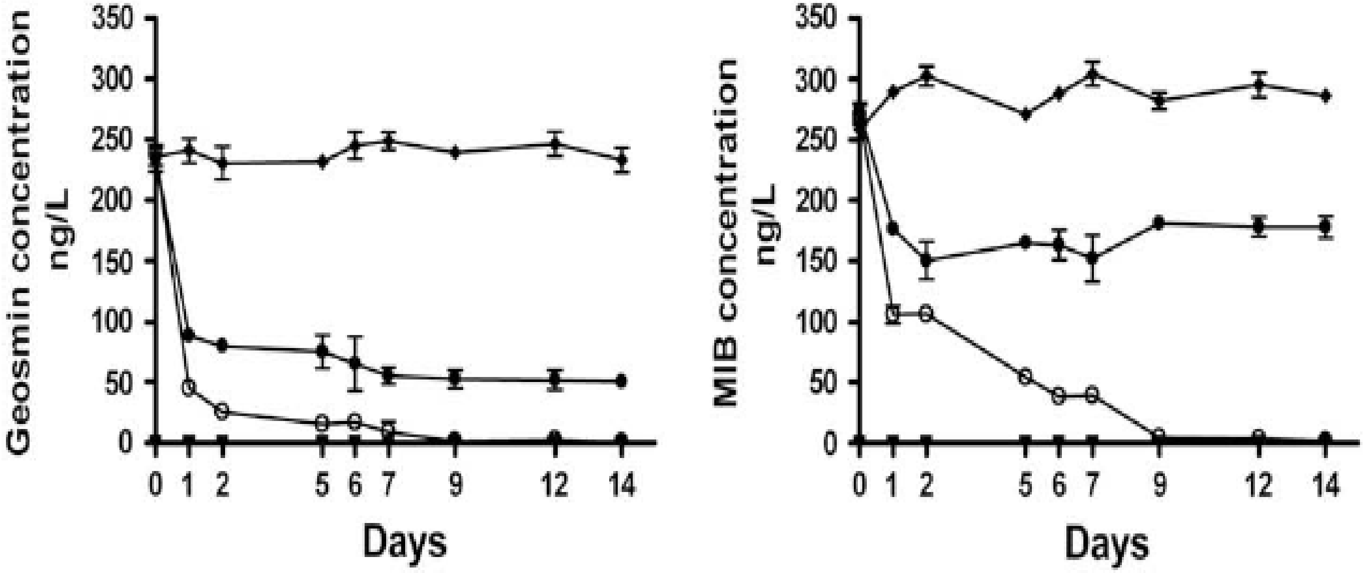
Release of geosmin and MIB from sludge

Table 1 – Release of geosmin and MIB (in weight) from sludge during successive washings[a]

Sample	MIB (ng)	Geosmin (ng)	TOC (mg)	MIB/TOC (ng/mg)	Geosmin/TOC (ng/mg)
Sludge (t = 0)	1929	2388	nr[b]	nr	nr
Water					
1st washing	361	93	6.75	53.5	13.8
2nd washing	225	74	4.18	53.8	17.7
3rd washing	149	68	2.60	57.3	26.2
Release into the water phase (%)	38	9.8	nr	nr	nr

a Sterilized sludge containing geosmin and MIB was incubated in sterile distilled water. After 72, 144 and 216 h of incubation, water was replaced with clean water and concentrations of MIB, geosmin and total organic matter (TOC) were measured in the displaced water.
b Not relevant.

