Relationships between the deep chlorophyll maximum and hydrographic characteristics across the Atlantic, Indian and Pacific oceans

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SUPPLEMENTARY MATERIAL

Table S1. – Oceans and zones visited during the seven legs of the Malaspina-2010 expedition. The initial and final stations of each province and leg are indicated.

			Stations	
Leg	Ocean	Zone	Initial	Final
1	Atlantic	Subtropical	1	4
1	Atlantic	Tropical	5	10
1	Atlantic	Equatorial	11	18
1	Atlantic	Subtropical	19	41
2	Atlantic	Coastal	42	44
3	Pacific	Coastal	45	47
3	Indian	Subtropical	48	65
3	Indian	Coastal	66	69
4	Indian	Subtropical	70	76
4	Indian	Coastal	77	78
5	Pacific	Subtropical	79	89
5	Pacific	Equatorial	90	97
5	Pacific	Tropical	98	115
6	Pacific	Equatorial	116	126
7	Pacific	Coastal	127	130
7	Atlantic	Tropical	131	139
7	Atlantic	Subtropical	140	147

Table S2. – Cruise schedule of Malaspina 2010

Leg	Beginning (place, date)	End (place, date)
1	Cádiz, 14-12-2010	Rio de Janeiro, 13-01-2011
2	Rio de Janeiro 17-01-2011	Cape Town, 6-02-2011
3	Cape Town, 11-02-2011	Perth, 13-03-2011
4	Perth, 17-03-2011	Sydney, 30-03-2011
5	Auckland, 16-04-2011	Honolulu, 8-05-2011
6	Honolulu, 10-05-2011	Cartagena de Indias, 10-06 2011
7	Cartagena de Indias, 19-06-2011	Cartagena, 14-07-2011

Table S3. – Parameters of the linear regression equations of the DCM depth on the nitracline depth (m) for the oceans and zones and for the whole data set ("All"). CI=confidence interval. N=number of observations.

Oceans	Intercept	Slope (Lower, upper, 95% CI)	r^2	N	p
Atlantic	38.27	0.60 (0.51, 0.68)	0.82	48	p<0.0001
Indian	44.21	0.58 (0.39, 0.77)	0.56	32	p<0.0001
Pacific	27.18	0.60 (0.47, 0.73)	0.75	32	p<0.0001
All	36.20	0.60 (0.53, 0.67)	0.73	112	p<0.0001

Zones	Intercept	Slope (Lower, upper, 95% CI)	r^2	N	p
Equatorial	18.18	0.81 (0.61, 1.00)	0.87	14	p<0.0001
Tropical	33.46	0.59 (0.39, 0.79)	0.57	27	p<0.0001
Subtropical	60.01	0.45 (0.33, 0.56)	0.54	56	p<0.0001
Coastal	31.95	0.60 (0.38, 0.81)	0.73	15	p<0.0001

Table S4. – Parameters of significant linear regression equations between dependent and independent variables for the oceans and zones and for the whole data set. (A) Regression of the logarithms of integrated Chl *a* concentration [log(Chl *a*_int)] on the Chl *a* concentration at the surface [log(Chl *a*_srf)]. (B) Regressions of log(Chl *a*_srf) and log(Chl *a*_int) on sea surface temperature (SST) and the σ200-σ6 stratification index. (C) Regression of the logarithm of Chl *a* concentration at the DCM [log(Chl *a*_DCM)] on the DCM depth for the depth intervals 0–200 m, 0–100 m and 100–200 m. CI=confidence interval, se=standard error.

A

Independent variable = log(Chl *a*_srf)

Dependent variable = log(Chl *a*_int)

Oceans	Intercept	se	Slope (Lower, upper, 95% CI)	se	r^2	N	p
Atlantic	1.79	0.04	0.23 (0.17, 0.30)	0.03	0.48	56	0.0000
Indian	1.74	0.06	0.24 (0.13, 0.36)	0.06	0.38	32	0,0002
Pacific	1.80	0.05	0.20 (0.08, 0.32)	0.06	0.23	42	0.0014
All	1.81	0.03	0.25 (0.13, 0.36)	0.03	0.43	130	0.0000
Zones							
Equatorial	1.83	0.06	0.27 (0.06, 0.47)	0.10	0.29	20	0.0143
Tropical	1.83	1.69	0.24 (0.09, 0.39)	0.07	0.27	30	0.003
Subtropical	1.65	0.04	0.13 (0.07, 0.20)	0.03	0.21	64	0.0001
Coastal	1.87	0.10	0.31 (0.06, 0.56)	0.12	0.33	16	0.0191

