The role of micronectonic vertical migrants in the ocean carbon pump

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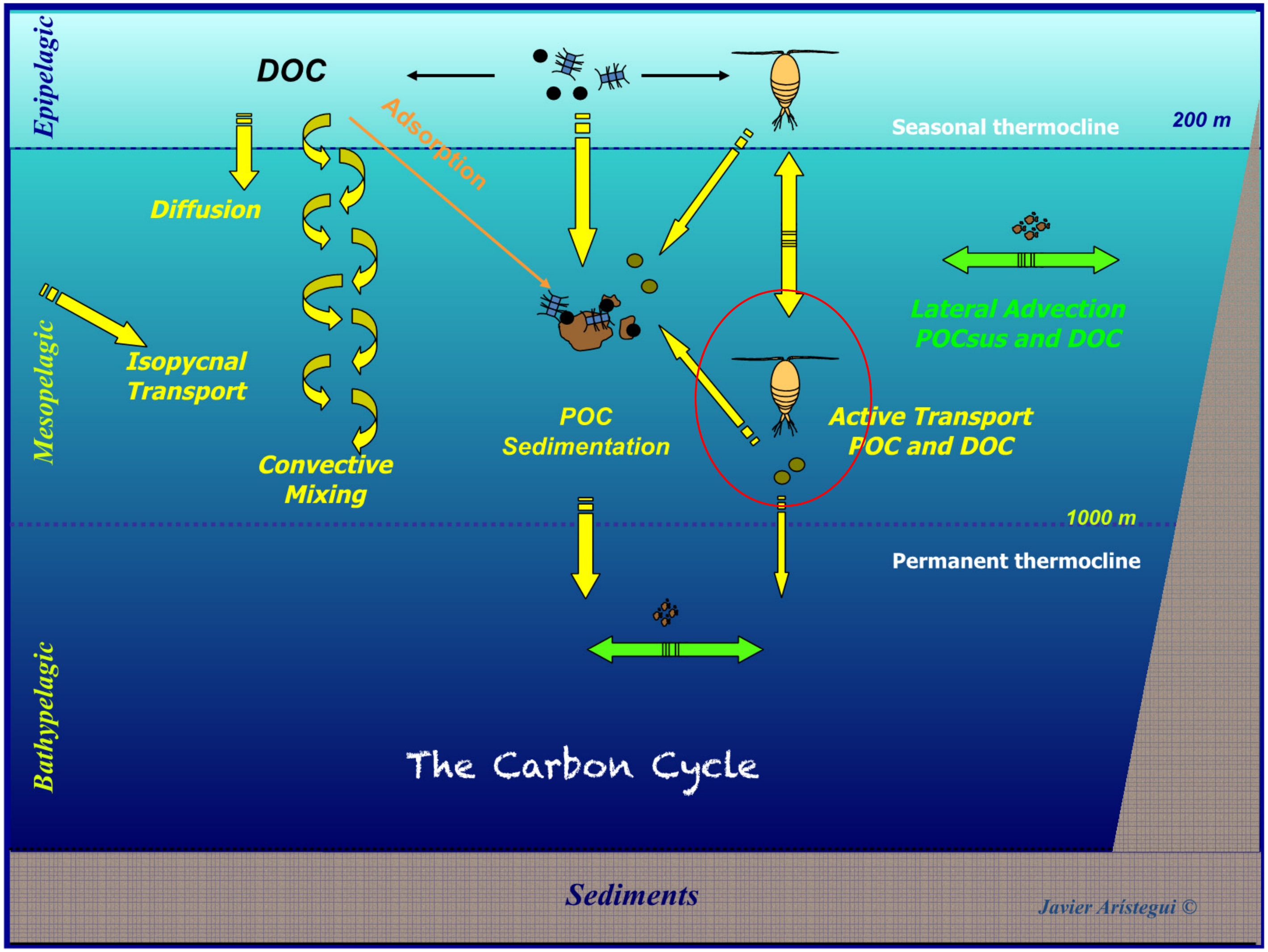
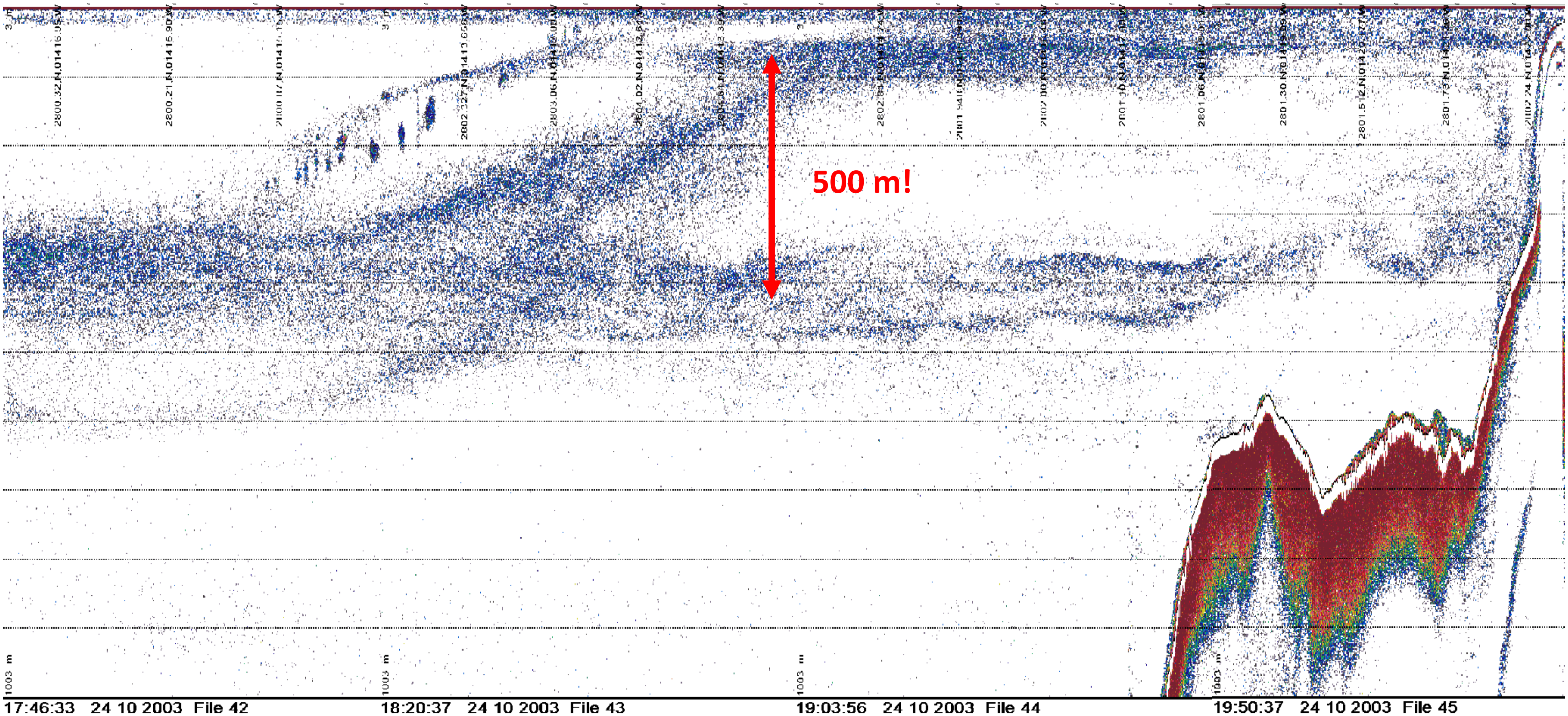

Epipelagic
DOC
Adsorption
Seasonal thermocline
200 m
Diffusion
Lateral Advection
POCsus and DOC
Mesopelagic
Isopycnal
Transport
POC
Sedimentation
Active Transport
POC and DOC
Convective
Mixing
1000 m
Permanent thermocline
Bathypelagic
The Carbon Cycle
Sediments
Javier Arístegui ©

Active Flux



Bordes et al. (2010)

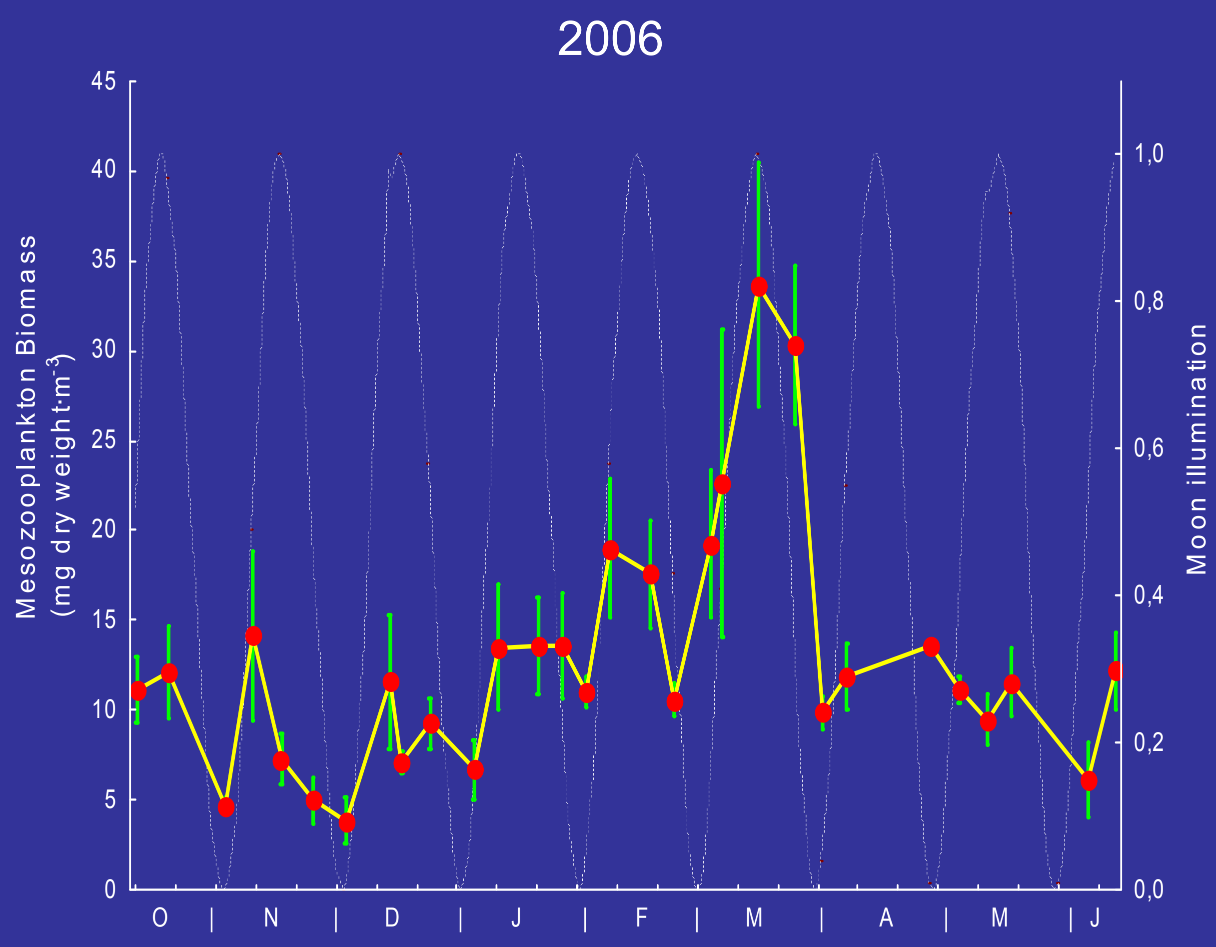
Table 4.1. Zooplankton active flux estimated in different oceanic regions.

Location	Time of year	Migrant biomass (mg $C \cdot m^{-2}$)	Respiratory flux (mg $C \cdot m^{-2} \cdot d^{-1}$)	Gut flux (mg $C \cdot m^{-2} \cdot d^{-1}$)	% of POC flux	References
Oligotrophic area						
HOT		30.2 - 33.8	1.3-1.7	-	4[a]	Roman *et al.*, 2002
Equator divergence		2.8 - 21.8	0.9-1.2	-	<1-2[a]	Roman et al. (2002)
BATS	March/April	192 (84–540)	14.5 (6.2-40.8)	-	34 (18-70)[a]	Dam *et al.* (1995)
BATS	year-round	50 (0-123)	2.0 (0-9.9)	-	8 (0-39)[b]	Steinberg *et al.* (2000)
BATS	year-round	83 (0.7-468)	-	0.8 (0.007-4.5)	4 (0.03-21)[c]	Schnetzer and Steinberg (2002)
Western Equator	October	46.9	3	-	6	Le Borgne and Rodier (1997)
North (Oceanic)	Oct-Nov	30 ± 10	2.2 ± 0.3	-	-	Isla and Anadón (2004)
Eastern Equator	March - April	96 ± 25.2	4.2 ± 1.2	-	18[a]	Zhang and Dam (1997)
Eastern Equator	October	154.8 ± 32.4	7.3 ± 1.4	-	25[a]	Zhang and Dam (1997)
ALOHA	Year-round	162 (108-216)	3.6 (2.6 - 19.1)	-	15 (12-18)[a]	Al-Mutairi and Landry (2001)
ALOHA	June - July	157.9	3.7	-	18[a]	Steinberg *et al.* (2008)
Eu- Meso-trophic area						
Central Equator (HNLC)	October	52.9	6	-	4[a]	Le Borgne and Rodier (1997)
North (coastal)	Oct-Nov	360 ± 70	30.3 ± 1.9	-	-	Isla and Anadón (2004)
North (poleward current)	Oct-Nov	270 ± 210	10.4 ± 6.3	-	-	Isla and Anadón (2004)
Western Equator	October	46.9	3	-	6[a]	Le Borgne and Rodier (1997)
Western Equator	February	367 (144 - 447)	22.7 (7.3-19.1)	4.8 (2.6-4.4)	24 (13-35)[a]	Hidaka *et al.* (2001)
Canary Current						
Canary Islands	March	204 (108 - 341)	0.8 (0.5-1.4)	0.1 (0.05-0.18)[e]	1.8 (1.1-2.7)[d]	Chapter 3.2
Canary Islands	June	580 - 1280	1.8 - 8.3	0.1 - 0-4[e]	15-53[d]	Yebra *et al.* (2005)
Canary Islands	August	247 - 125	4.2 - 1.9	0.3 - 2.4[e]	20-45[d]	Hernández-León *et al.* (2001a)
26ºN	Sept-Oct	325 (106 - 486)	0.6 (0.02 - 1.2)	0.8 (0.01 - 3.0)[e]	3.3 (0.1-9.0)[f]	Chapter 3.3
	May-June	314 (163.2 - 408)	2.3 (1.7 - 3.4)	0.2 (0.03 - 0.4)[e]	47.8 (26.9-64.4)[f]	Chapter 3.4
21ºN	Sept-Oct	857 (368 - 1601)	6.5 (1.1 - 14.9)	22.7 (1.3-96.1)[e]	66.0 (0.1-149.5)[f]	Chapter 3.3
	May-June	314 (426.4 - 4480)	2.3 (2.7 - 48.6)	9.5 (0.05-28.0)[e]	118.6 (29.1-273.7)[f]	Chapter 3.4

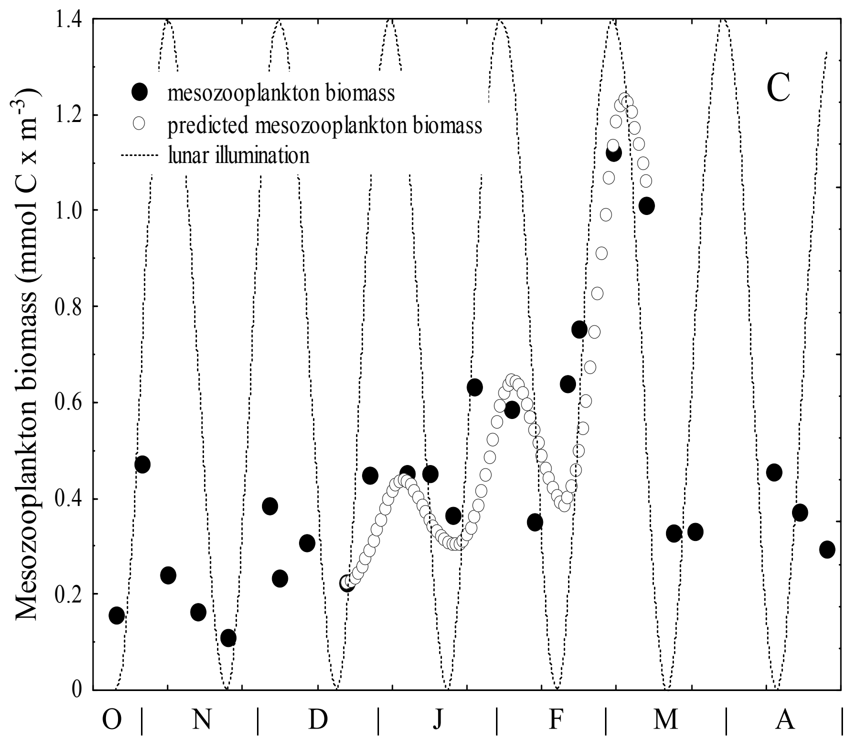
[a] %POC flux represents only respiratory flux. [b]Active flux includes DOC. [c]Active flux represents only gut flux. [d]Respiratory flux plus gut flux. [e]Gut flux assessed with GF.

[f]Potential ingestion assessed from respiration.