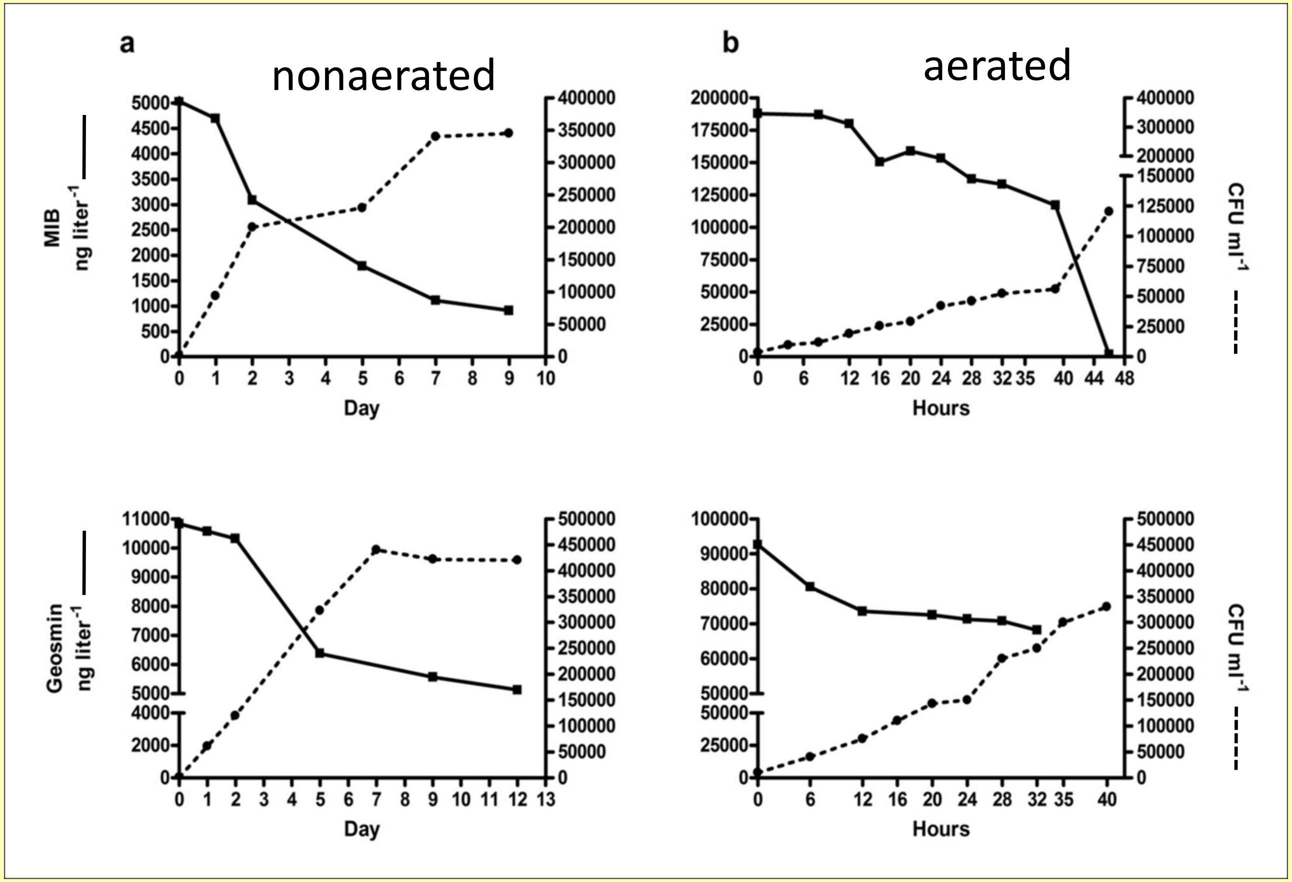
Differentiation between physical/chemical sorption and biodegradation



–♦– without sludge
–●– sterilized sludge
–o– untreated sludge
–■– without geosmin/MIB