B

Independent variable = SST

Dependent variable = log Chl *a*_srf)

Oceans	Intercept	se	Slope (lower, upper, 95% CI)	se	r^2	N	p
Atlantic	-1.91	0.34	0.04 (0.01, 0.06)	0.01	0.10	61	0.011
Indian	0.40	0.39	-0.06 (-0.10, -0.03)	0.02	0.28	34	0.001
Zones							

Subtropical	-0.51	0.22	-0.03 (-0.04, -0.01)	0.01	0.10	66	0.009

Independent variable = σ200-σ6

Dependent variable = log (Chl *a*_srf)

Oceans	Intercept	se	Slope (lower, upper, 95% CI)	se	r^2	N	p
Atlantic	-1.28	0.07	0.11 (0.04, 0.18)	0.03	0.16	54	0.003
Indian	-0.57	0.18	-0.22 (-0.41, -0.02)	0.09	0.14	34	0.029
Pacific	0.11	0.03	0.12 (0.07, 0.17)	0.02	0.40	42	0.000
All	-1.22	0.05	0.13 (0.09, 0.17)	0.02	0.22	130	0.000
Zones							
Equatorial	-1.26	0.15	0.16 (0.09, 0.24)	0.04	0.55	19	0.000

Independent variable = SST

Dependent variable = log(Chl *a*_int)

Oceans	Intercept	se	Slope (lower, upper, 95% CI)	se	r^2	N	p
All	1.331	0.081	0.010 (0.030, 0.016)	0.003	0.06	130	0.004
Zones	Intercept	se	Slope (lower, upper, 95% CI)	se	r^2	N	p
Tropical	2.331	0.247	-0.029 (-0.049, -0.008)	0.010	0.23	30	0.007
Subtropical	1.361	0.065	0.006 (0.001, 0.012)	0.003	0.07	64	0.032

Independent variable = σ200- σ6

Dependent variable = log(Chl *a*_int)

Oceans	Intercept	se	Slope (lower, upper, 95% CI)	se	r^2	N	p
Atlantic	1.474	0.024	0.035 (0.011, 0.059)	0.012	0.14	54	0.005
All	1.467	0.021	0.045 (0.029, 0.062)	0.008	0.19	128	0.000

C

Independent variable = log(Chl *a*_srf)

Dependent variable =DCM depth, m (0-200 m)

Oceans	Intercept	se	Slope (lower, upper, 95% CI)	se	r^2	N	p
Atlantic	36.7	12.5	-68.8 (-92, -45.5)	11.6	0.38	59	0.000
Indian	25.6	9.67	-76.3 (-95.2, -57.3)	9.28	0.69	32	0.000
Pacific	-2.28	13.4	-117 (-151, -83)	16.8	0.57	38	0.000
All	23.41	6.88	-81.1 (-94.8, -67.4)	6.92	0.52	129	0.000

Independent variable = DCM depth, m (0-200 m)

Dependent variable = log(Chl *a*_DCM)

Oceans	Intercept	se	Slope (lower, upper, 95% CI)	se	r^2	N	p
Atlantic	0.0938	0.0447	-0.0039 (-0.0047, -0.0031)	0.0004	0.63	59	0.000
Indian	-0.0920	0.1050	-0.0031 (-0.0052, -0.0011)	0.0010	0.25	32	0.004
Pacific	-0.0267	0.0485	-0.003 (-0.004, -0.0019)	0.0005	0.48	38	0.000
All	-0.0014	0.0340	-0.0034 (-0.004, -0.0027)	0.0003	0.46	129	0.000

Table S5. – (A) Parameters of the RMA regression equations of the logarithm of the Chl *a* concentration in the micro- [log(Chl *a*_micro)], nano- [log(Chl *a*_nano)] and picophytoplankton [log(Chl *a*_pico)] size fractions on the logarithm of the total Chl *a* concentration, calculated as the sum of all the fractions [log(Chl *a*_pol)] for the light levels. (B) Parameters of the RMA regression equations of the fractional (per unit) contribution of micro- (f_micro), nano- (f_nano) and picophytoplankton (f_pico) on Chl *a*_pol, for the different light levels. CI=confidence interval, N=number of observations, ns=non-significant.