Putzeys (2013)



Hernández-León et al. (2010)



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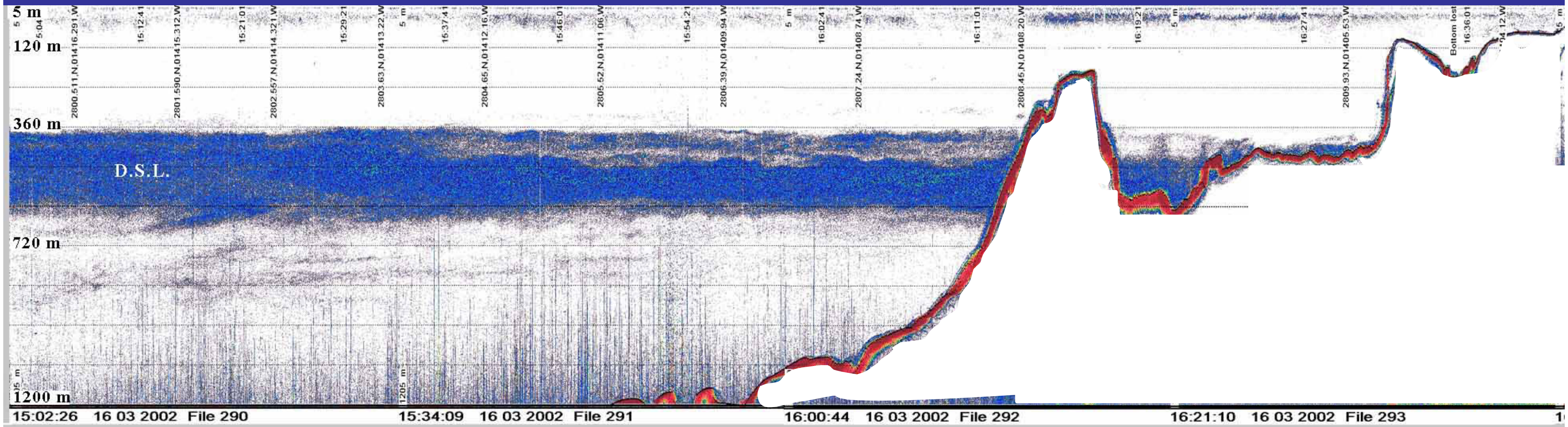
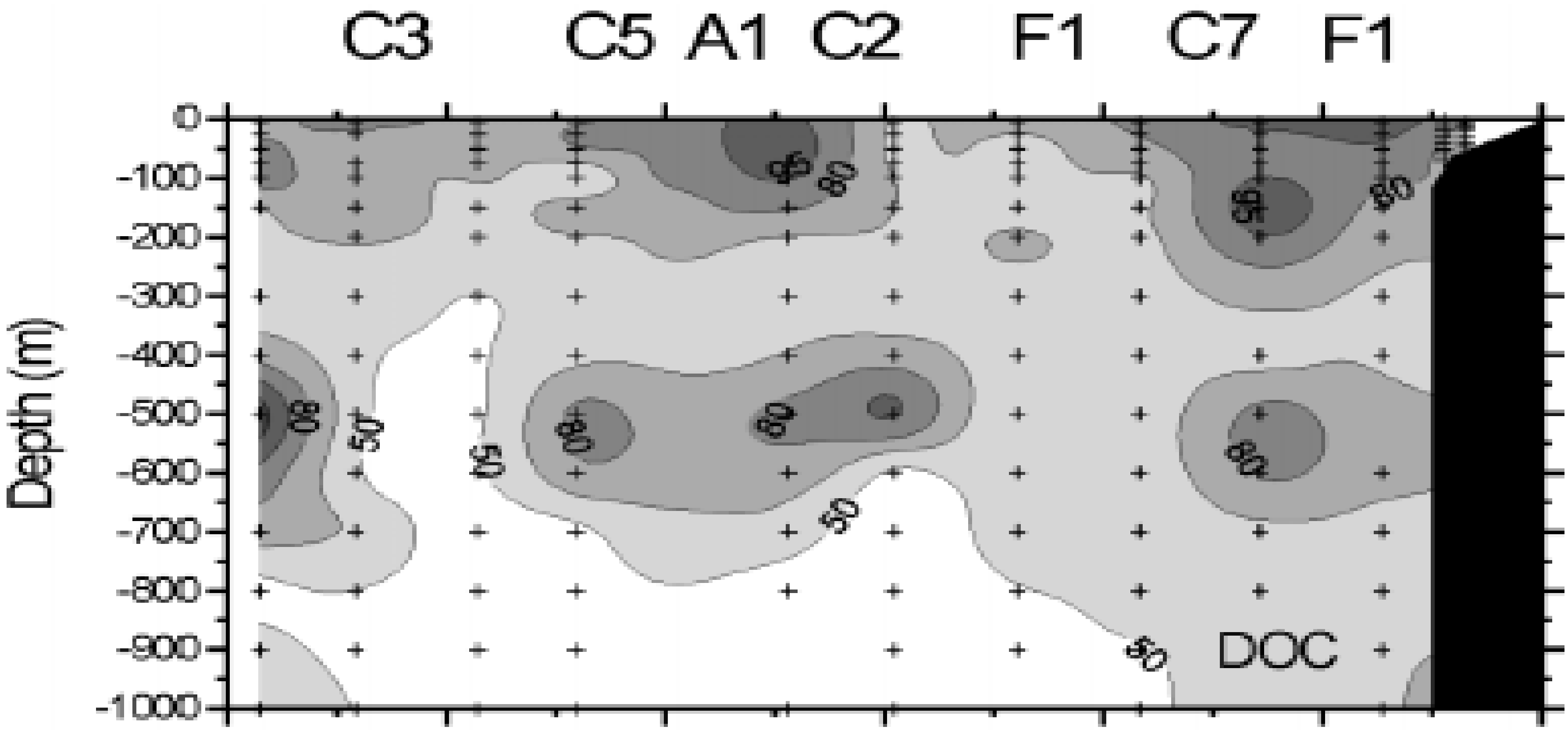


Bordes et al. (2010)

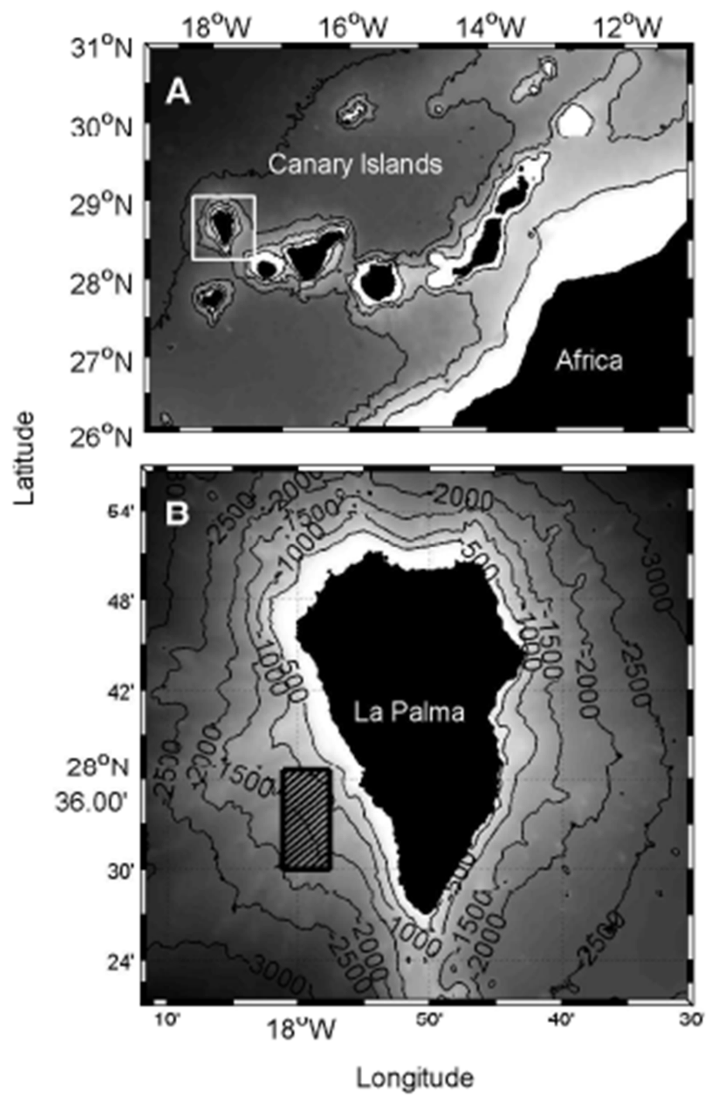


Arístegui et al. (2003)

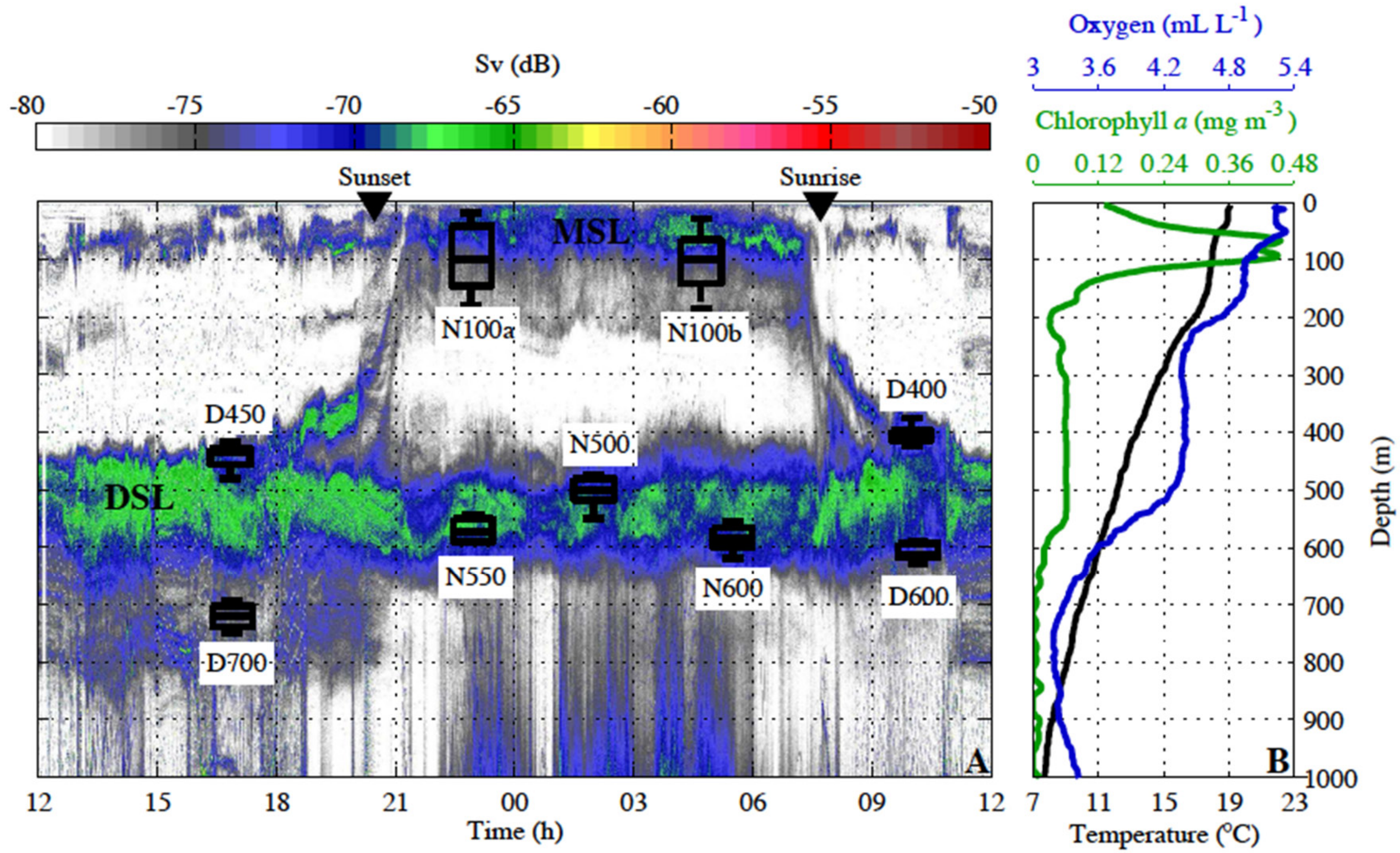
But,

Hidaka et al. (2001) showed that flux due to micronektonic organisms was 56-60% of total active flux.

MOHT
Oozeki et al. (2004)



Ariza et al. (in prep.)



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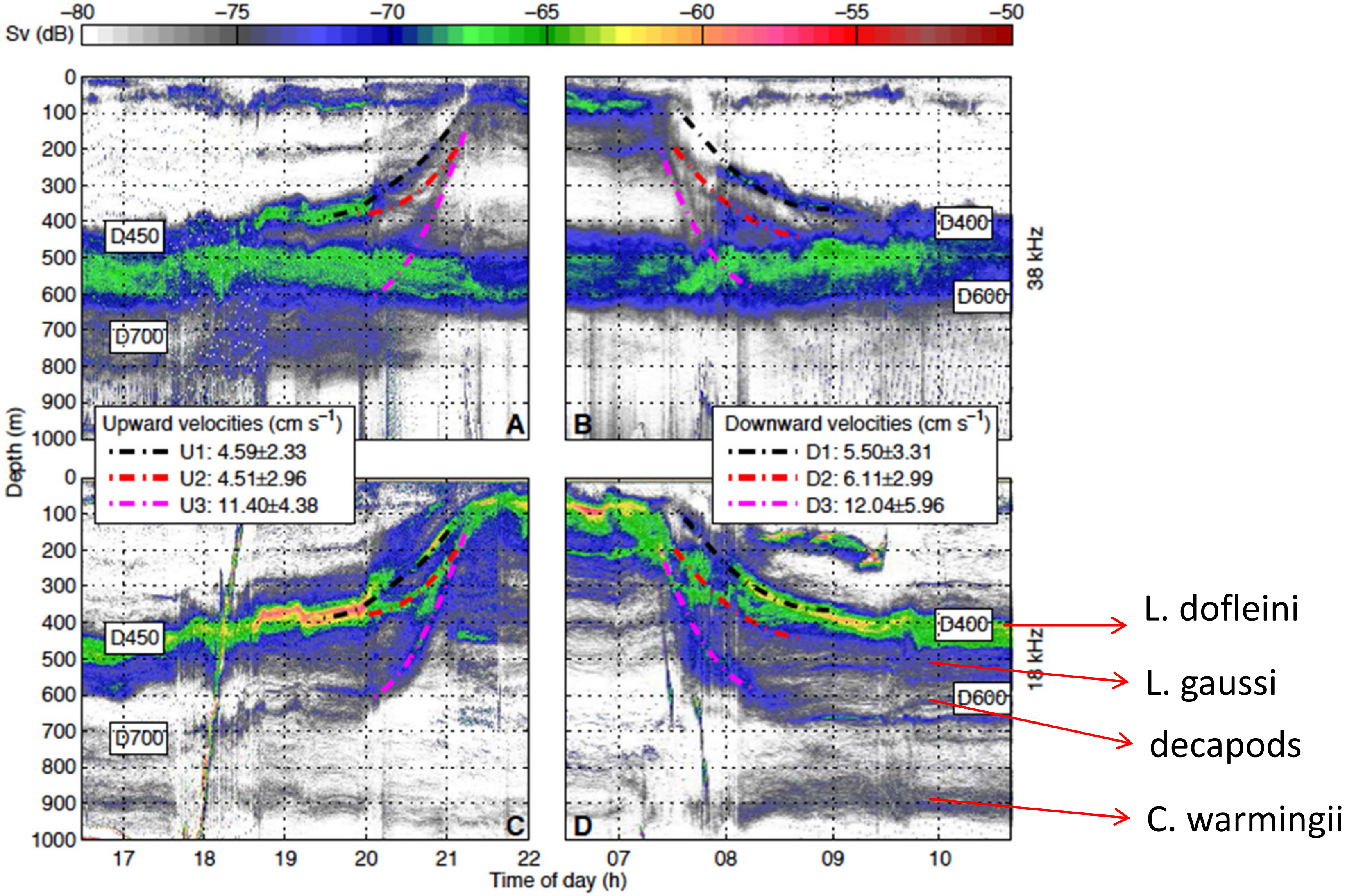

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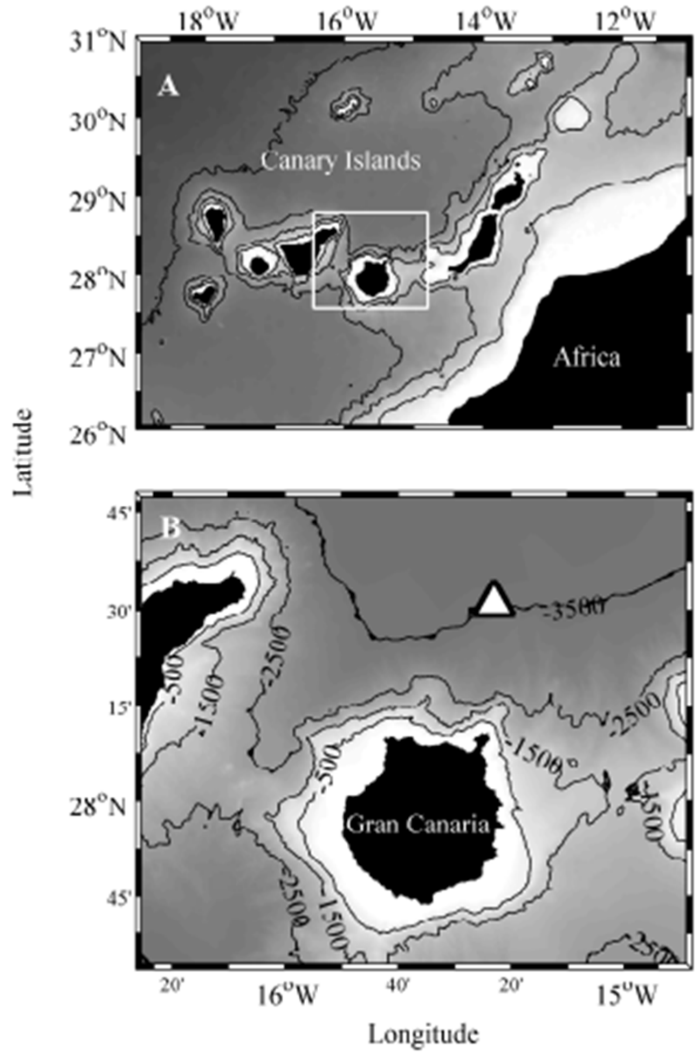

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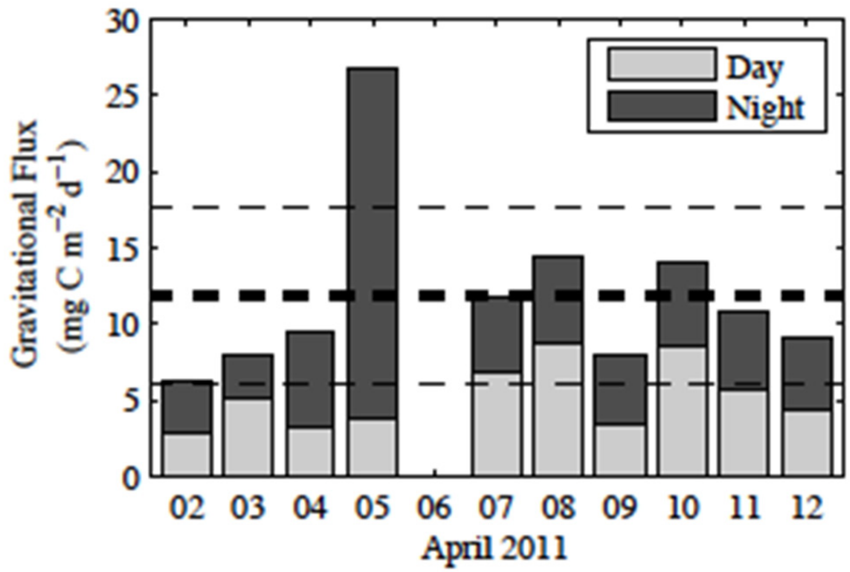