Biodegradation

Variovorax paradoxus



Biodegradation

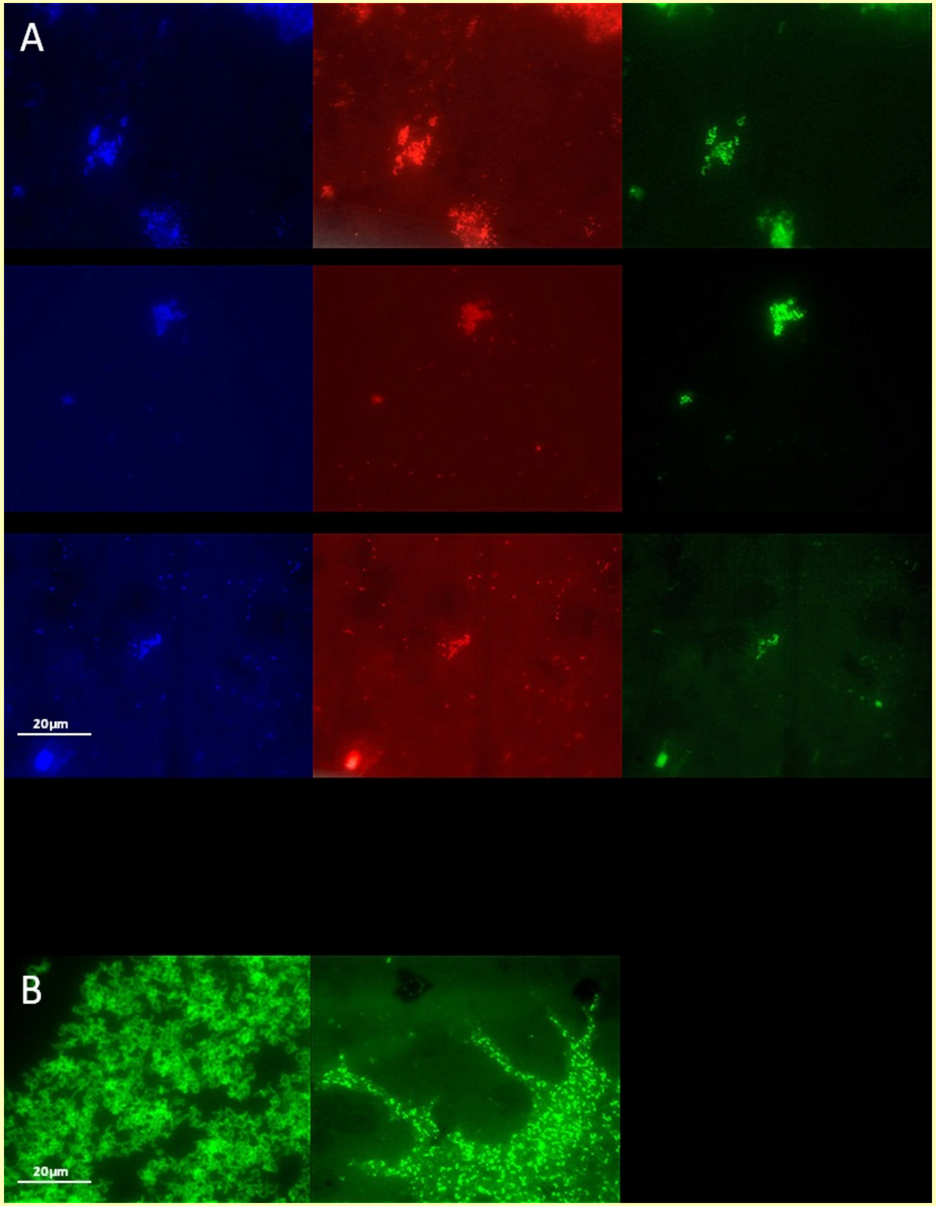


FIG 7 FISH analysis of sludge bacteria with DAPI (blue), EUB338 (red) and the targeting probes (green) HGCr69A (top panels), RHCOC3 (middle panels), and COM1424 (bottom panels) (A) and the *Rhodococcus sp.-like isolate* with the 16S rRNA targeting probe RHCOC3 (left) and the *Comamonas sp.-* like isolate with the 16S rRNA targeting probe COM1424 probe (right) (B).

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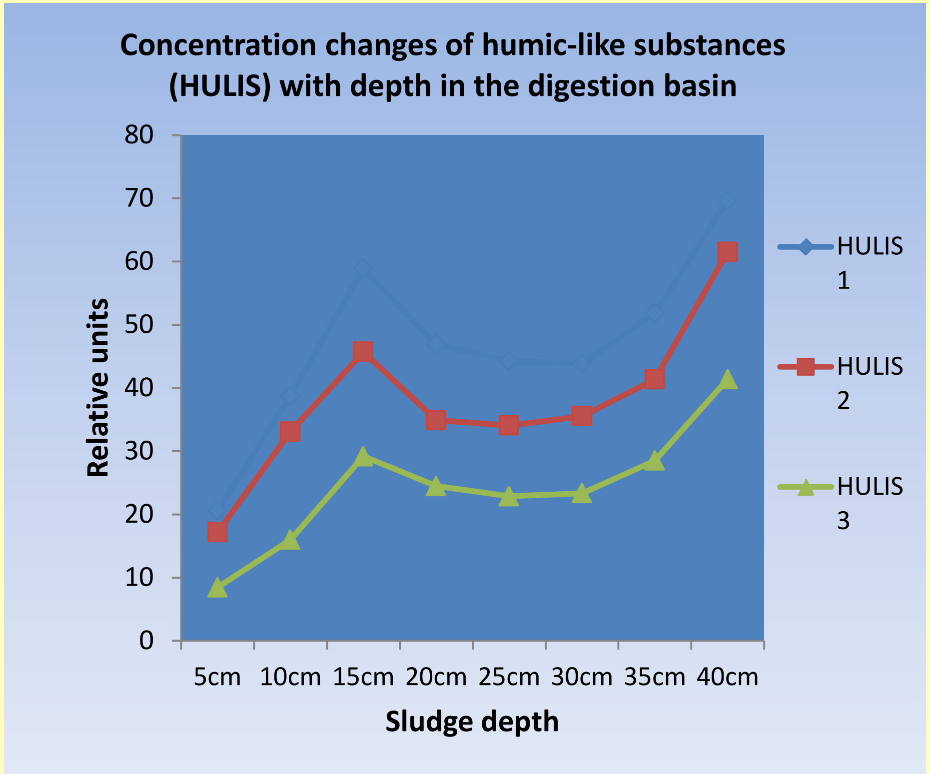
Humic Acids and Fish Health



Survival of carps after challenge with *Streptococcus iniae*

Accumulative survival percent		Days from exposure
Zero-discharge system	Semi closed system	
100	100	**1-13**
88	78	**14**
84	56	**15**
64	30	**16**
24	4	**17**
8	0	**18**
0	0	**19**

Conclusions

*Like in natural water bodies, anaerobic processes have a beneficial effect on the overall water quality in RAS.