A

Independent variable =log(Chl *a*_pol)

Dependent variables

Surface	Intercept	Std error	Slope (lower, upper, 95% CI)	Std error	r^2	N	p
log(Chl *a*_micro)	-0.69	0.11	1.40 (1.18, 1.59)	0.09	0.39	134	≤0.0001
log(Chl *a*_nano)	-0.52	0.08	1.01 (0.86, 1.14)	0.07	0.41	134	≤0.0001
log(Chl *a*_pico)	0.00	0.04	1.24 (1.14, 1.32)	0.04	0.88	134	≤0.0001
20%							
log(Chl *a*_micro)	-0.66	0.10	1.47 (1.26, 1.65)	0.09	0.48	128	≤0.0001
log(Chl *a*_nano)	-0.51	0.06	0.99 (0.86, 1.11)	0.06	0.48	128	≤0.0001
log(Chl *a*_pico)	-0.08	0.04	1.20 (1.12, 1.27)	0.34	0.89	128	≤0.0001
DCM							
log(Chl *a*_micro)	-1.11	0.10	1.31 (1.07, 1.54)	0.10	0.28	130	≤0.0001
log(Chl *a*_nano)	-0.39	0.06	1.49 (1.13, 1.75)	0.11	0.29	130	≤0.0001
log(Chl *a*_pico)	-0.08	0.02	1.19 (1.07, 1.30)	0.04	0.87	130	≤0.0001
All light levels							
log(Chl *a*_micro)	-1.04	0.04	1.15 (1.07, 1.22)	0.04	0.50	392	≤0.0001
log(Chl *a*_nano)	-0.58	0.03	0.98 (0.91, 1.04)	0.03	0.56	392	≤0.0001
log(Chl *a*_pico)	-0.07	0.01	1.20 (1.16, 1.24)	0.02	0.93	392	≤0.0001

B

Independent variable = log(Chl *a*_pol)

Dependent variables

Surface	Intercept	Std error	Slope (lower, upper, 95% CI)	Std error	r^2	N	p
f_micro						134	ns
f_nano	-0.12	0.04	-0.42 (-0.48, -0.35)	0.03	0.23	134	≤0.0001
f_pico	1.10	0.04	0.49 (0.41, 0.58)	0.04	0.16	134	≤0.0001
20%							
f_micro						128	ns
f_nano	-0.07	0.04	-0.43 (-0.50, -0.35)	0.03	0.19	128	≤0.0001
f_pico	1.00	0.04	0.47 (0.38, 0.55)	0.04	0.13	128	≤0.0001
DCM							
f_micro	0.03	0.01	-0.19 (-0.23, -0.14)	0.02	0.06	130	0.0037
f_nano	-0.01	0.03	-0.52 (-1,48, -0.40)	0.04	0.03	130	0.039
f_pico	0.92	0.03	0.62 (0.49, 0.75)	0.05	0.05	130	0.0086
All light levels							
f_micro	-0.10	0.01	-0.22 (-0.26, -0.019)	0.01	0.02	392	0.0043
f_nano	0.02	0.01	-0.35 (-0.38, -0.32)	0.02	0.21	392	≤0.0001
f_pico	0.95	0.02	0.41 (0.37, 0.44)	0.02	0.22	392	≤0.0001

Table S6. – Particulate organic carbon (POC, µM), Chl *a*_tot concentrations, POC/Chl *a*_tot ratios for surface and DCM, and ratio between Chl *a*_tot at DCM (Chl *a*_DCM) and Chl *a*_tot at the surface (Chl *a*_srf). Only stations with DCM and for which both POC and Chl *a*_tot data from surface and DCM were available were used.