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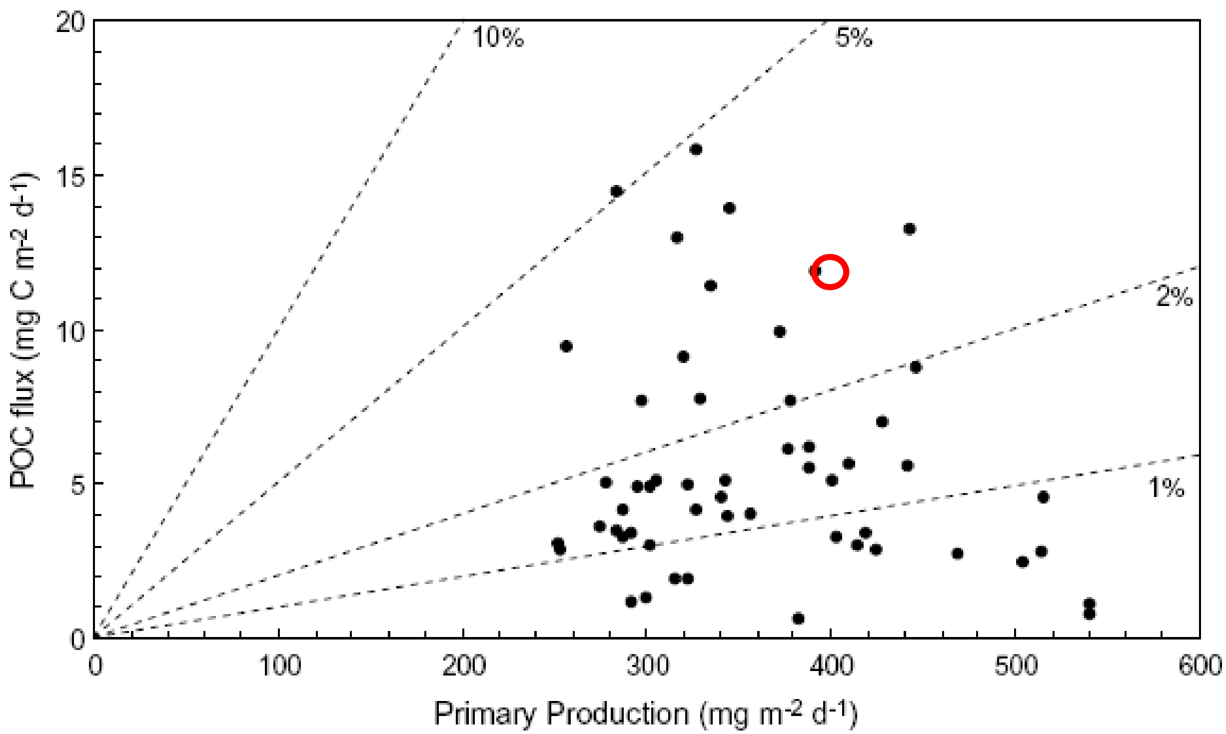
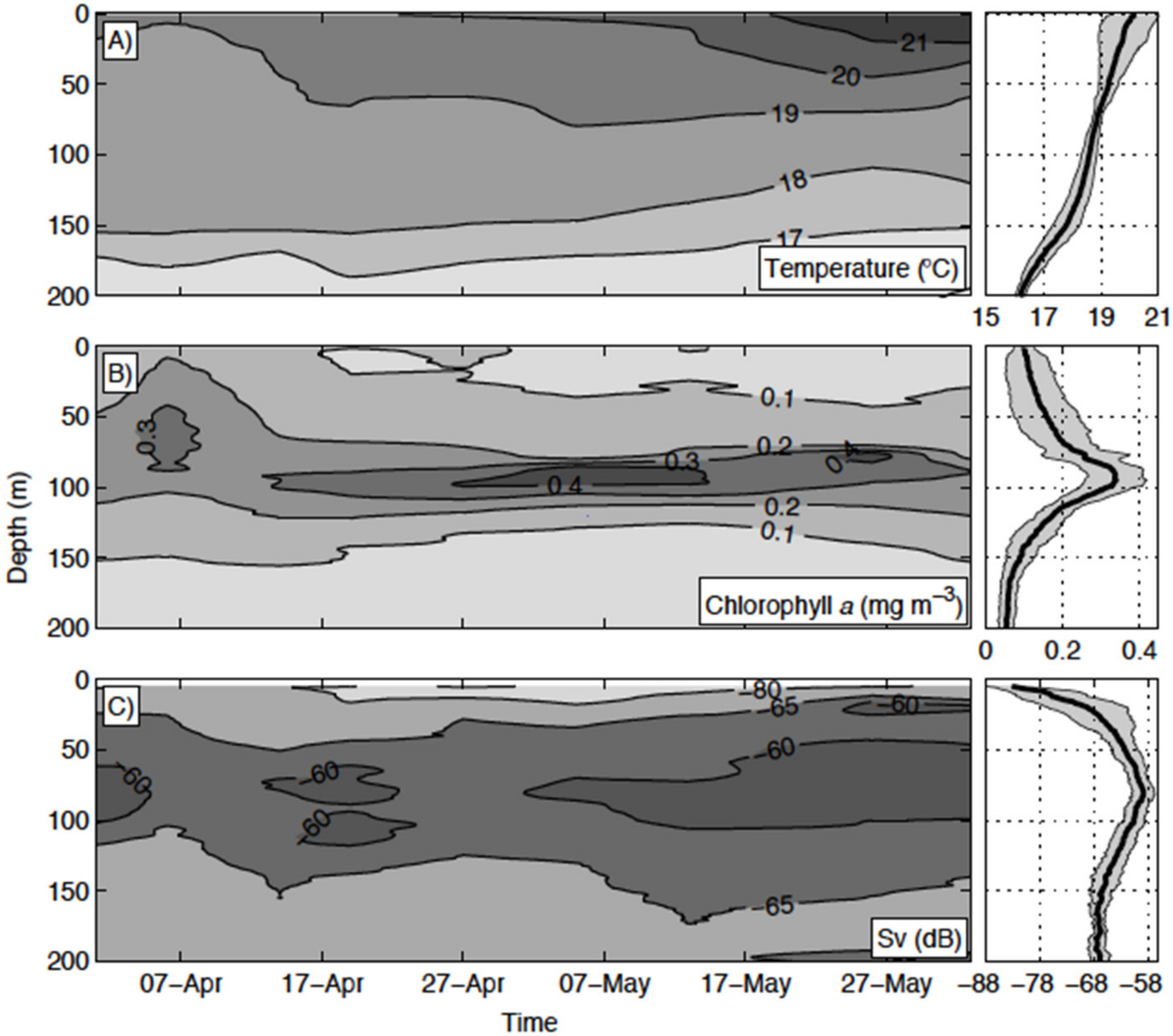


Neuer et al. (2007)



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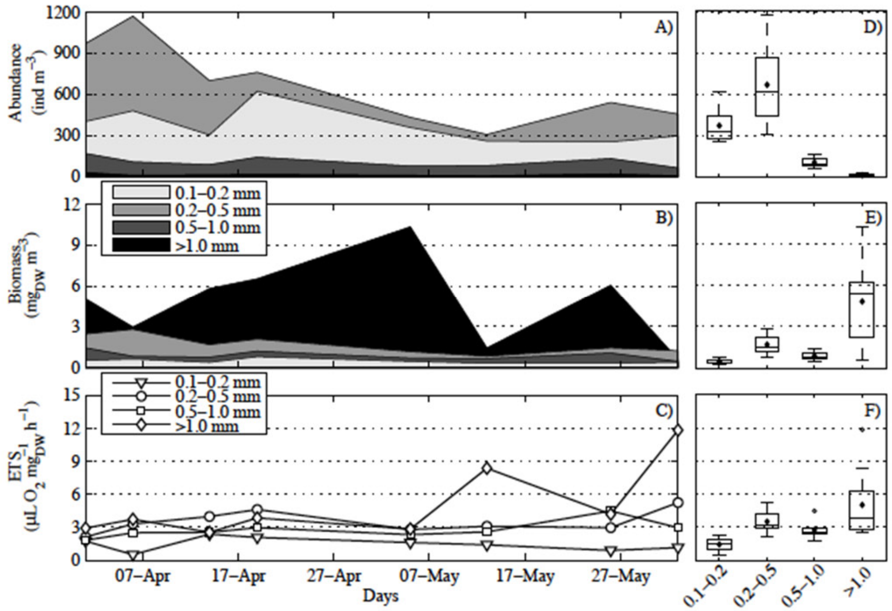

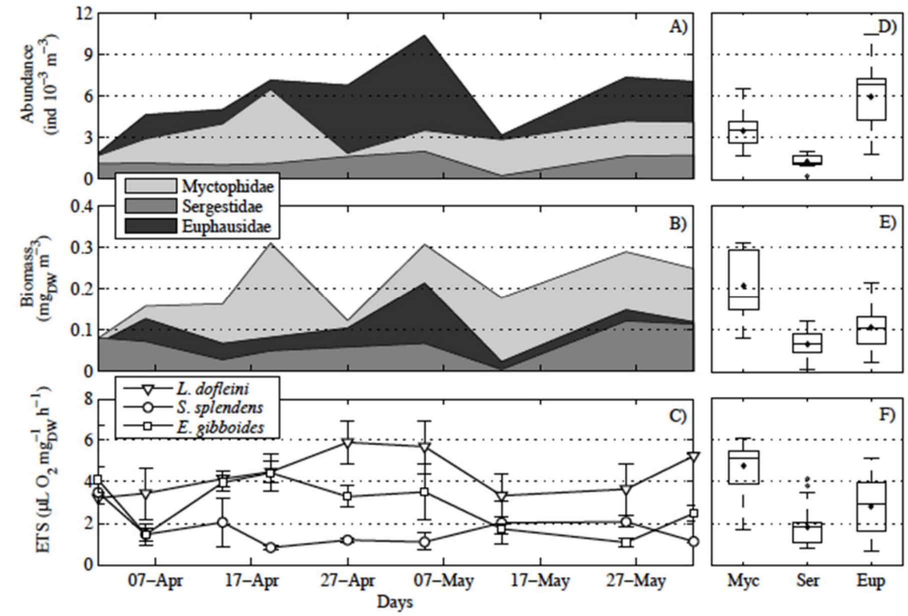

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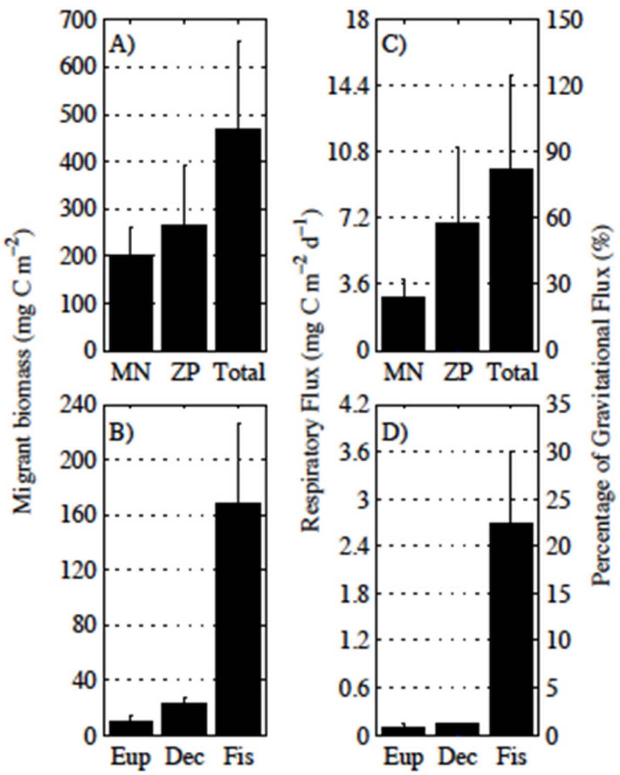


Passive flux: 11.9 ±5.8 $mgC \cdot m^{-2} \cdot d^{-1}$

Resp. flux zooplankton: 6.9 ±4.2 $mgC \cdot m^{-2} \cdot d^{-1}$

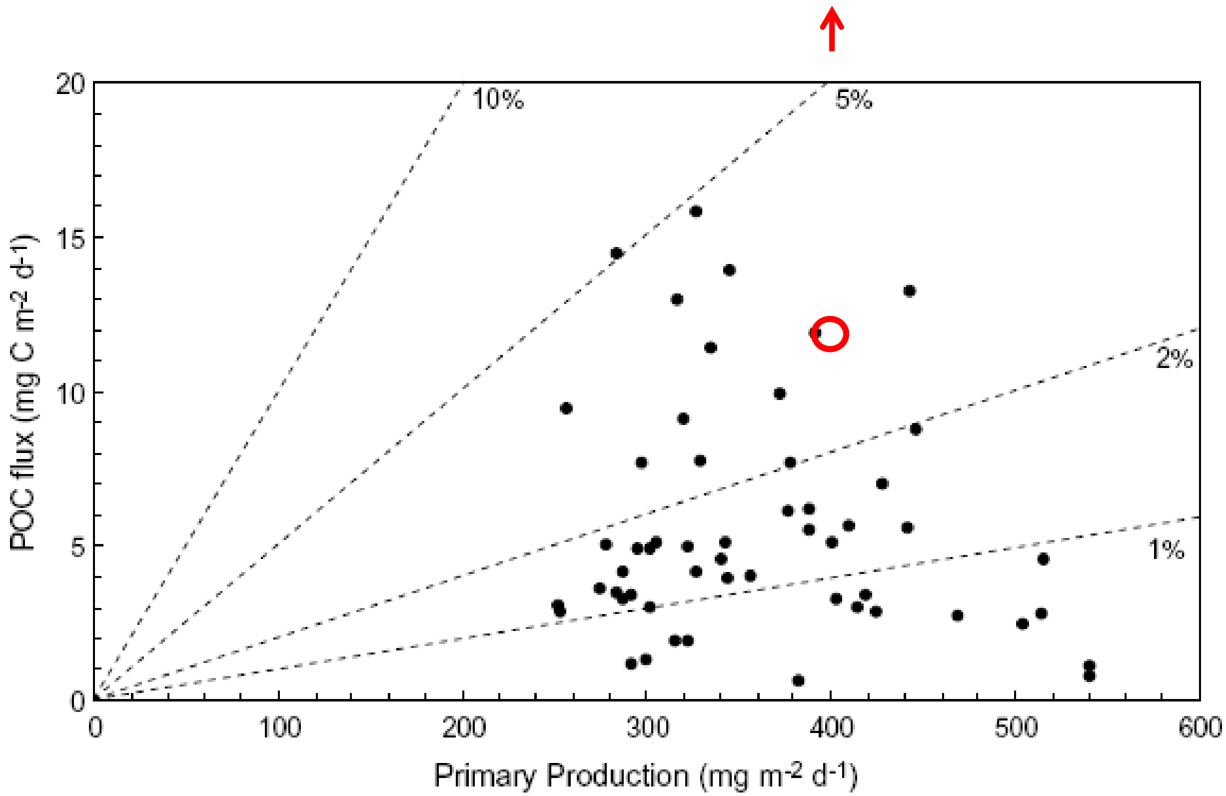
Respiratory flux micronekton: 2.9 ±1.0 $mgC \cdot m^{-2} \cdot d^{-1}$

Gut flux micronekton: 2.1 ±0.7 $mgC \cdot m^{-2} \cdot d^{-1}$

Excretion flux micronekton: ? $mgC \cdot m^{-2} \cdot d^{-1}$

Mortality: ? $mgC \cdot m^{-2} \cdot d^{-1}$

Ariza et al. (in prep.)



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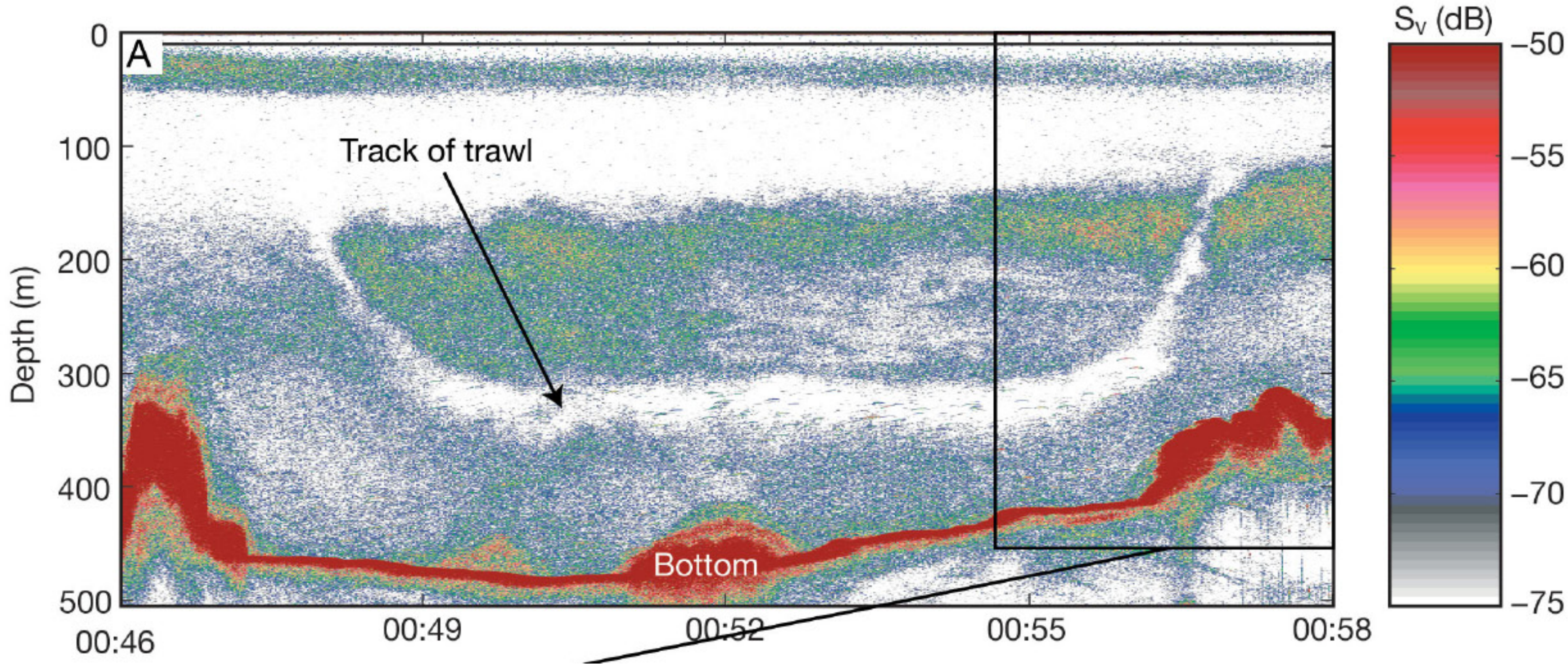
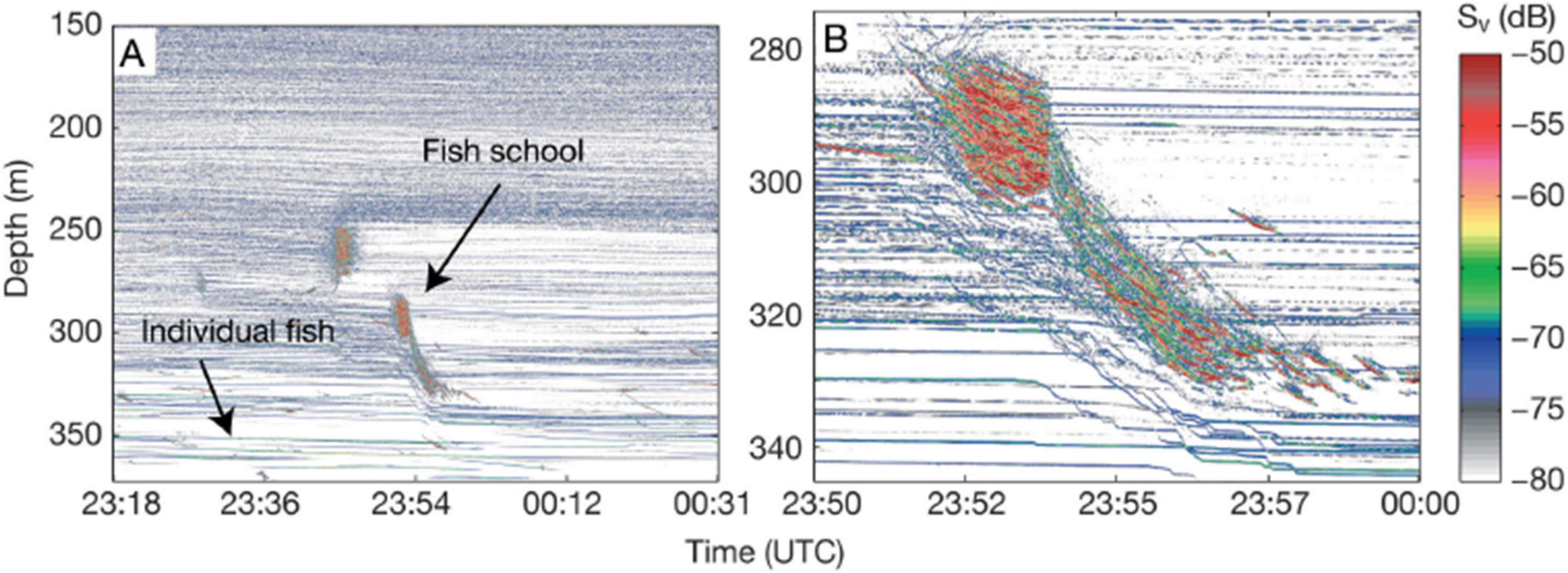
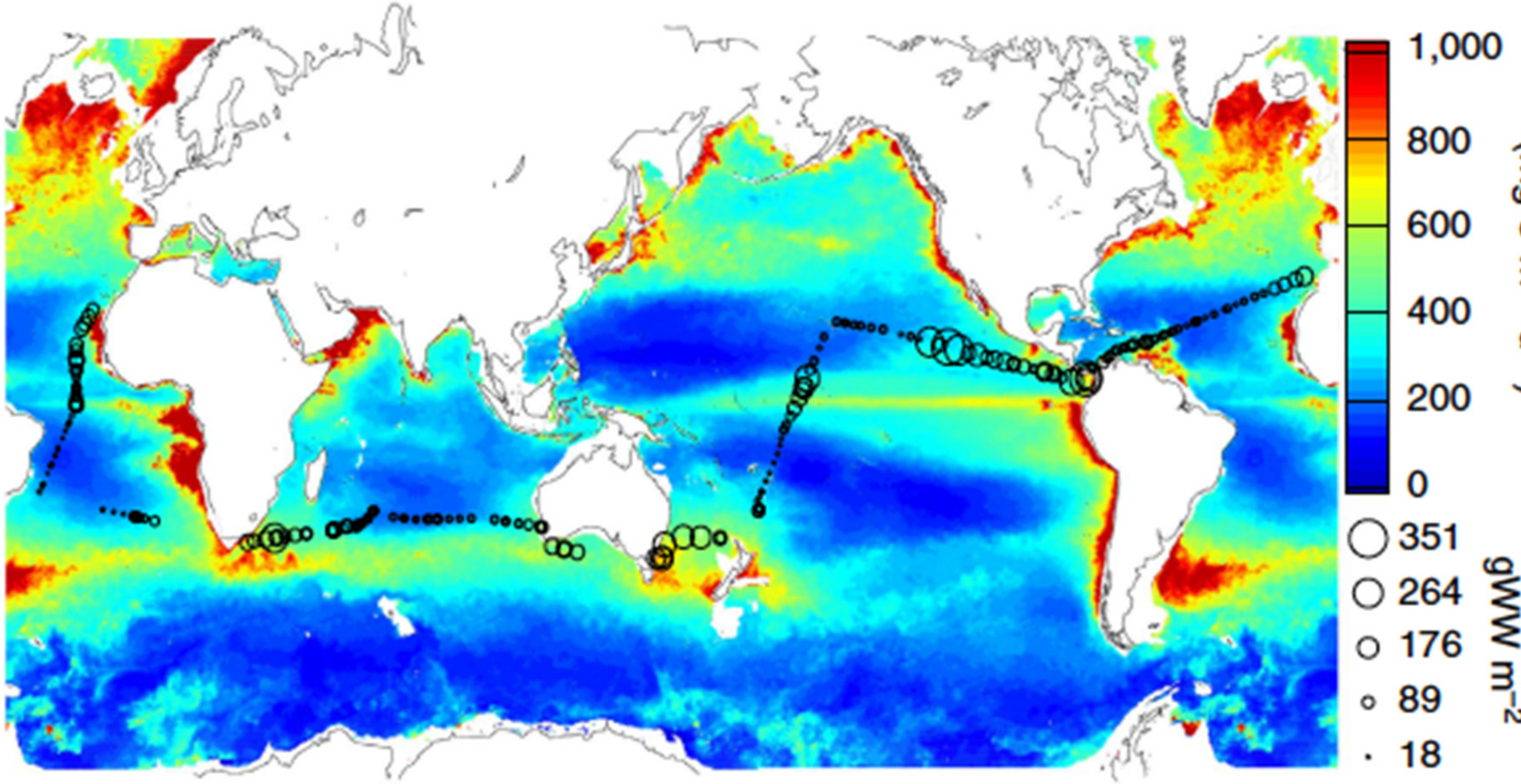