*In addition to water savings and reduction of waste discharge, the following beneficial effects of anaerobic treatment could be discerned:

**Nitrate removal*
**Phosphate removal*
**Alkalinity control*
**Removal of off flavor compounds*
**Production beneficial humic substances*

Acknowledgement

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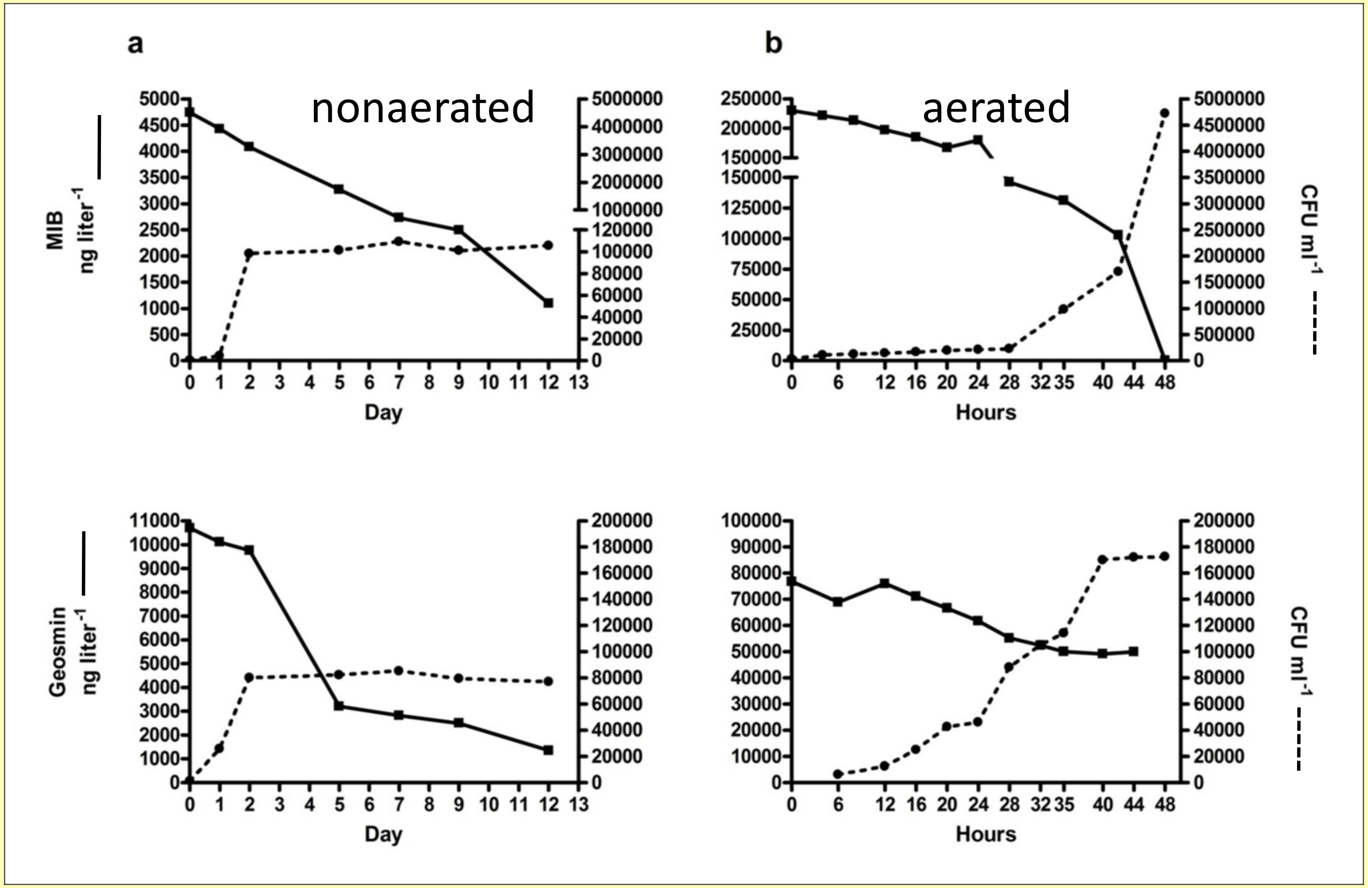
Yossi Tal
Yoram Barak
Eddie Cytryn
Lior Guttman

Cooperating Scientists

Prof. Michael Krom
Dr. Amir Neori
Dr. Dror Minz

Biodegradation

Rhodococcus sp.



Biodegradation

Comamonas sp.