	Surface				DCM				
Station	Depth, m	Chl *a,* mg m^{-3}	POC, mg m^{-3}	POC/Chl *a*	Depth, m	Chl *a,* mg m^{-3}	POC, mg m^{-3}	POC/Chl *a*,	Chl *a*_DCM/ Chl *a*_srf
6	4	0.22	19.9	89.9	88	0.37	15.7	42.3	1.67
9	4	0.20	20.6	102.4	76	0.56	23.9	42.5	2.79
11	4	0.26	26.4	102.6	66	0.58	20.8	35.8	2.25
14	4	0.44	29.4	66.9	80	0.76	20.0	26.4	1.73
15	4	0.22	23.8	108.5	80	0.81	16.7	20.5	3.72
18	4	0.11	27.8	254.7	110	0.50	24.7	49.0	4.62
19	4	0.10	37.7	379.6	120	0.45	20.7	45.6	4.57
21	4	0.04	18.4	453.6	150	0.36	15.8	43.6	8.93
22	4	0.05	18.1	390.0	140	0.46	21.0	46.0	9.80
24	4	0.11	26.5	240.2	130	0.35	16.0	45.6	3.19
28	4	0.08	29.8	364.6	120	0.47	26.6	56.8	5.74
29	4	0.10	18.0	186.9	120	0.35	12.3	35.4	3.60
30	4	0.08	23.5	301.6	130	0.30	0.2	0.8	3.89
31	4	0.05	19.2	405.6	140	0.31	12.7	40.9	6.55
32	4	0.09	6.0	64.3	126	0.33	12.0	36.5	3.51
33	4	0.04	21.0	579.1	120	0.33	0.2	0.7	9.16
34	4	0.04	40.9	1164.0	150	0.33	0.2	0.7	9.40
35	4	0.03	14.5	416.1	136	0.34	18.0	53.8	9.60
37	4	0.04	21.8	543.3	110	0.45	29.4	65.9	11.11
38	4	0.03	16.5	493.0	106	0.30	18.0	59.9	8.98
39	4	0.06	26.7	446.0	110	0.28	28.6	103.2	4.64
40	4	0.04	17.3	420.9	70	0.37	18.2	49.3	8.98

41	4	0.06	22.0	380.4	86	0.48	40.7	84.1	8.35
42	4	0.07	20.1	287.9	74	0.84	25.6	30.5	12.04
43	4	0.06	39.0	609.4	48	0.81	51.8	64.1	12.61
44	4	0.22	51.3	231.4	56	1.06	46.8	44.1	4.79
47	6	0.09	29.8	325.8	80	0.97	30.5	31.6	10.58
52	6	0.10	14.5	147.7	136	0.26	11.8	44.9	2.69
53	4	0.09	28.8	337.7	110	0.38	24.3	63.9	4.46
54	6	0.06	15.9	251.6	110	0.46	18.1	39.4	7.29
55	6	0.06	10.6	188.9	130	0.28	12.2	43.9	4.96
56	8	0.04	19.5	472.4	132	0.27	16.0	58.6	6.62
57	6	0.05	11.2	215.5	142	0.27	7.5	27.9	5.18
58	4	0.04	8.1	214.0	128	0.27	8.6	32.1	7.02
59	4	0.04	11.5	292.0	136	0.25	6.6	26.6	6.33
60	6	0.03	8.7	251.7	152	0.23	7.1	30.2	6.80
61	8	0.04	10.3	254.6	120	0.25	13.0	53.1	6.09
62	4	0.05	20.8	424.6	120	0.39	23.0	59.4	7.93
63	6	0.07	12.7	186.7	116	0.29	15.6	54.5	4.21
64	4	0.06	14.9	234.0	110	0.45	15.0	33.3	7.06
65	6	0.10	53.0	530.2	102	0.37	18.8	51.1	3.68
66	4	0.16	17.1	105.5	102	0.47	15.1	31.8	2.93
67	6	0.10	27.0	265.1	92	0.47	25.5	54.5	4.60
68	4	0.12	15.7	132.2	100	0.54	23.5	43.4	4.56
69	4	0.13	17.3	134.9	80	0.11	9.8	87.6	0.87
70	4	0.11	16.7	158.7	104	0.28	11.2	39.6	2.70
71	4	0.15	18.0	120.6	76	0.32	22.1	68.5	2.15
72	4	0.17	15.9	92.2	66	0.44	17.9	41.0	2.54
73	8	0.18	15.4	86.9	72	0.33	18.2	55.4	1.85
74	6	0.24	28.3	117.8	72	0.28	19.5	69.2	1.17
75	4	0.35	28.6	80.8	55	0.40	23.7	59.3	1.13