Kaartvedt et al. (2012)



Kaartvedt et al. (2012)

Malaspina Cruise



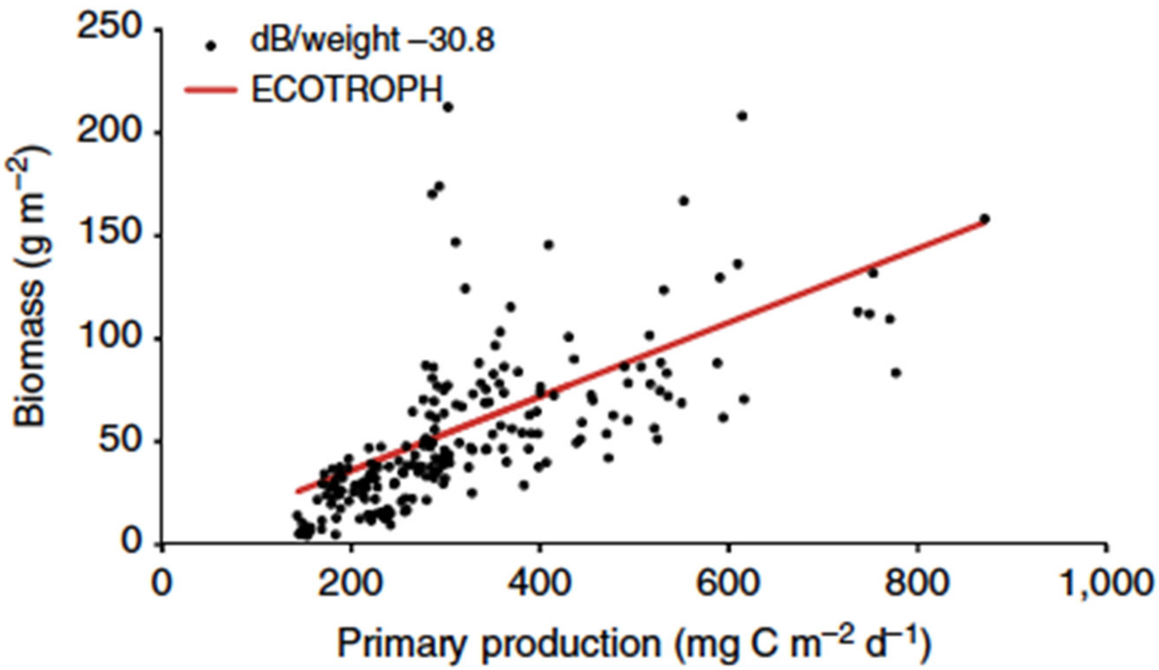
Irigoien et al. (2014)

Table 1 | Acoustic fishes biomass estimates.

s_A estimate	Total s_A	Acoustic fishes biomass estimates					
		Average	Median	75%	25%	Max	Min
		-34.6 db kg^{-1}	-30.8 db kg^{-1}	-28.4 db kg^{-1}	-42.2 db kg^{-1}	-26.8 db kg^{-1}	-46.8 db kg^{-1}
OLS: $s_A = 2384.4^* \ln(PP) - 11678$	4.24E+17	28,363	11,824	6,804	163,215	4,707	470,717
OLS: $\ln(s_A) = 1.52^* \ln(PP) - 1.36$	4.70E+17	31,449	13,110	7,544	180,972	5,219	521,930
GWR: $\ln(s_A) = 1.36^* \ln(PP) - 0.2$	5.57E+17	37,264	15,534	8,939	214,433	6,184	618,432
GWR different equations for PP above and below 400*	4.38E+17	29,321	12,223	7,034	168,725	4,866	486,607
Cruise average $s_A$xocean surface deeper 1,000 m	4.14E+17	27,427	11,433	6,579	157,826	4,552	455,176

GWR, geographically weighted regression; OLS, ordinary least squares regression. Total backscatter between 40° N and 40° S estimated from PP (total s_A) and different acoustic to weight (db kg^{-1}) ratios (see Table 2).
*See Supplementary Table 1 for details on the GWR equation parameters above and below 400 mg C m^{-2} d^{-1}.

Irigoien et al. (2014)



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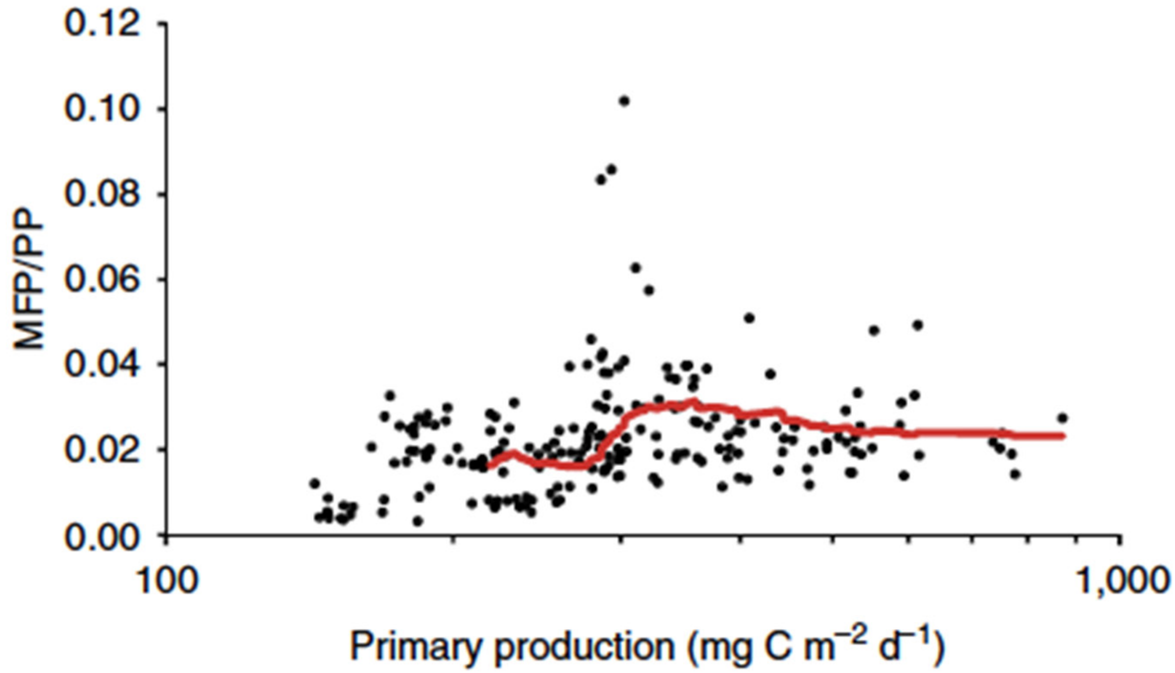

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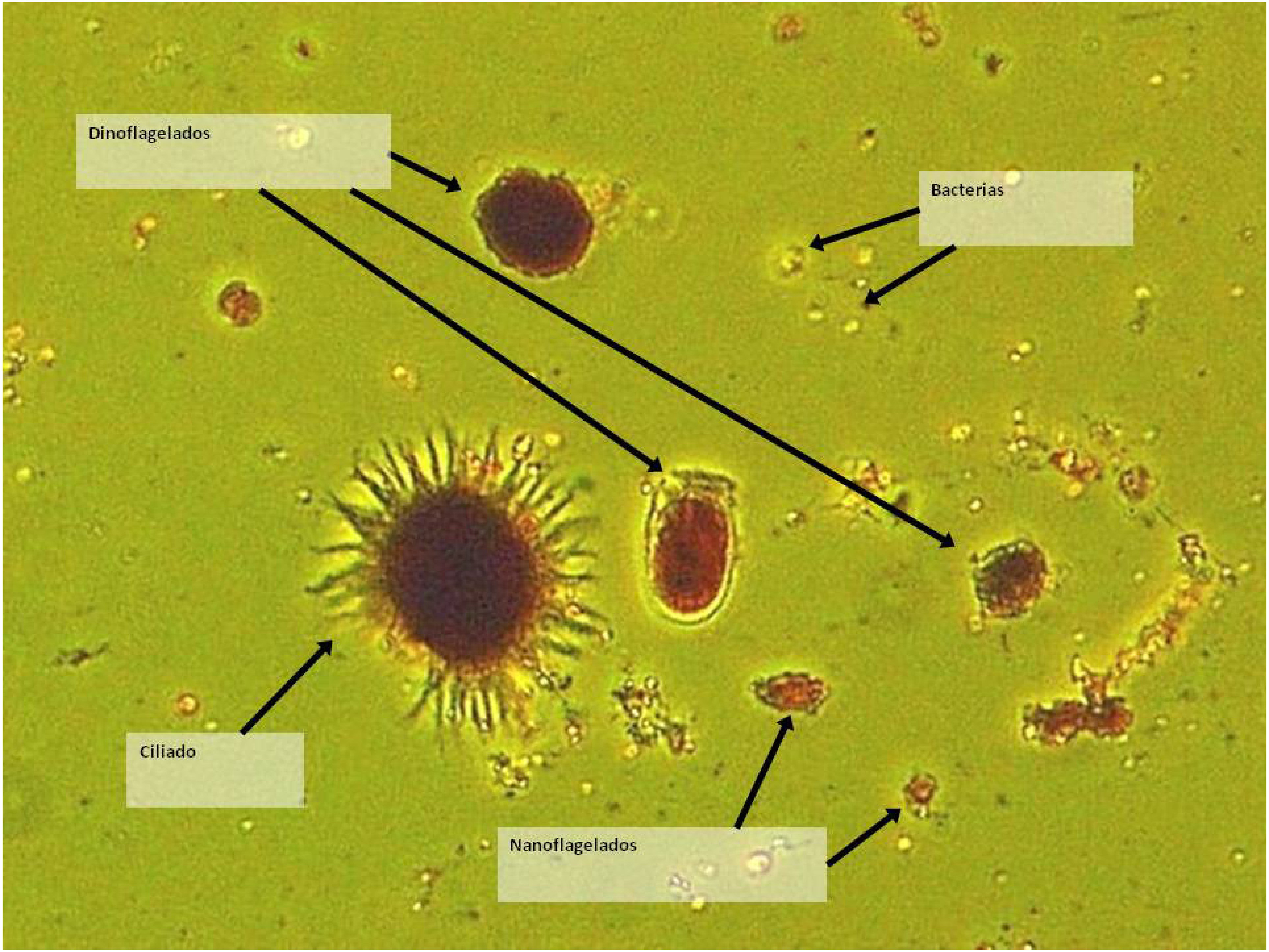
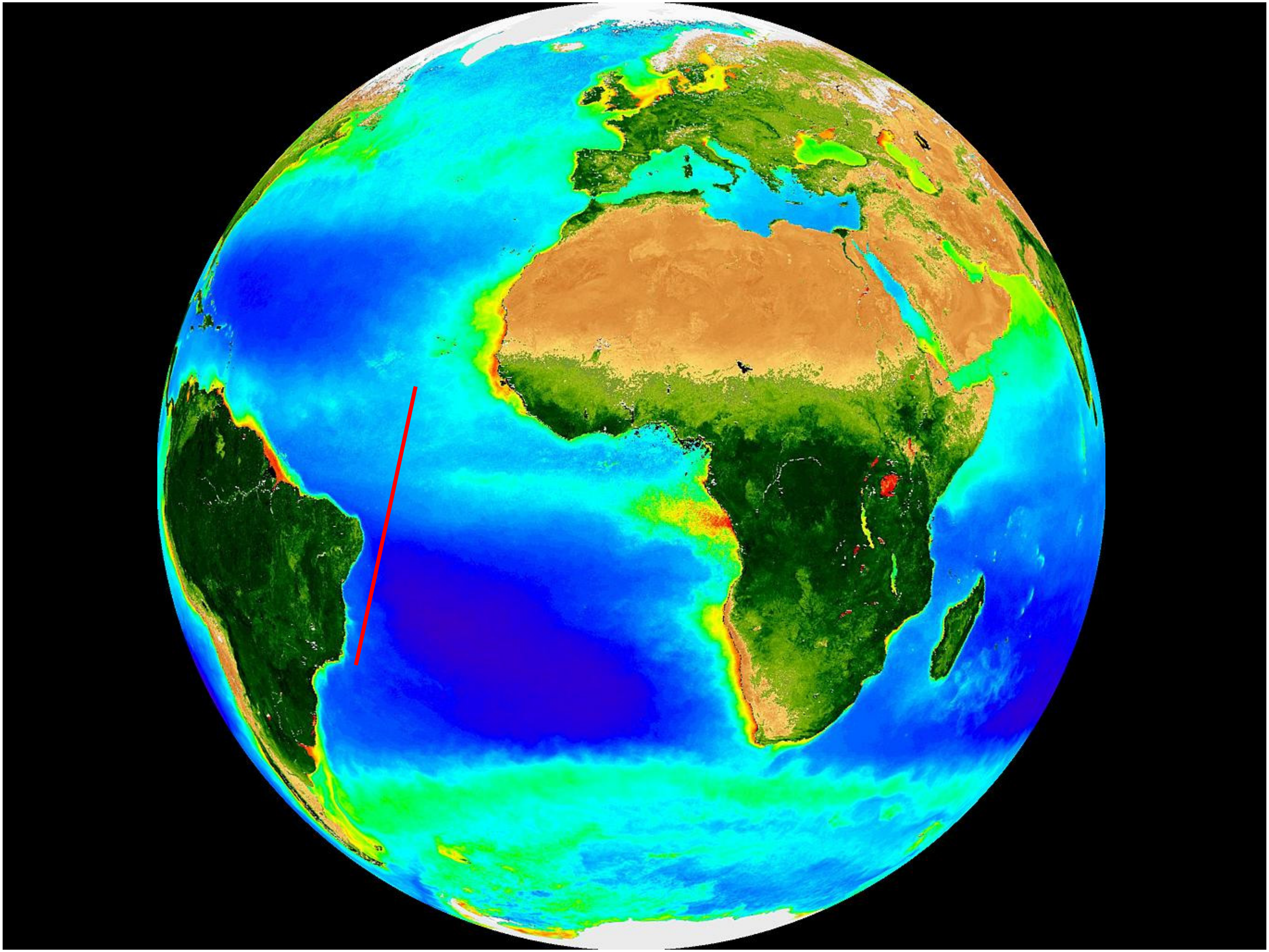

Dinoflagelados
Bacterias
Ciliado
Nanoflagelados

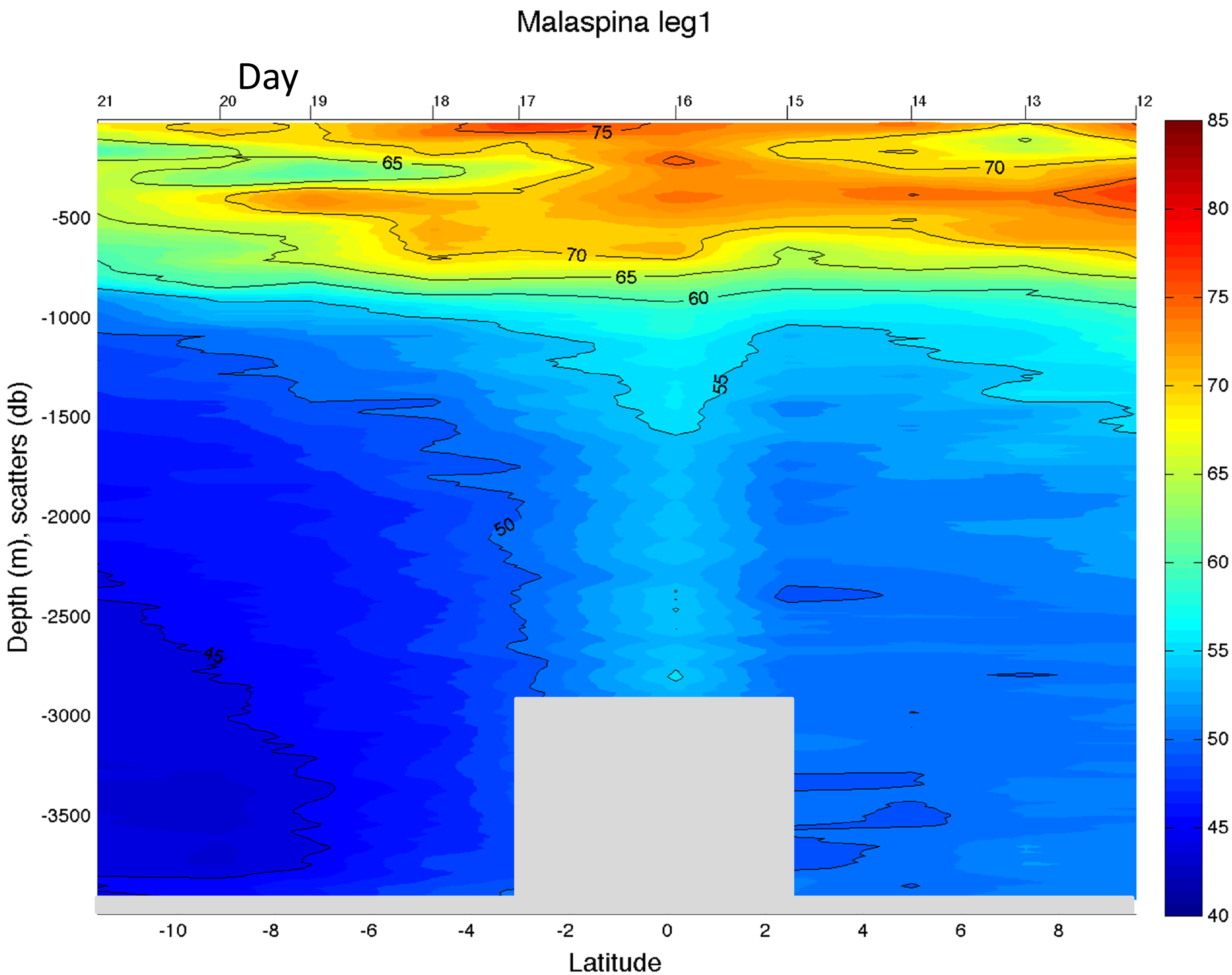
- **Some potential reasons:**
  - **Oligotrophic areas generally warmer**
  - **Phytoplankton small, microbial loop, but not sinking**
  - **Transparency improves visual predation**
  - **Refuge against predators in deep waters.**

Two main conclusions with high implications for biogeochemistry:

- **Mesopelagic fish biomass at least 10 times higher than previously thought**

- **The role of mesopelagic fish in carbon fluxes needs to be re-evaluated**





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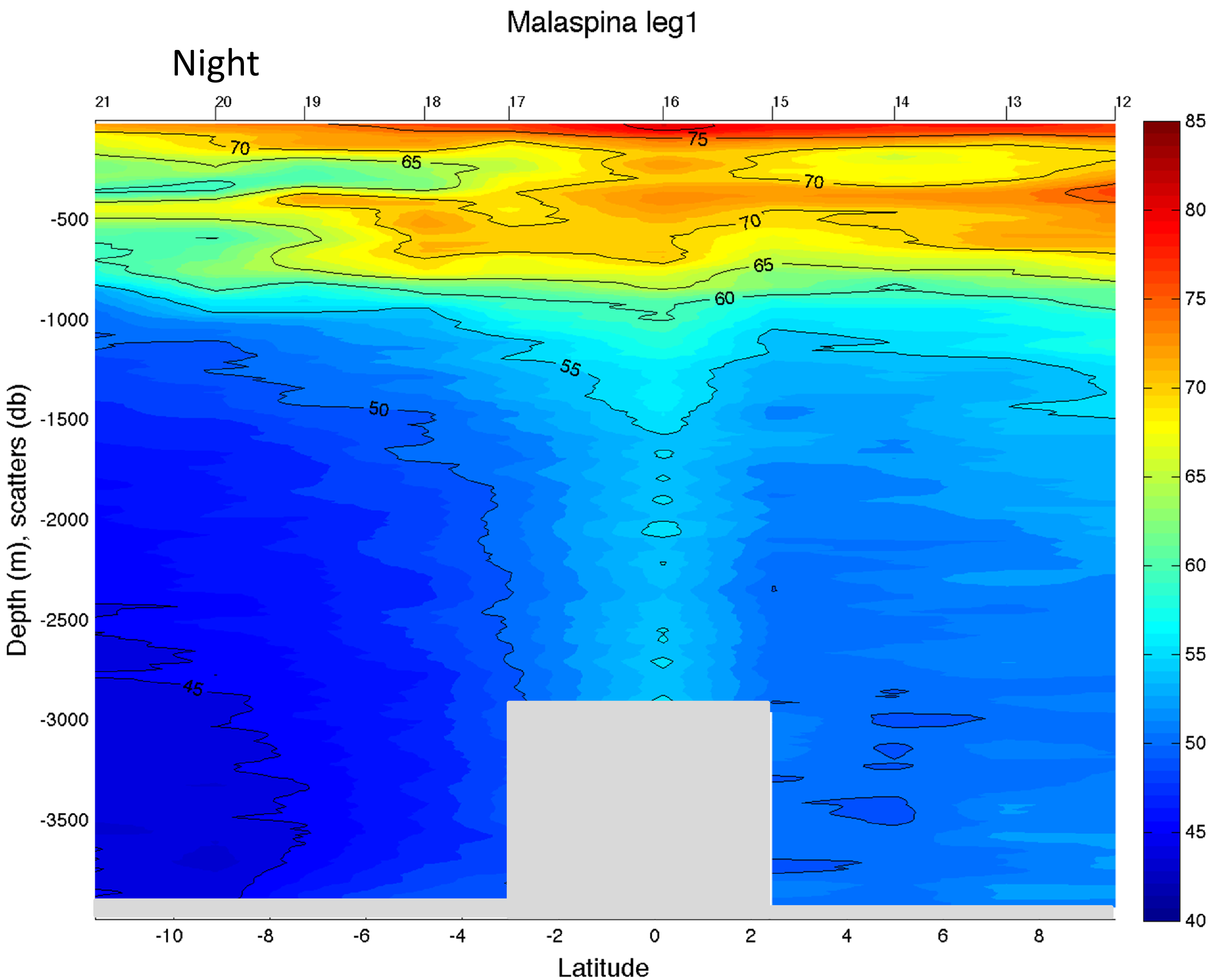

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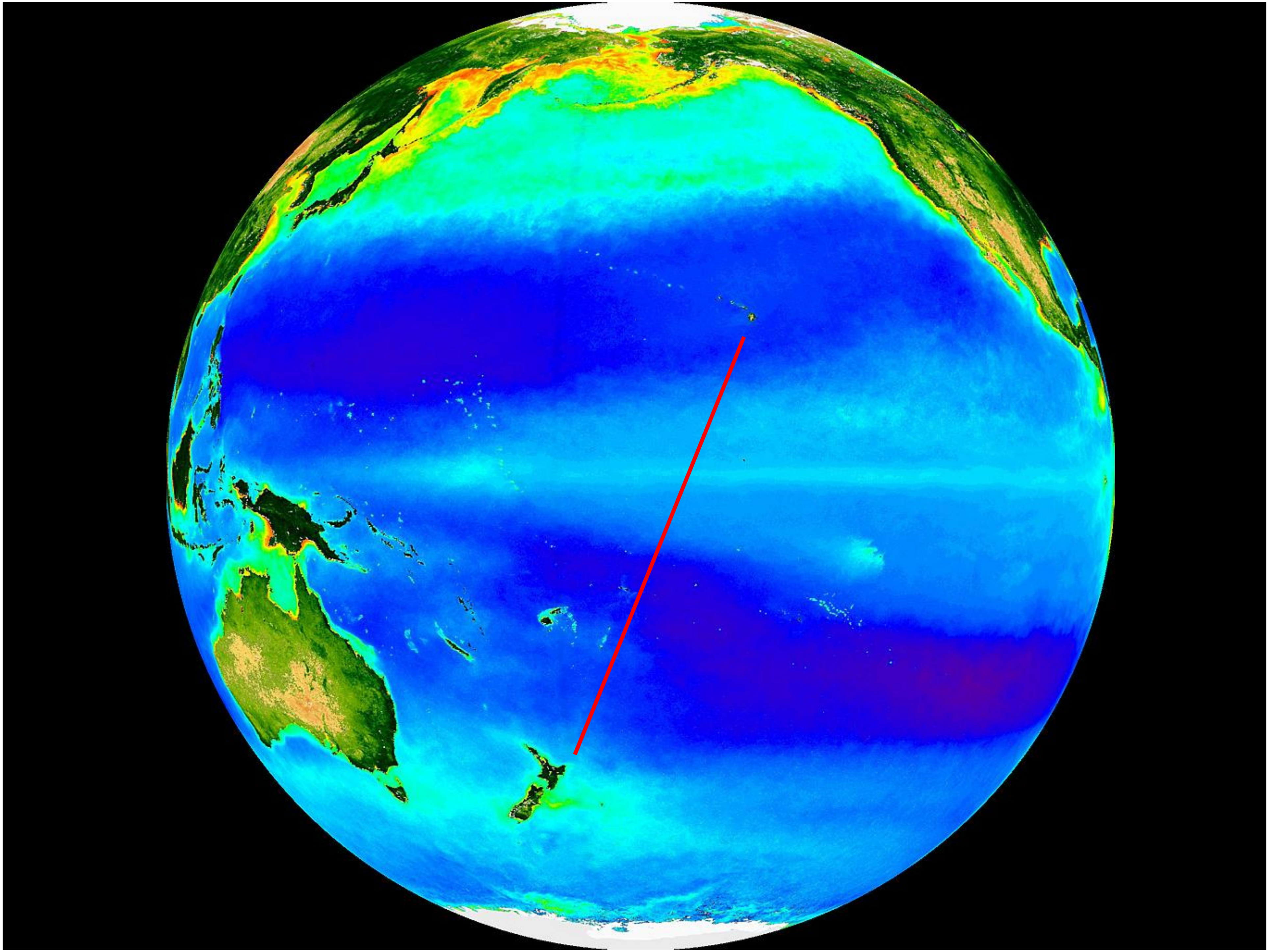
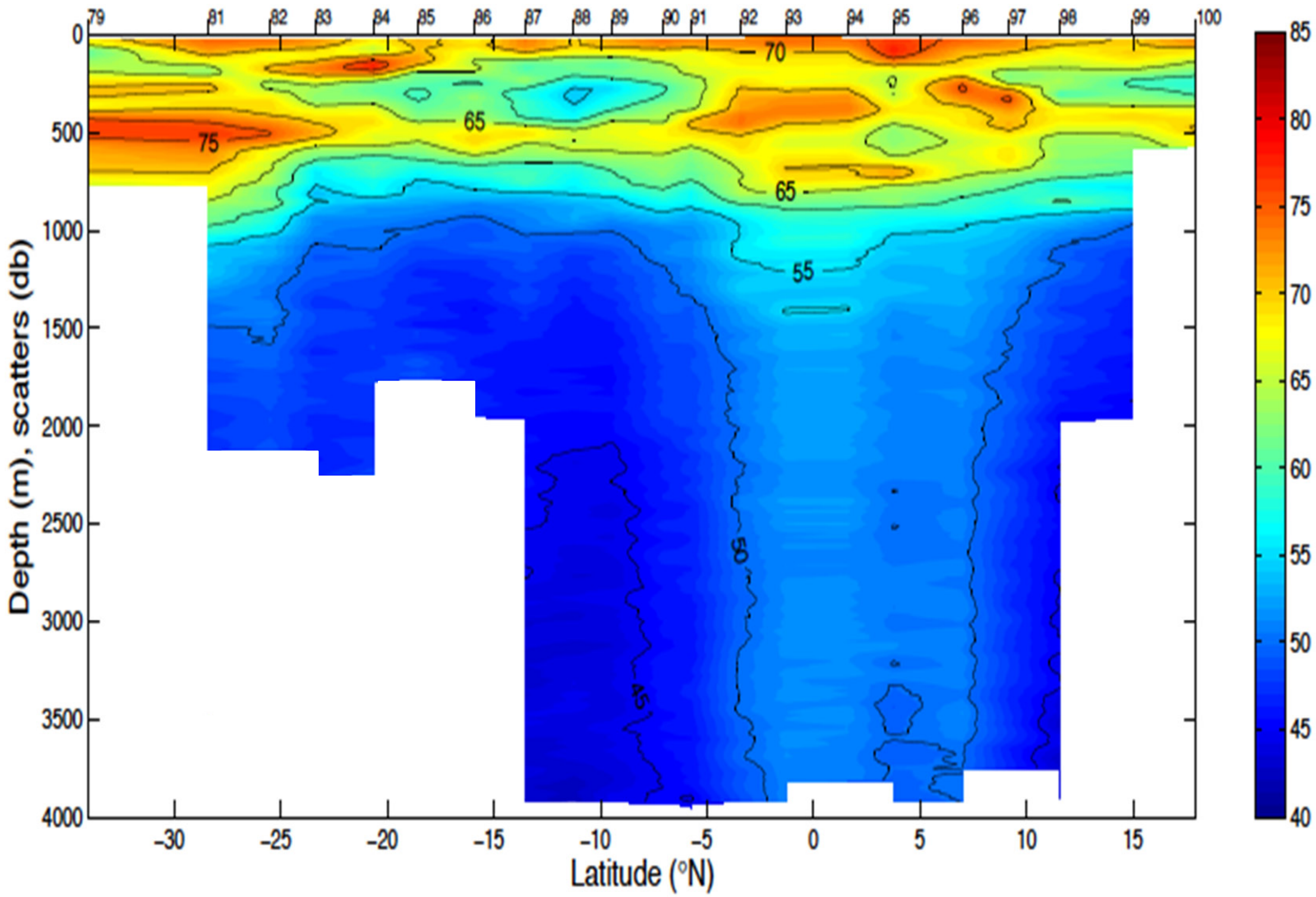


Day



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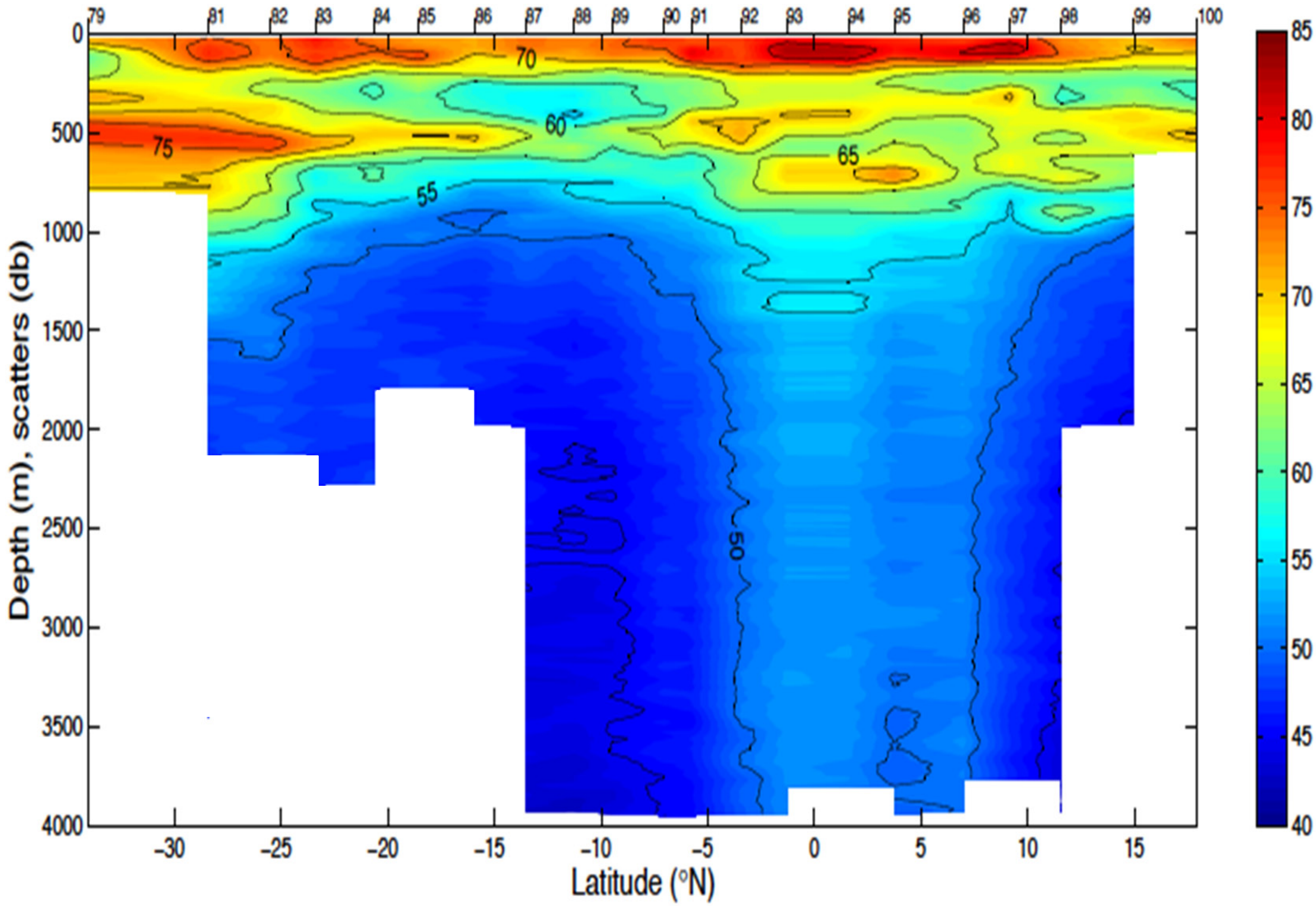
Night



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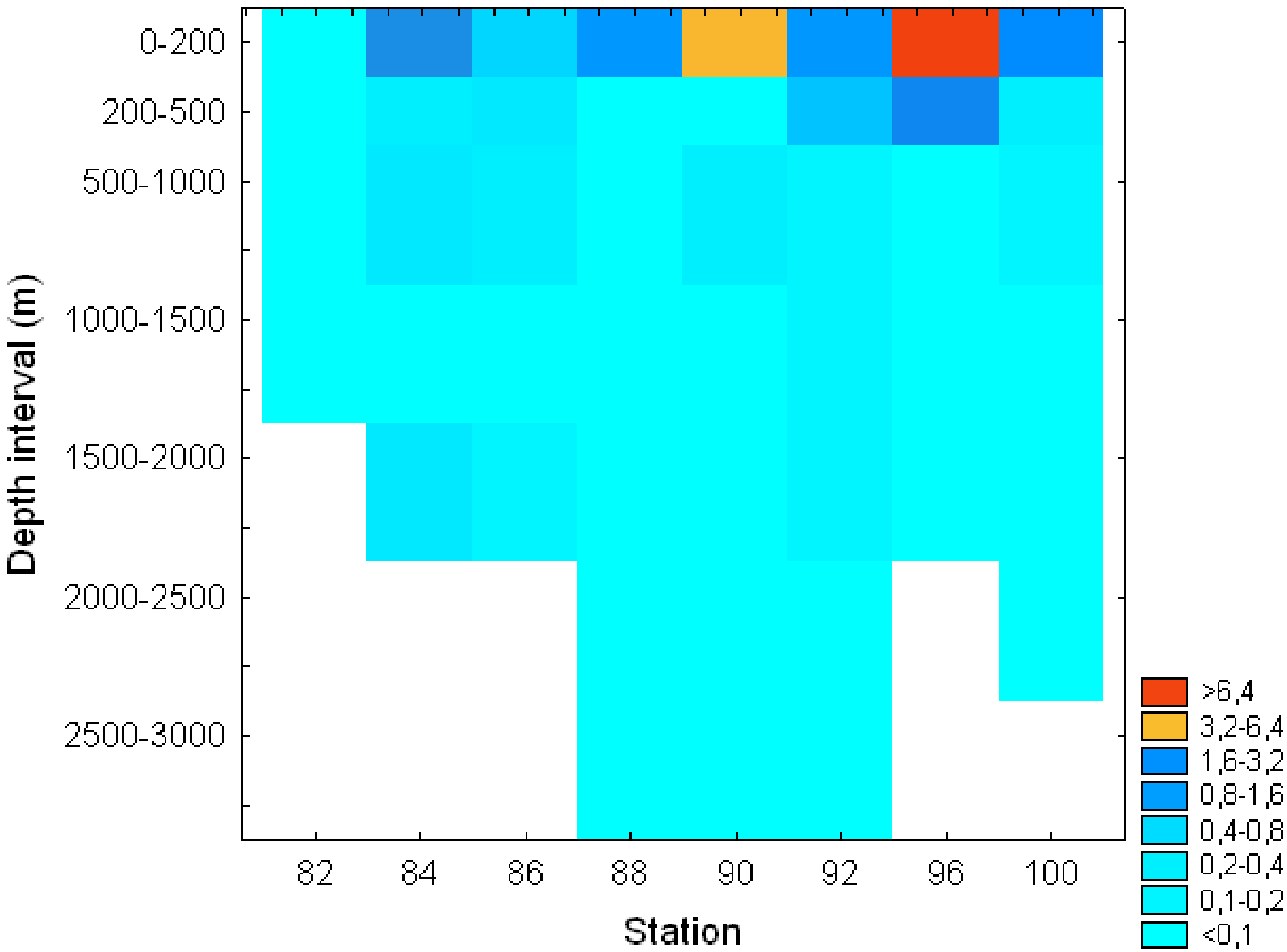
Pacific transect