79	4	0.12	36.1	307.1	88	0.43	53.2	122.4	3.70
82	4	0.13	17.3	133.1	108	0.41	25.1	61.7	3.14
83	4	0.16	44.1	272.5	110	0.42	30.5	71.7	2.63
86	4	0.10	26.6	262.8	106	0.38	15.5	40.8	3.76
87	4	0.09	24.4	282.8	114	0.51	15.5	30.5	5.89
89	6	0.07	16.0	240.9	110	0.31	16.5	53.2	4.66
98	4	0.08	16.5	201.6	140	0.36	13.9	38.8	4.39
101	4	0.16	18.3	114.4	126	0.38	23.1	61.5	2.34
102	4	0.19	21.7	116.4	140	0.37	19.4	52.1	2.00
103	4	0.09	55.1	592.1	106	0.83	38.8	46.7	8.93
104	4	0.17	18.8	112.8	116	0.50	19.1	38.4	2.99
106	6	0.11	19.5	177.4	126	0.41	21.6	52.2	3.77
107	4	0.10	32.5	339.6	130	0.47	22.5	47.7	4.93
109	4	0.14	28.3	202.4	126	0.34	23.5	68.4	2.46
111	4	0.21	17.2	80.0	100	0.32	12.7	39.3	1.50
113	4	0.25	15.8	62.2	138	0.47	81.9	175.2	1.84
115	4	0.18	29.8	162.6	78	0.61	27.8	45.3	3.35
118	4	0.32	63.1	197.9	60	0.65	31.8	49.2	2.03
119	4	0.45	31.3	69.0	34	0.93	33.6	36.3	2.04
120	4	0.18	27.3	148.0	38	0.64	55.3	86.4	3.47
121	4	0.37	26.5	72.3	44	0.64	30.3	47.3	1.74
122	4	0.53	57.3	109.0	20	0.78	86.8	111.7	1.48
124	4	0.21	67.9	323.4	24	0.78	39.2	50.5	3.70
126	4	0.31	35.9	114.8	46	0.67	28.6	42.9	2.13
127	4	0.13	47.5	366.4	70	0.70	19.6	28.0	5.39
128	4	0.14	19.9	137.6	106	0.58	19.5	33.5	4.02
129	4	0.09	28.1	307.0	96	0.51	23.3	45.3	5.62
130	4	0.19	24.7	127.8	76	0.77	21.7	28.3	3.98
131	4	0.27	28.0	105.0	90	0.32	22.8	71.5	1.19

132	4	0.31	20.9	68.2	124	0.36	14.9	41.4	1.17
133	4	0.05	20.7	384.5	140	0.38	13.7	35.7	7.10
134	4	0.07	22.3	305.2	130	0.39	16.5	42.1	5.38
135	4	0.06	19.7	350.8	130	0.33	11.2	33.8	5.90
136	4	0.06	24.0	413.4	120	0.43	12.5	28.7	7.48
137	4	0.05	49.1	1036.1	150	0.40	17.0	43.0	8.36
138	4	0.06	19.8	314.5	130	0.47	15.9	33.7	7.49
139	4	0.08	13.1	171.1	160	0.35	6.8	19.3	4.60
140	4	0.05	20.3	413.0	150	0.35	17.0	48.3	7.19
141	4	0.04	19.3	429.0	150	0.23	15.0	65.3	5.11
142	4	0.04	16.1	368.5	140	0.22	11.0	49.3	5.10
143	4	0.10	21.6	217.4	96	0.43	19.2	44.5	4.33
144	4	0.07	22.0	336.6	100	0.46	40.1	87.4	7.00
145	4	0.07	11.8	157.8	96	0.60	22.6	37.8	8.02
147	4	0.09	21.8	245.8	90	0.54	15.3	28.5	6.08
Average		0.13	24.5	270.1		0.45	21.8	48.8	5.0
SD		0.10	12.0	184.9		0.18	13.9	24.1	2.7

Table S7. – Statistical parameters of the temperature for the three light levels in the Atlantic, Indian and Pacific oceans.