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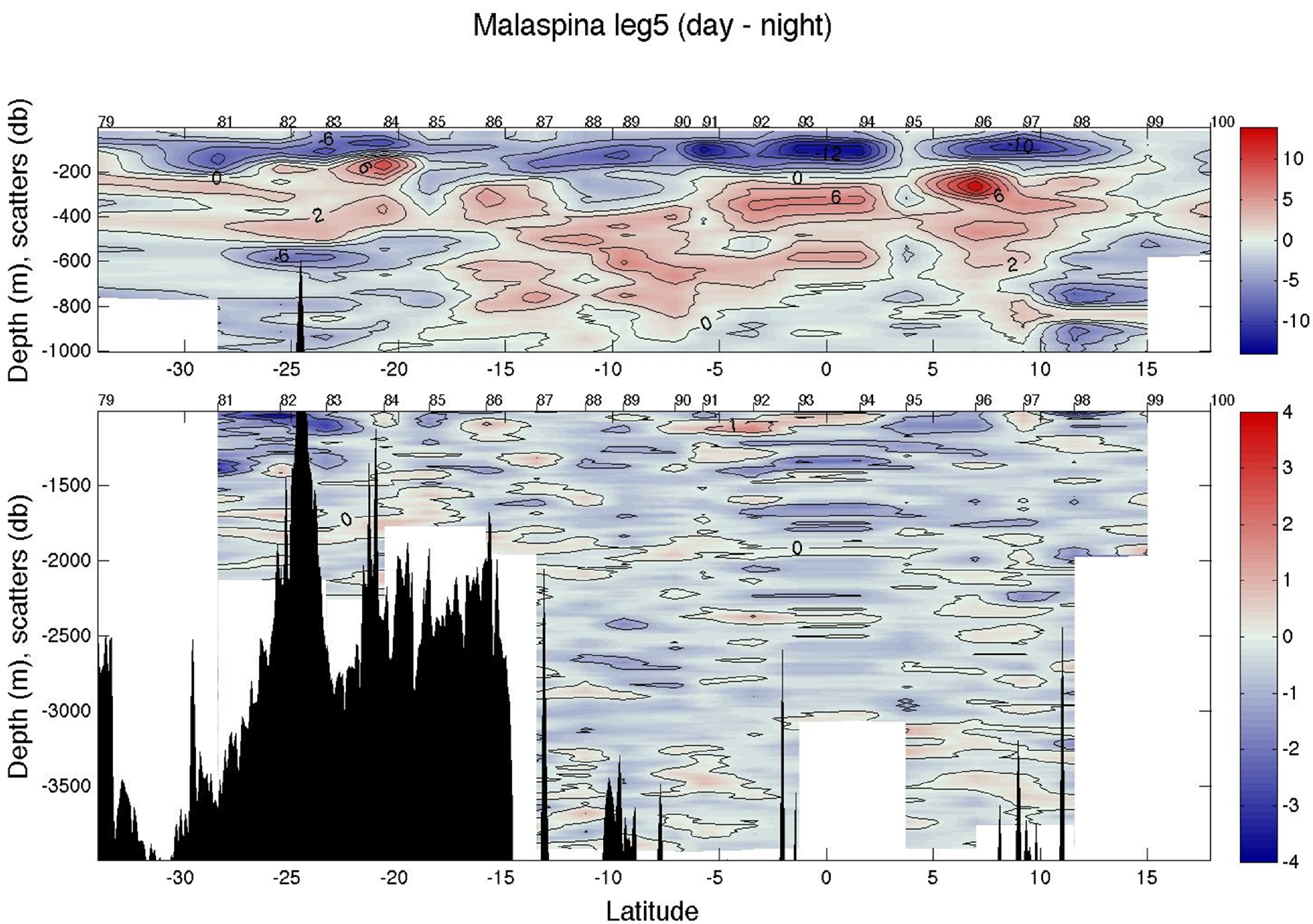

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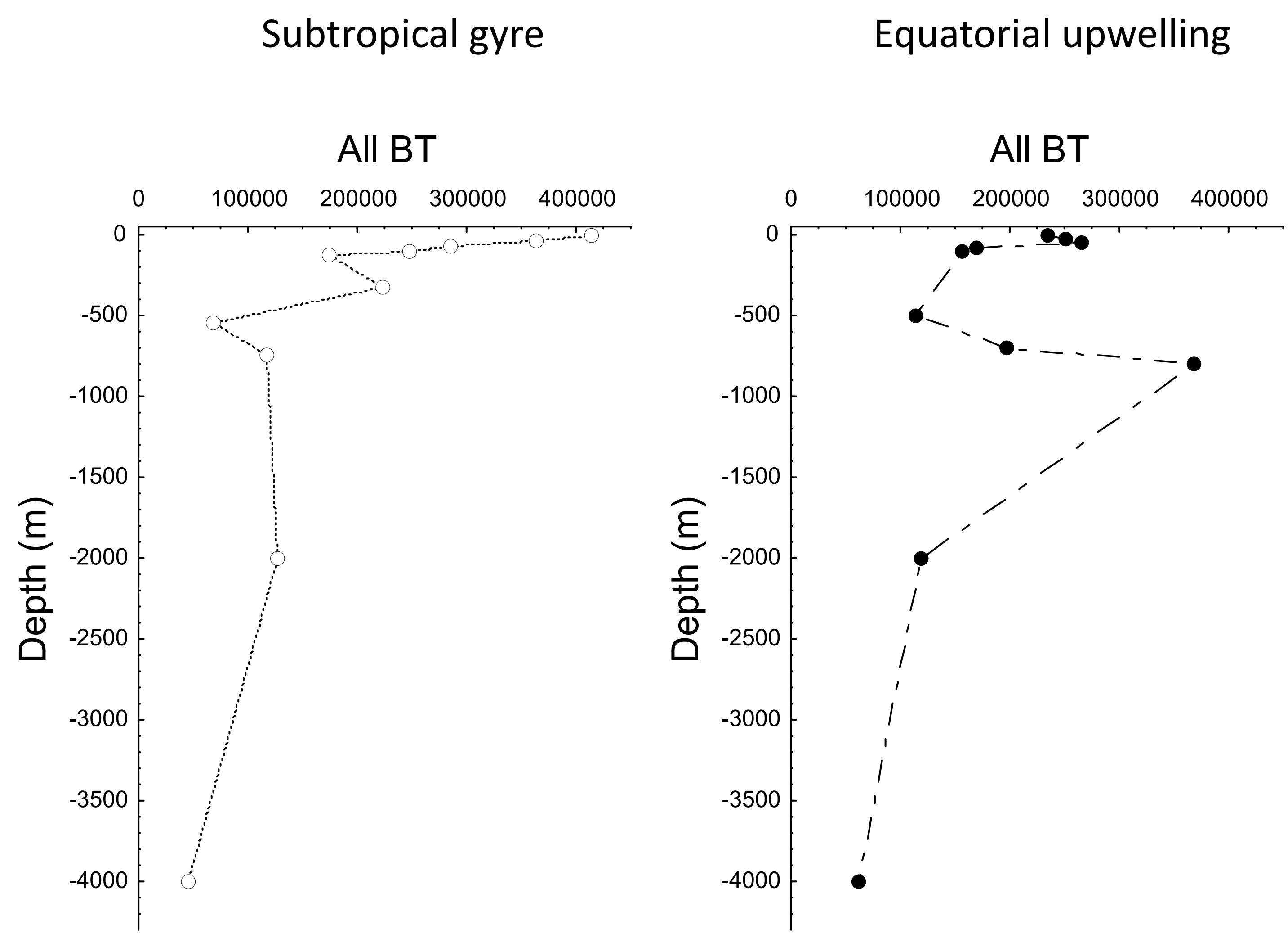

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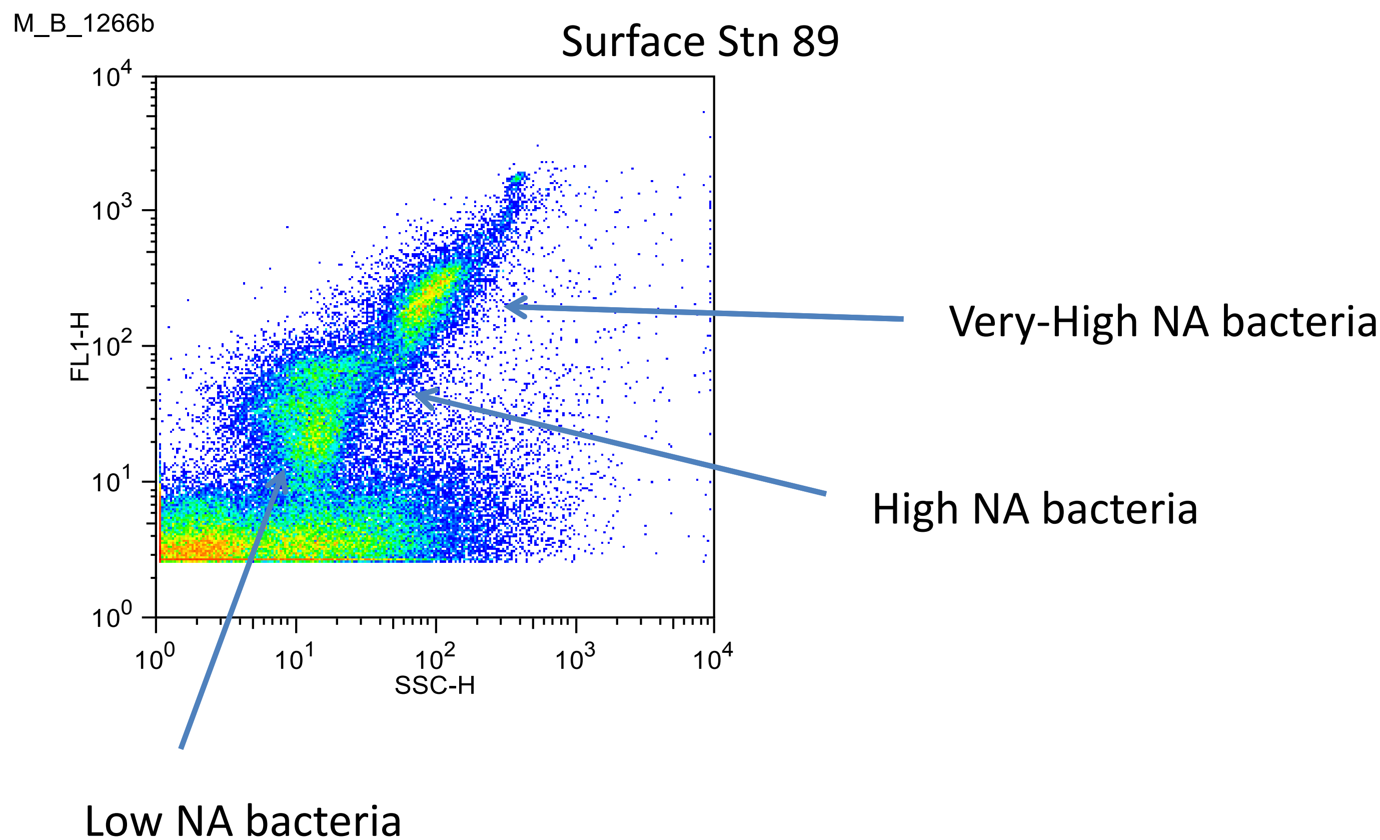
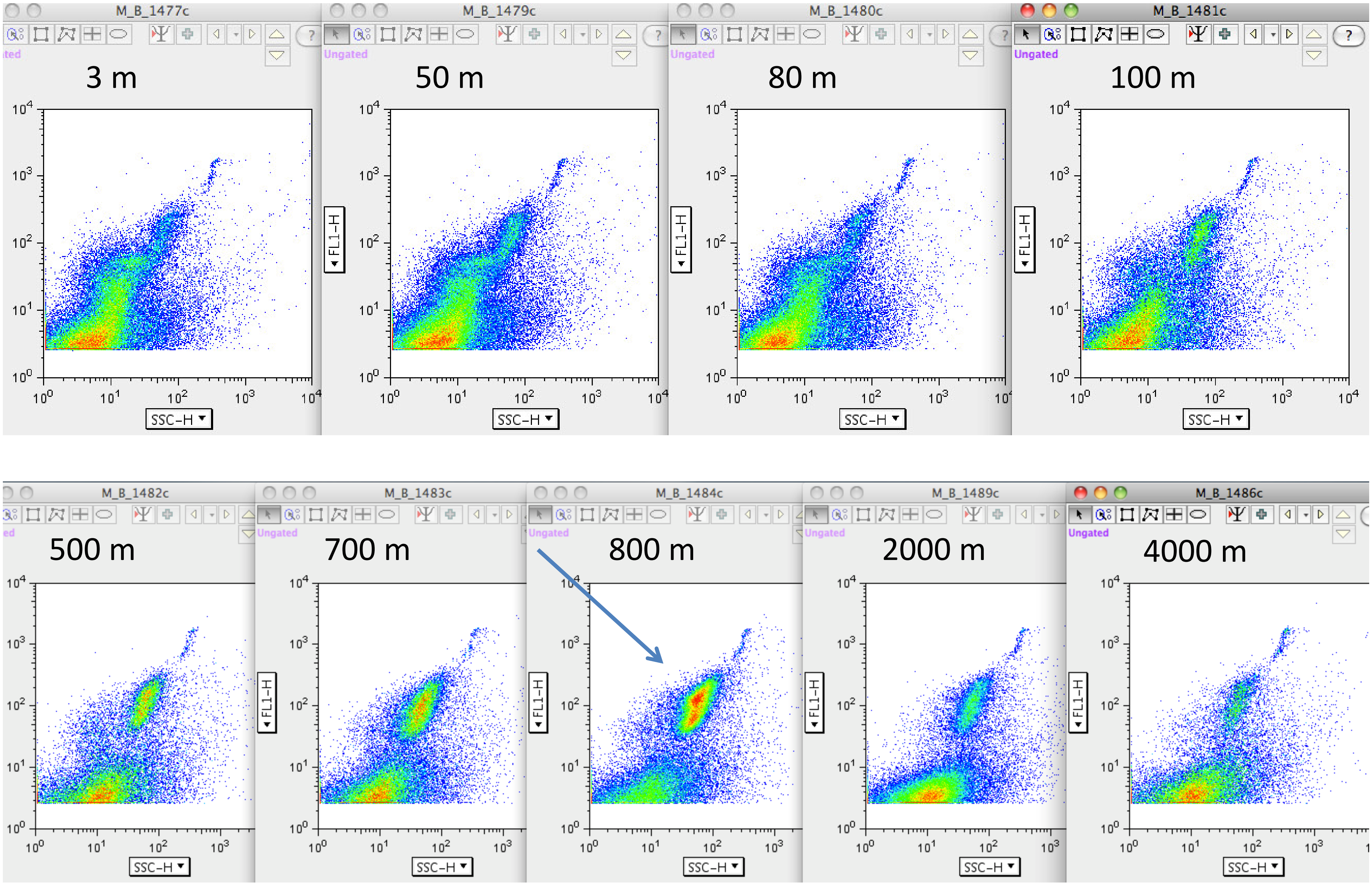
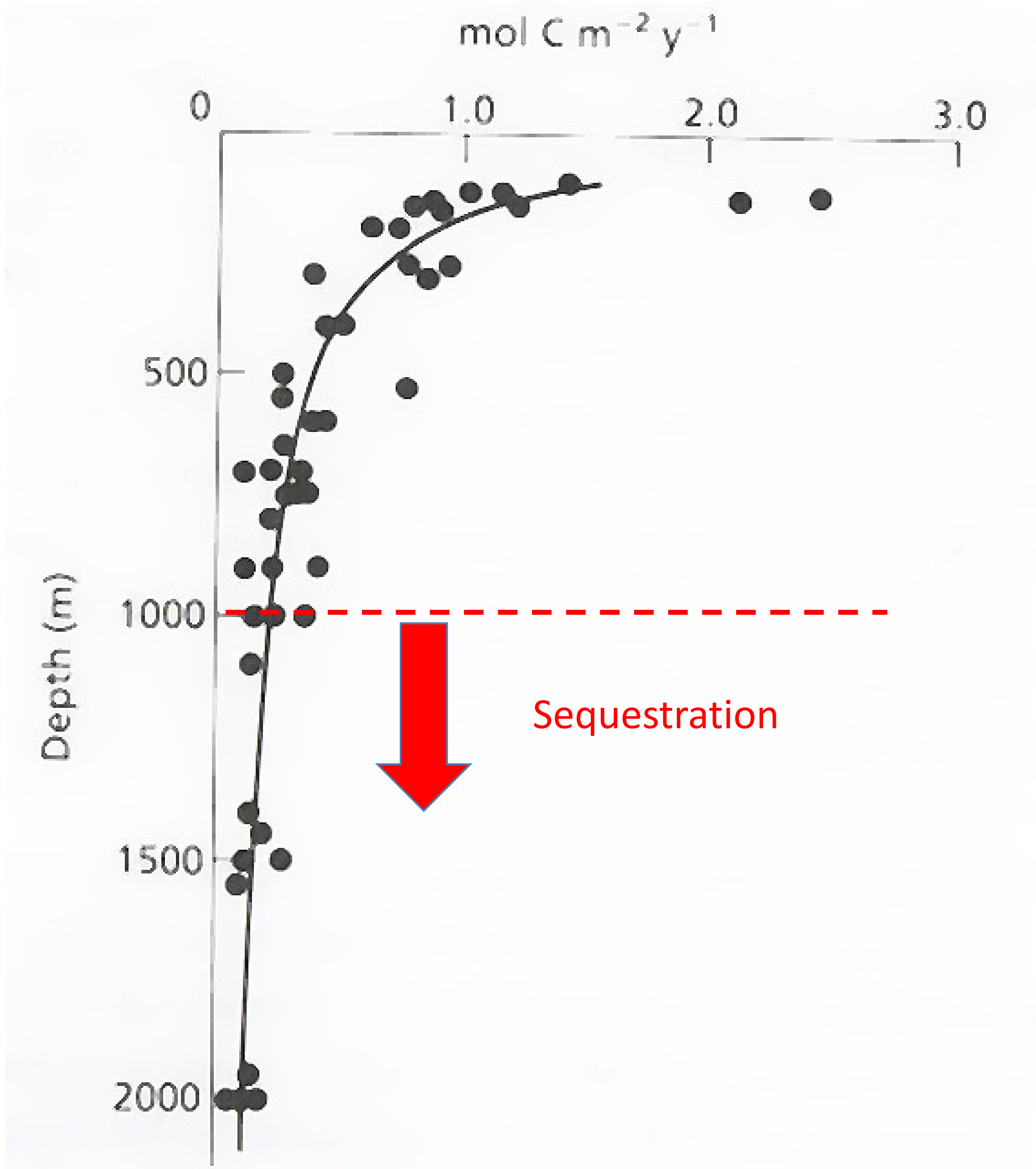

M_B_1266b
Surface Stn 89
FL1-H
SSC-H
Very-High NA bacteria
High NA bacteria
Low NA bacteria

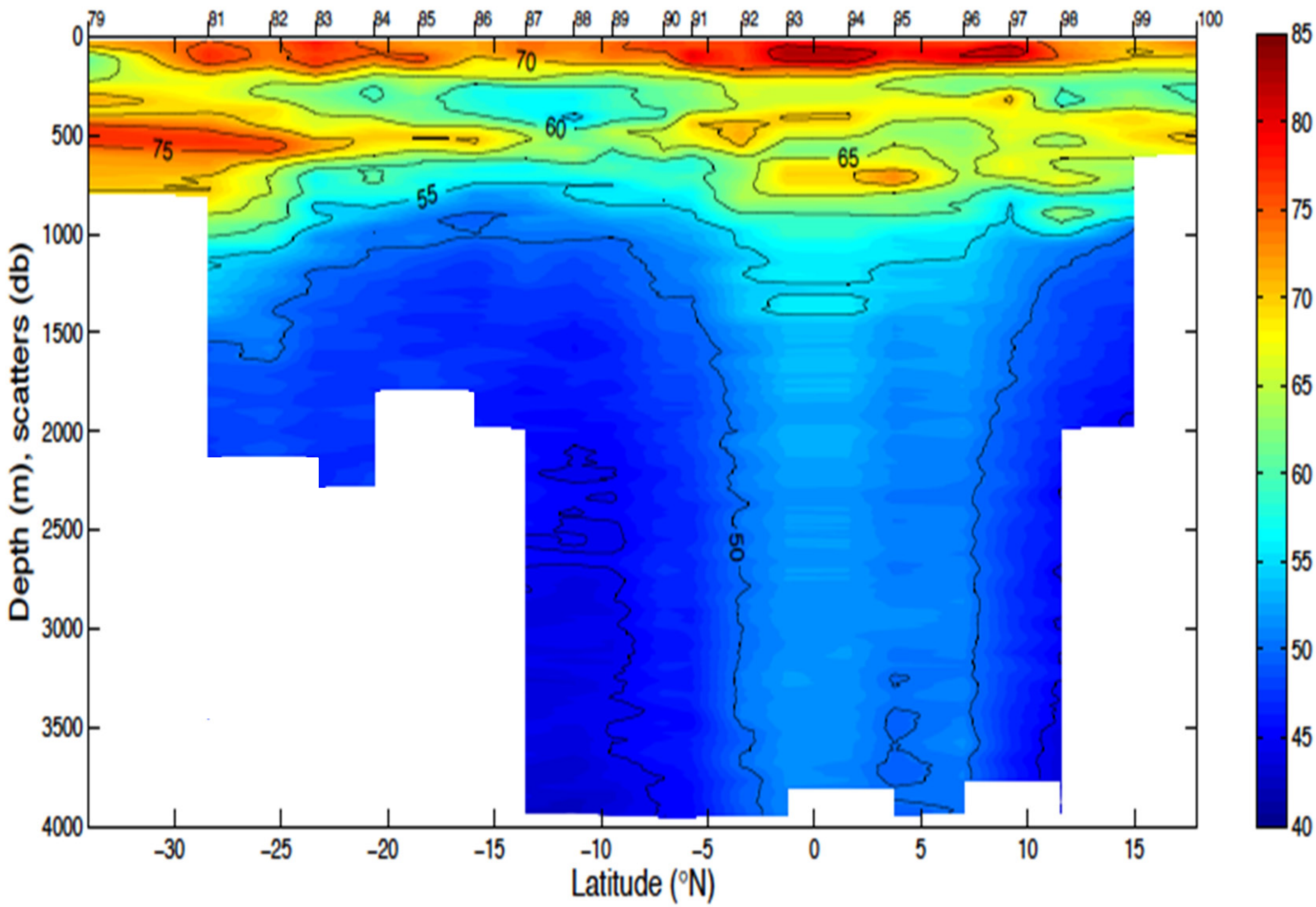
Stn 95



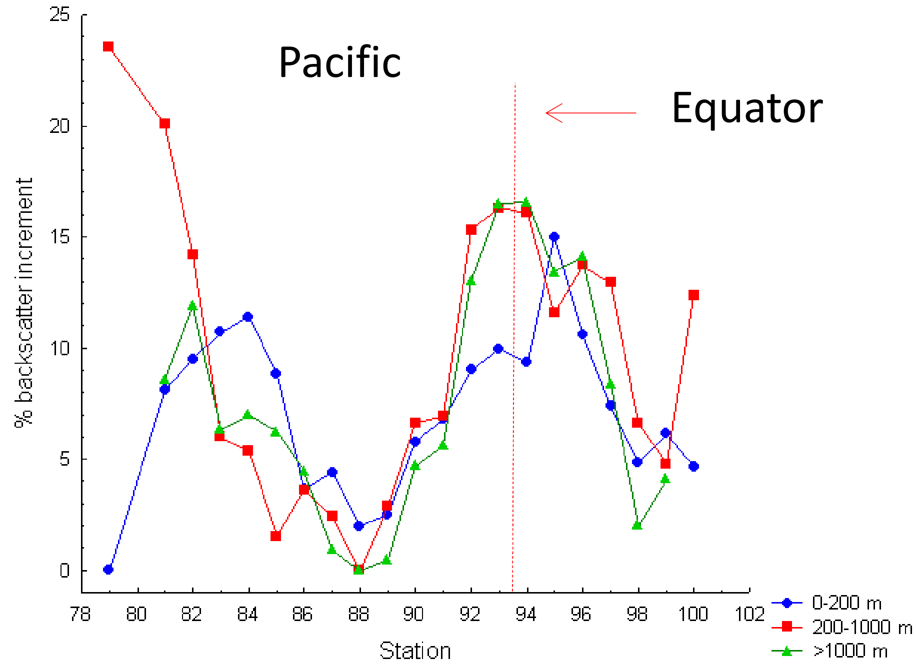
M_B_1477c
3 m
M_B_1479c
50 m
M_B_1480c
80 m
M_B_1481c
100 m
M_B_1482c
500 m
M_B_1483c
700 m
M_B_1484c
800 m
M_B_1489c
2000 m
M_B_1486c
4000 m
Ungated
FL1-H
SSC-H

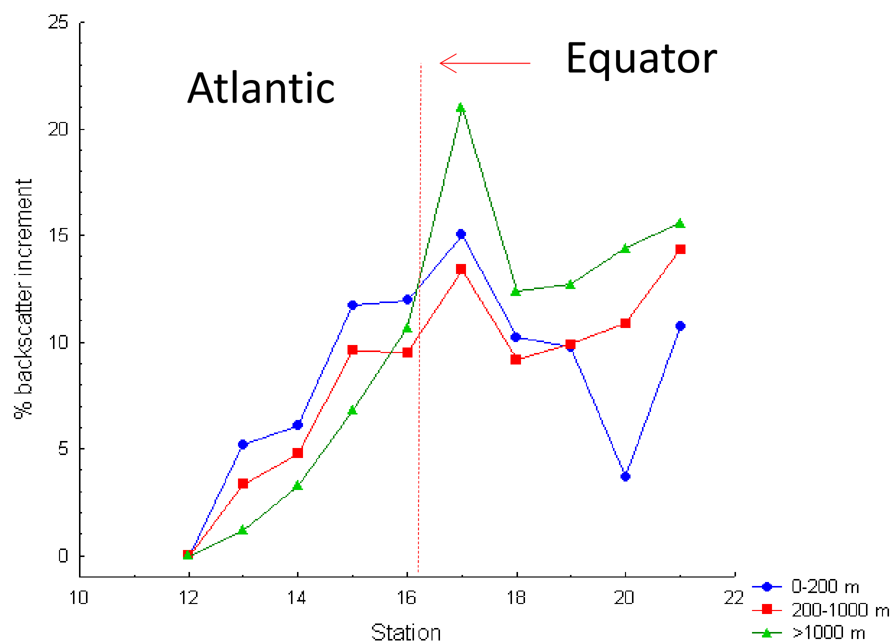


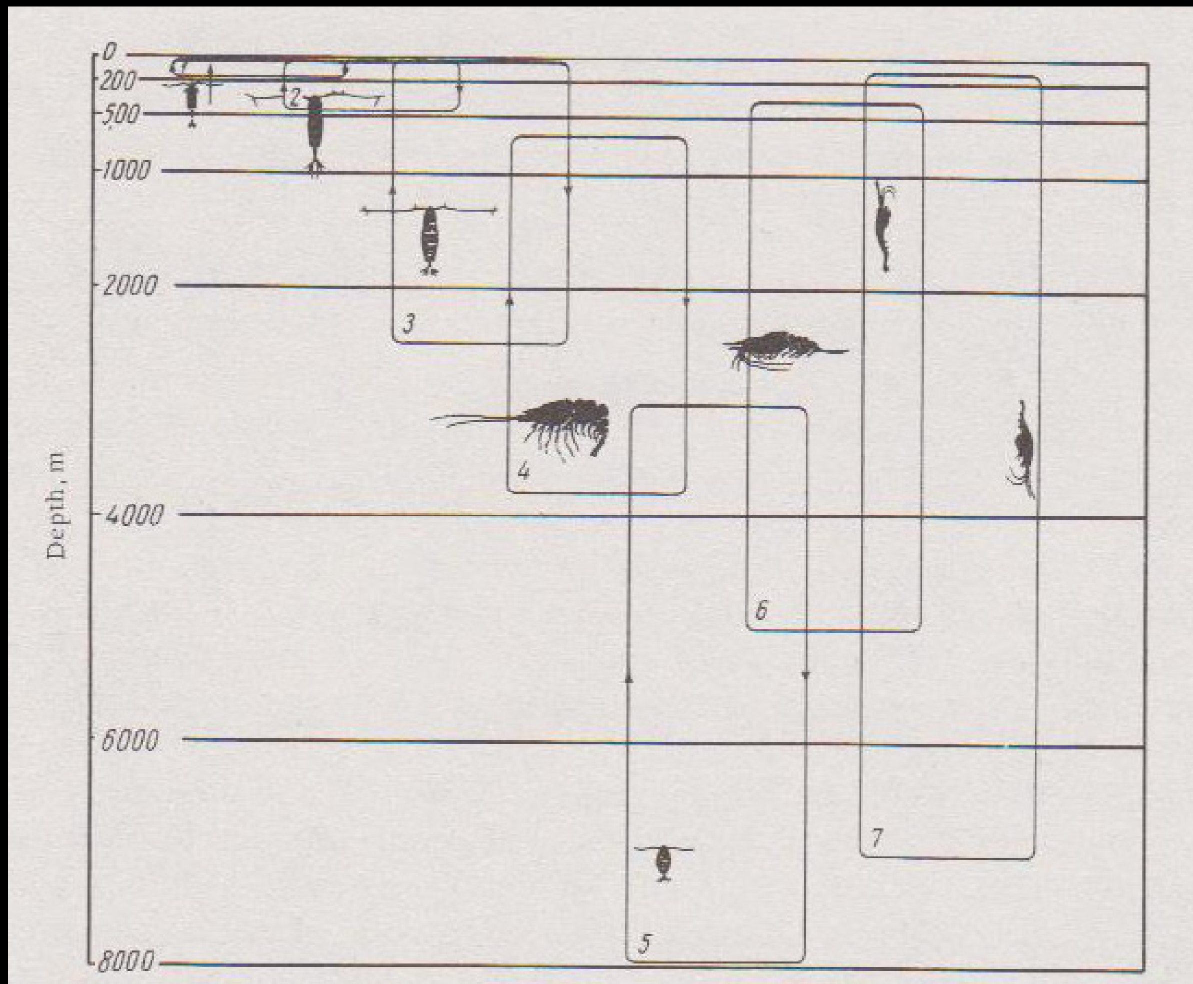
mol C m⁻² y⁻¹
0
1.0
2.0
3.0
500
1000
1500
2000
Depth (m)
Sequestration



79
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
70
60
75
65
55
50
Depth (m), scatters (db)
0
500
1000
1500
2000
2500
3000
3500
4000
-30
-25
-20
-15
-10
-5
0
5
10
15
Latitude (°N)
85
80
75
70
65
60
55
50
45
40


Pacific
Equator
% backscatter increment
Station
0-200 m
200-1000 m
>1000 m

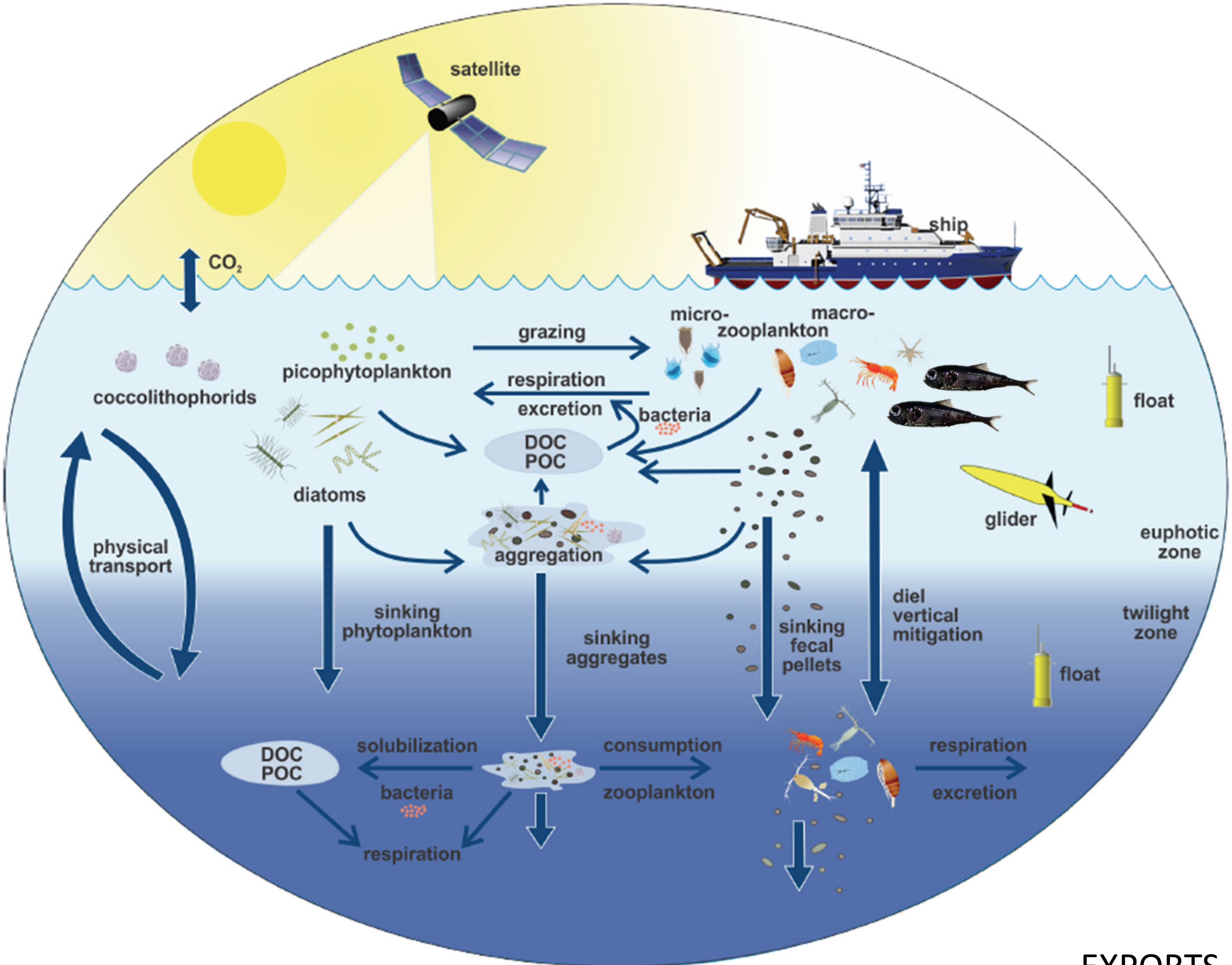

Atlantic
Equator
% backscatter increment
Station
0-200 m
200-1000 m
>1000 m



Vinogradov (1953)

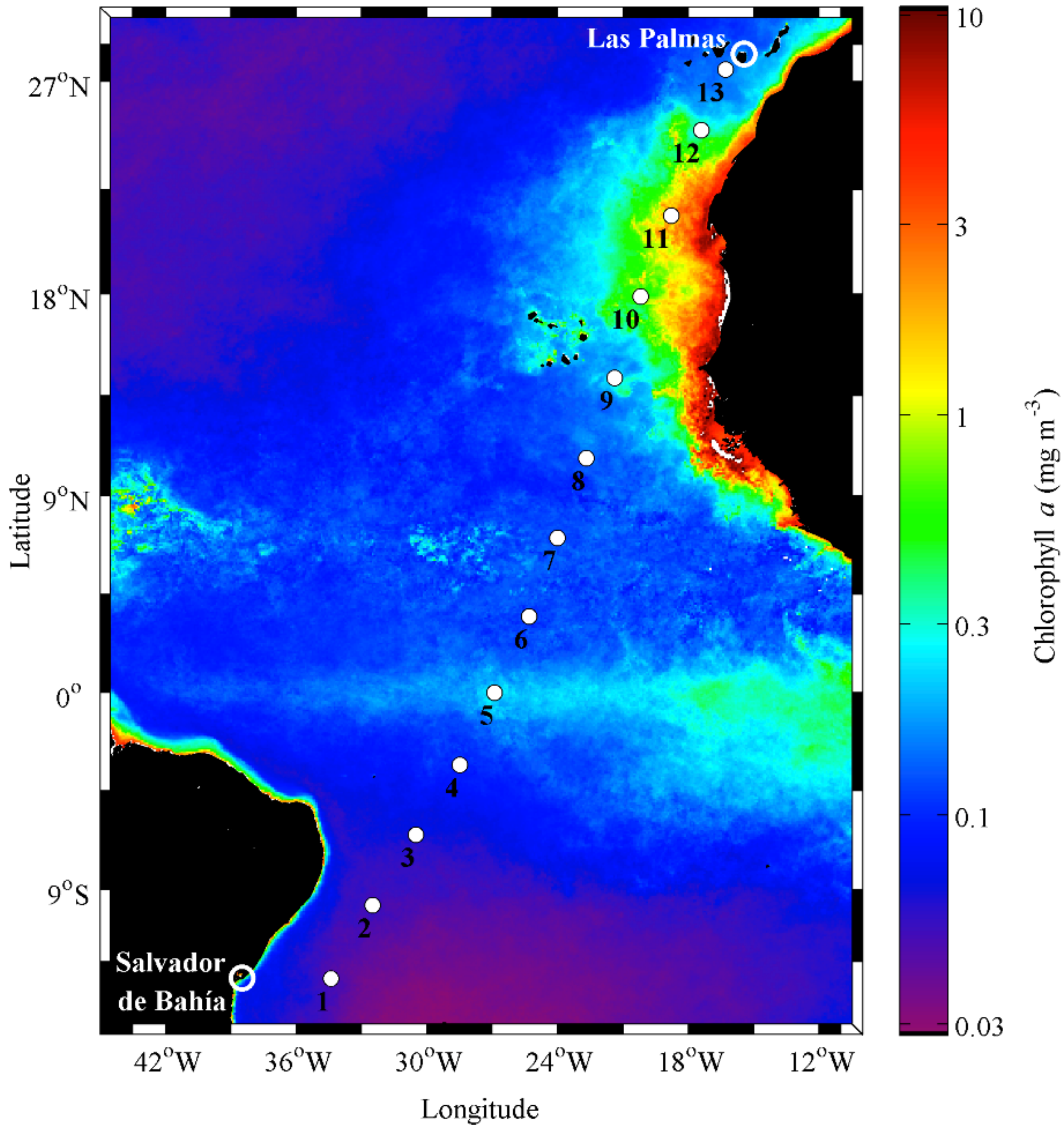
In summary,

- **Active flux seems to be similar to POC flux in subtropical waters**
- **Clear gap in our knowledge of the biological pump**
- **The acoustic signal below the upwelling zone reached 4000 m depth**
- **Enhancement of the biological pump efficiency (true sequestration)**
- **Ladder of Migration**


satellite
CO_2
ship
micro-
macro-
zooplankton
grazing
picophytoplankton
coccolithophorids
respiration
excretion
bacteria
DOC
POC
diatoms
float
glider
aggregation
physical
transport
euphotic
zone
twilight
zone
sinking
phytoplankton
sinking
aggregates
sinking
fecal
pellets
diel
vertical
mitigation
float
DOC
POC
solubilization
bacteria
consumption
zooplankton
respiration
excretion
respiration