	Temperature, °C		
Surface	Atlantic	Indian	Pacific
N	60	34	45
Median	25.96	23.00	27.36
Arithmetic mean	25.10	22.12	26.33
Standard deviation	2.78	2.87	2.48
20%			
N	60	32	44
Median	25.36	21.69	26.52
Arithmetic mean	24.54	21.50	25.37
Standard deviation	2.86	2.72	3.38
DCM			
N	60	32	44
Median	21.57	17.43	23.46
Arithmetic mean	21.40	17.46	23.31
Standard deviation	3.26	1.97	3.56

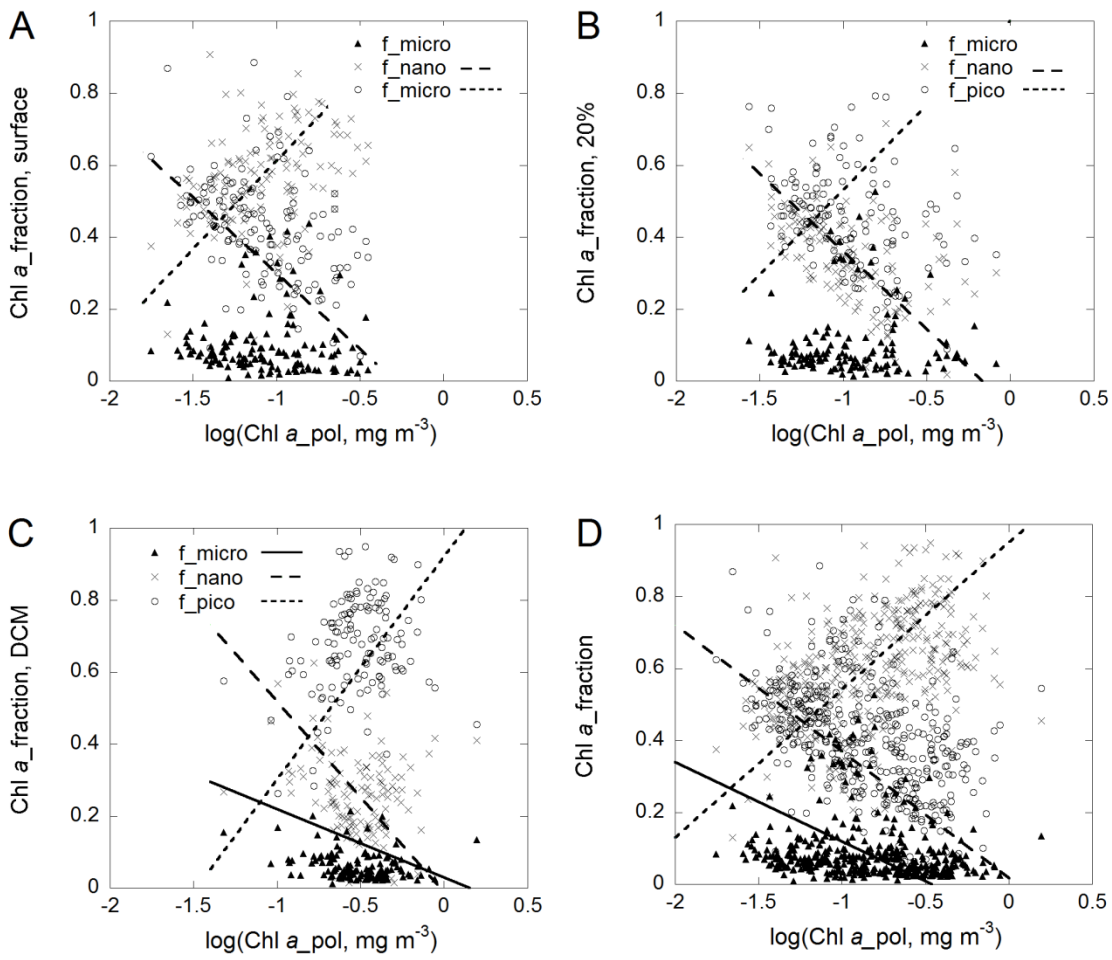

Fig. S1. – Relationship between the logarithm of the sum of Chl *a* for all size fractions [log(Chl *a*_pol)] and the proportion of Chl *a* in the microphytoplankton (f_micro), nanophytoplankton (f_nano) and picophytoplankton (f_pico) at the surface (A), the 20% light level (B), the DCM level (C) and all light levels pooled. The equations of the RMA regression lines (only the significant ones are shown) can be found in Table S5.

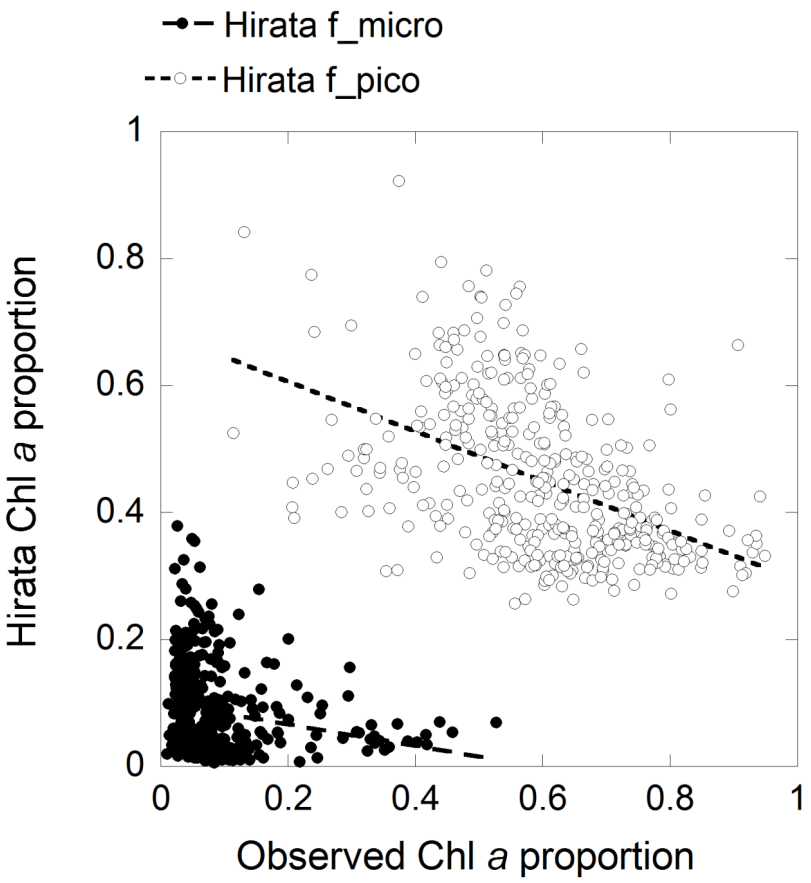

Fig. S2. – Relationship between the measured proportions of Chl *a* in the micro- and picvoplytoplankton size fractions calculated according to the Hirata algorithm (Hirata f_micro and Hirata f_pico, respectively). The equations are y=0.10–0.17x (correlation, R=0.19) for Hirata f_micro and y=0.68–0.39x (R=0.48) for Hirata f_pico.