EXPORTS

Migrants and Active Flux In the Atlantic Ocean

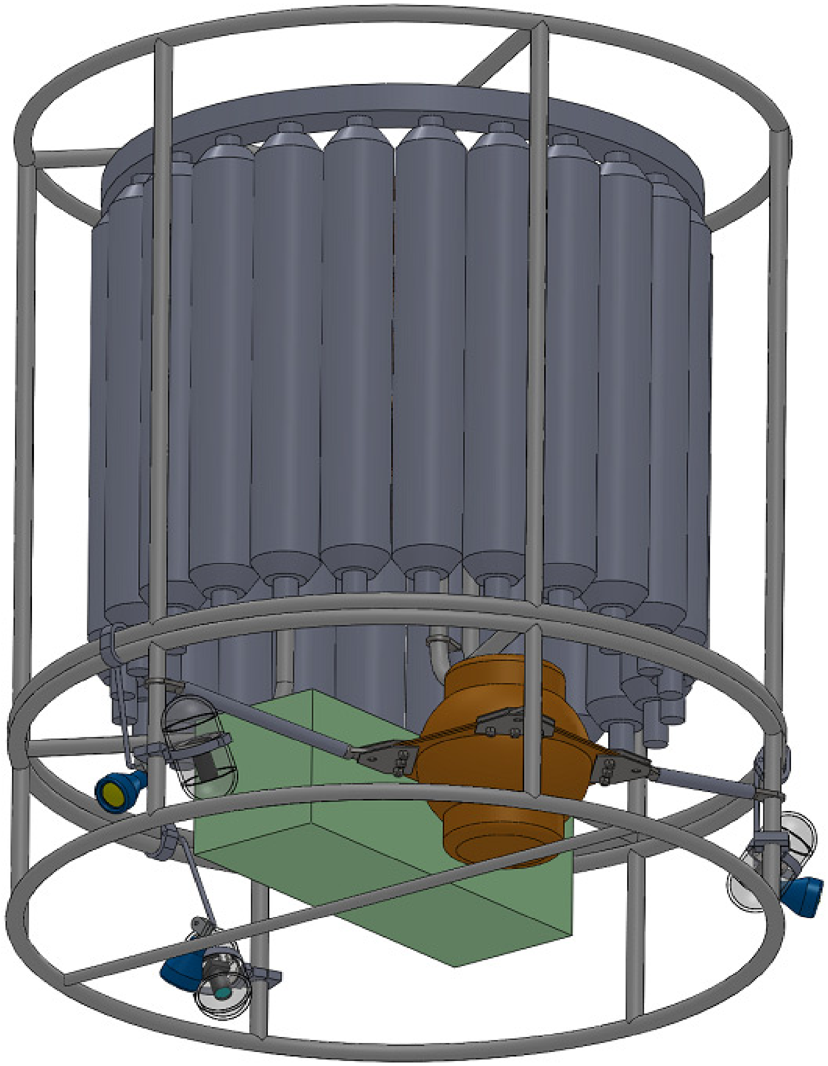


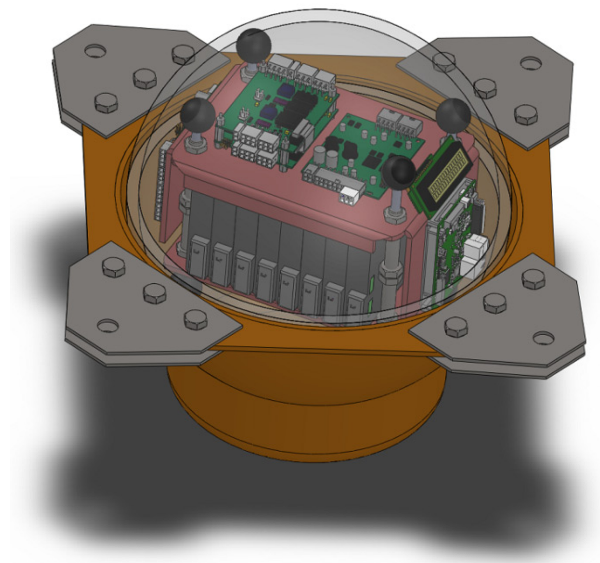
April 2015

MAFIA cruise

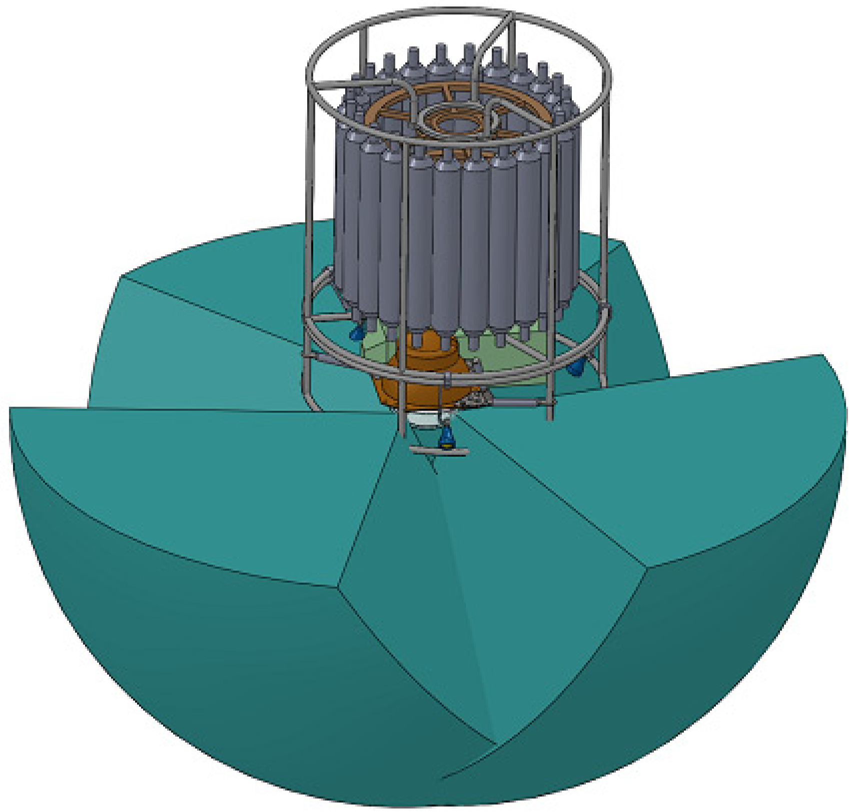
- Broadband acoustics

- 24 h stations:
  - LADCP acoustics (4000 m depth)
  - MOCNESS 1 m^2 (zooplankton)
  - MOHT 5 m^2 (small micronekton)
  - Midwater trawl (large micronekton)
  - Neuston net
  - Video recorder

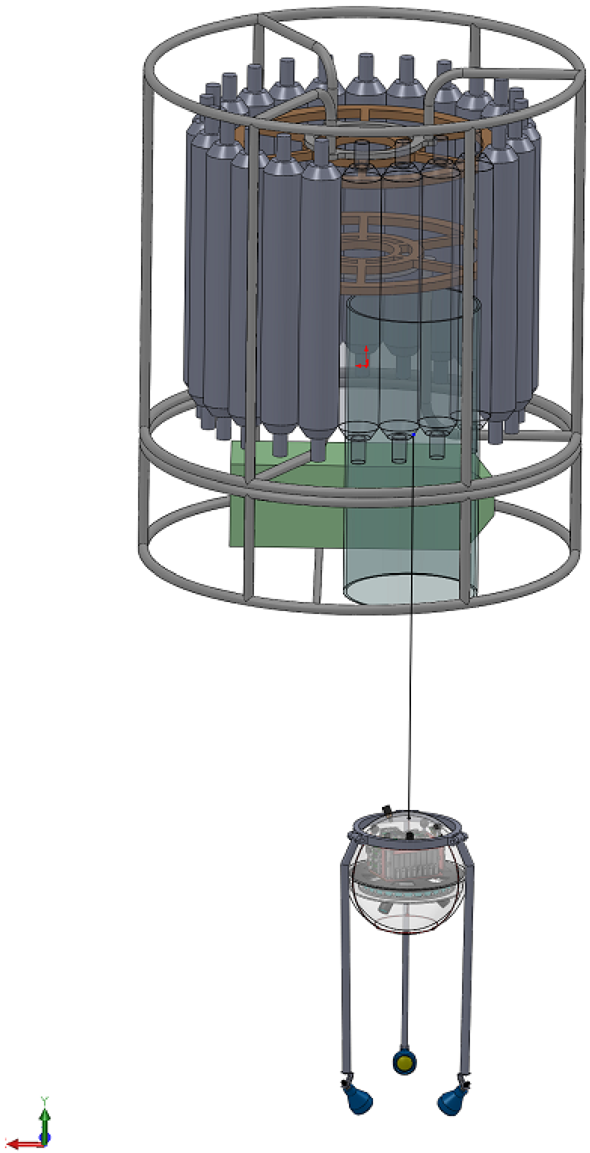


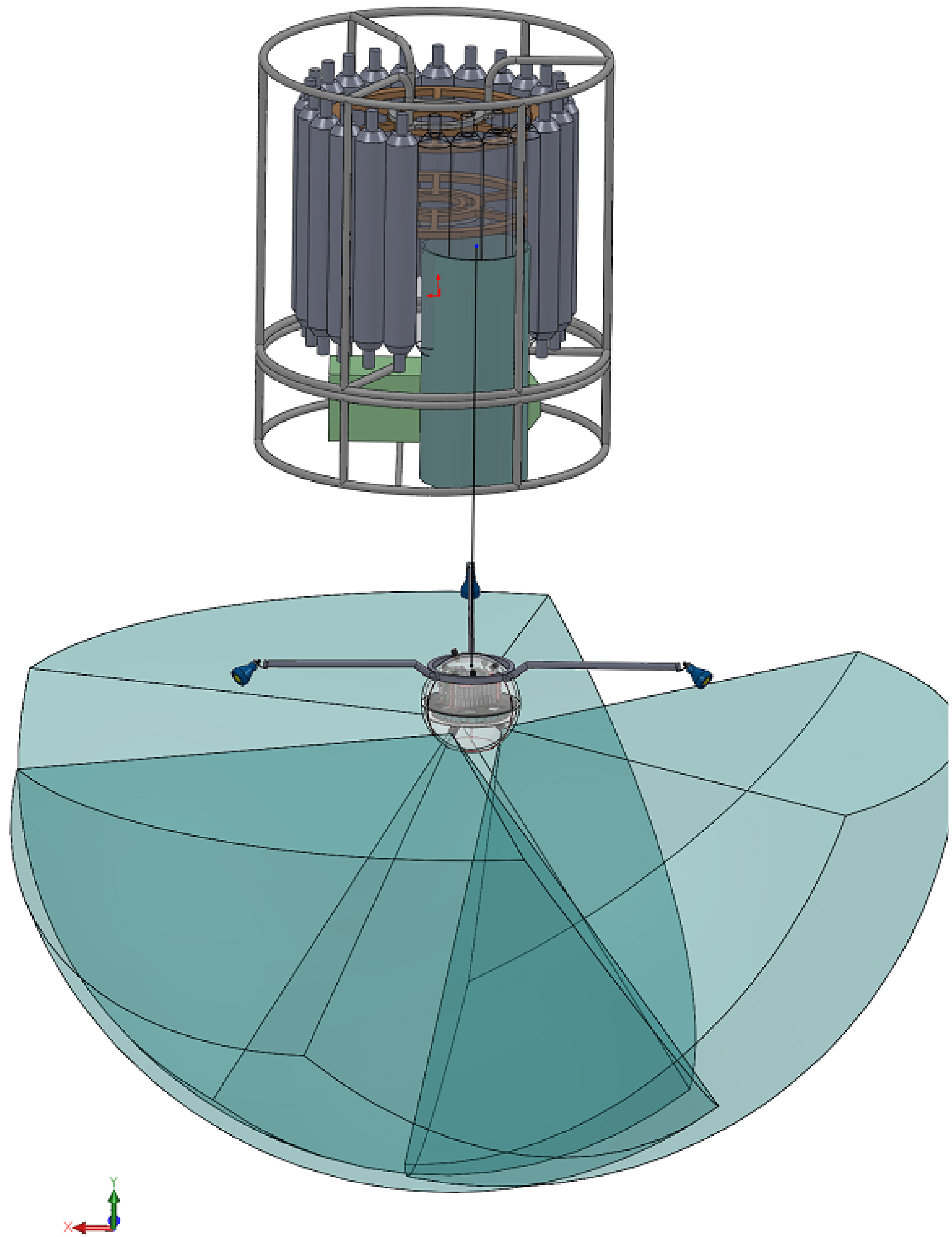


Cabrera-Gámez et al. (in prep.)

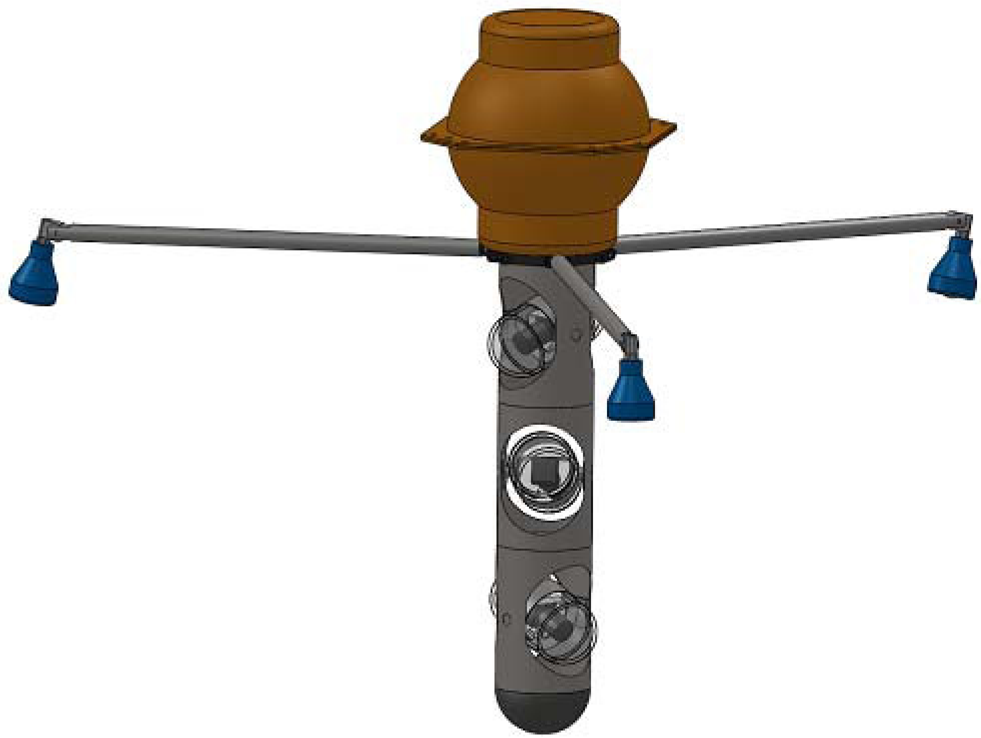


Cabrera-Gámez et al. (in prep.)



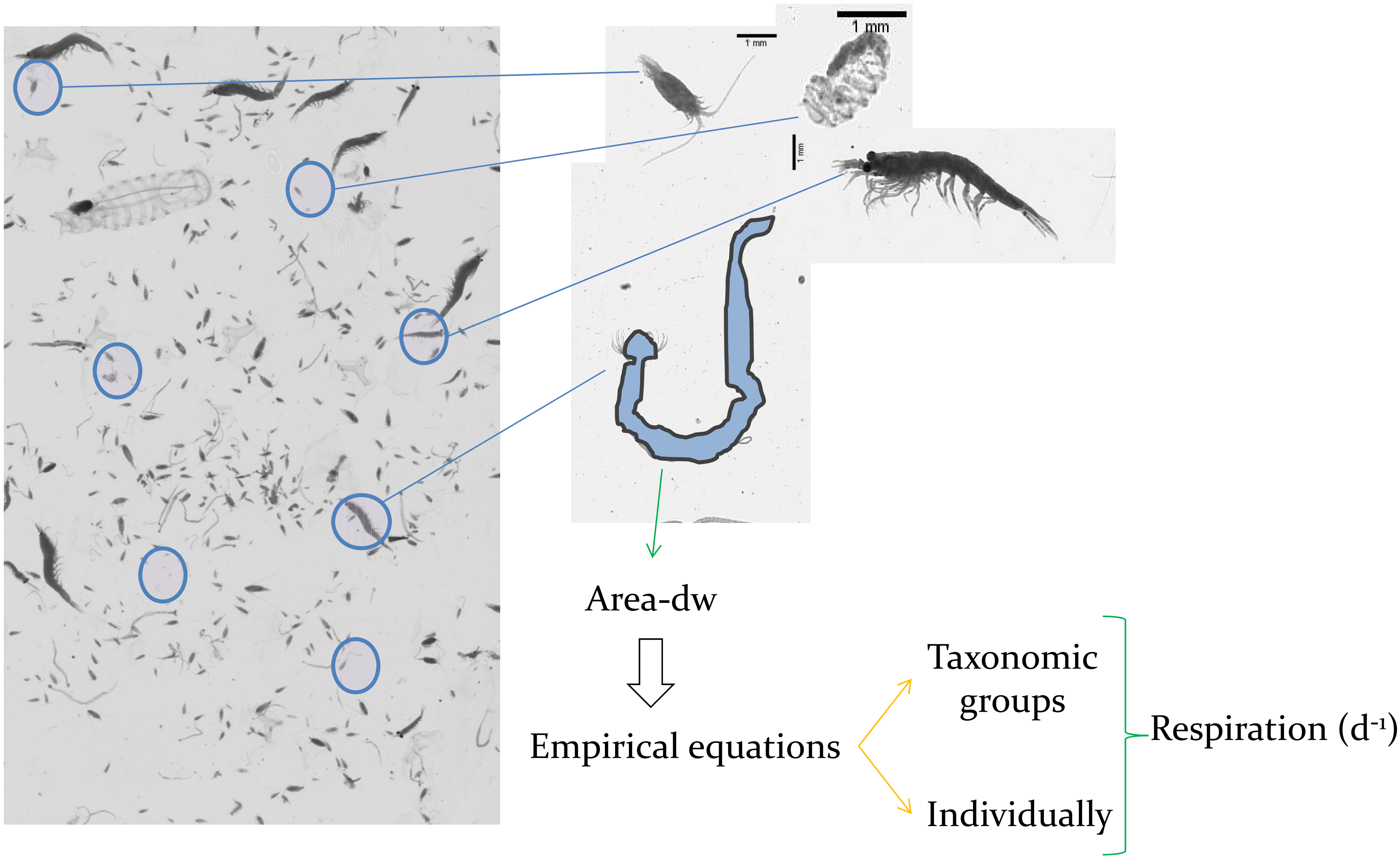


Cabrera-Gámez et al. (in prep.)



Cabrera-Gámez et al. (in prep.)

Thank you



1 mm
1 mm
1 mm
Area-dw
Empirical equations
Taxonomic groups
Individually
Respiration (d-1)