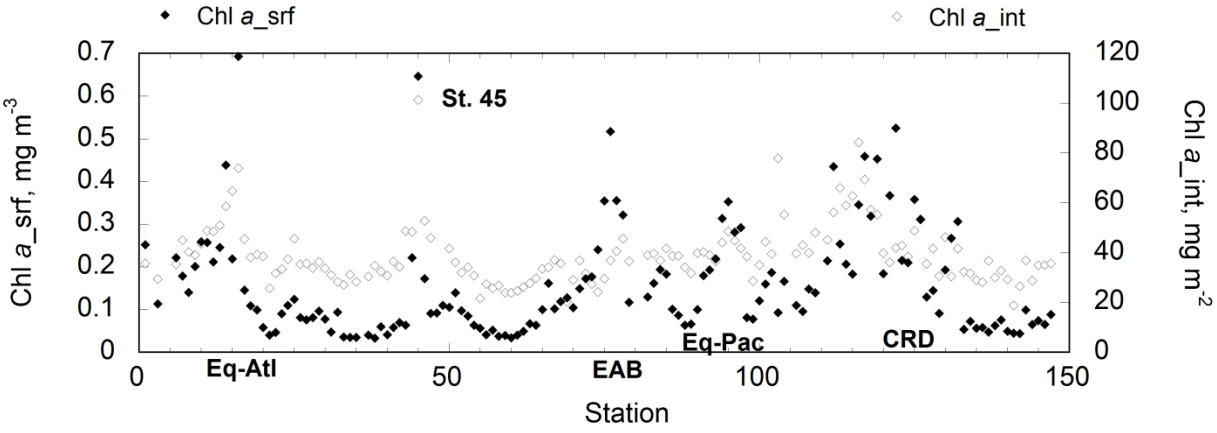

Fig. S3. – Spatial variability of surface Chl *a* (Chl *a*_srf) and integrated Chl *a* (Chl *a*_int) along the Malaspina-2010 cruise track.

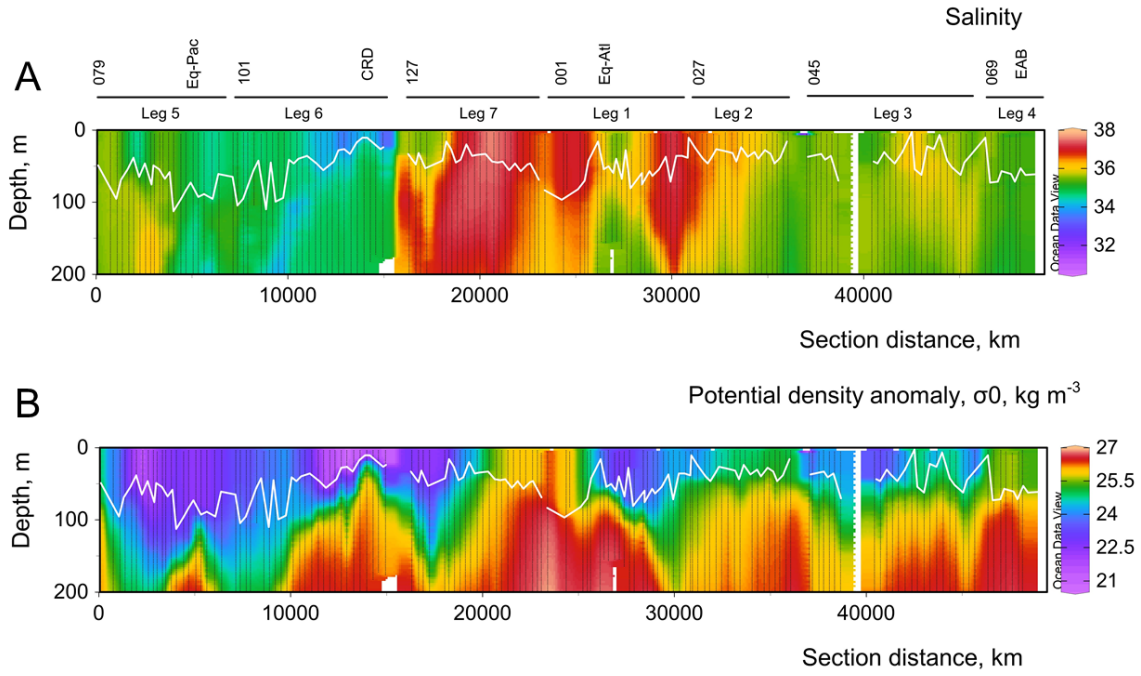

Fig. S4. – Salinity (A) and potential density anomaly (σ0, kg m^{-3}, panel B) distributions during the Malaspina-2010 expedition. The white lines indicate the mixed layer depth. The initial and final stations of each leg and the regions indicated in Fig. 1 are shown t the top of panel (A).

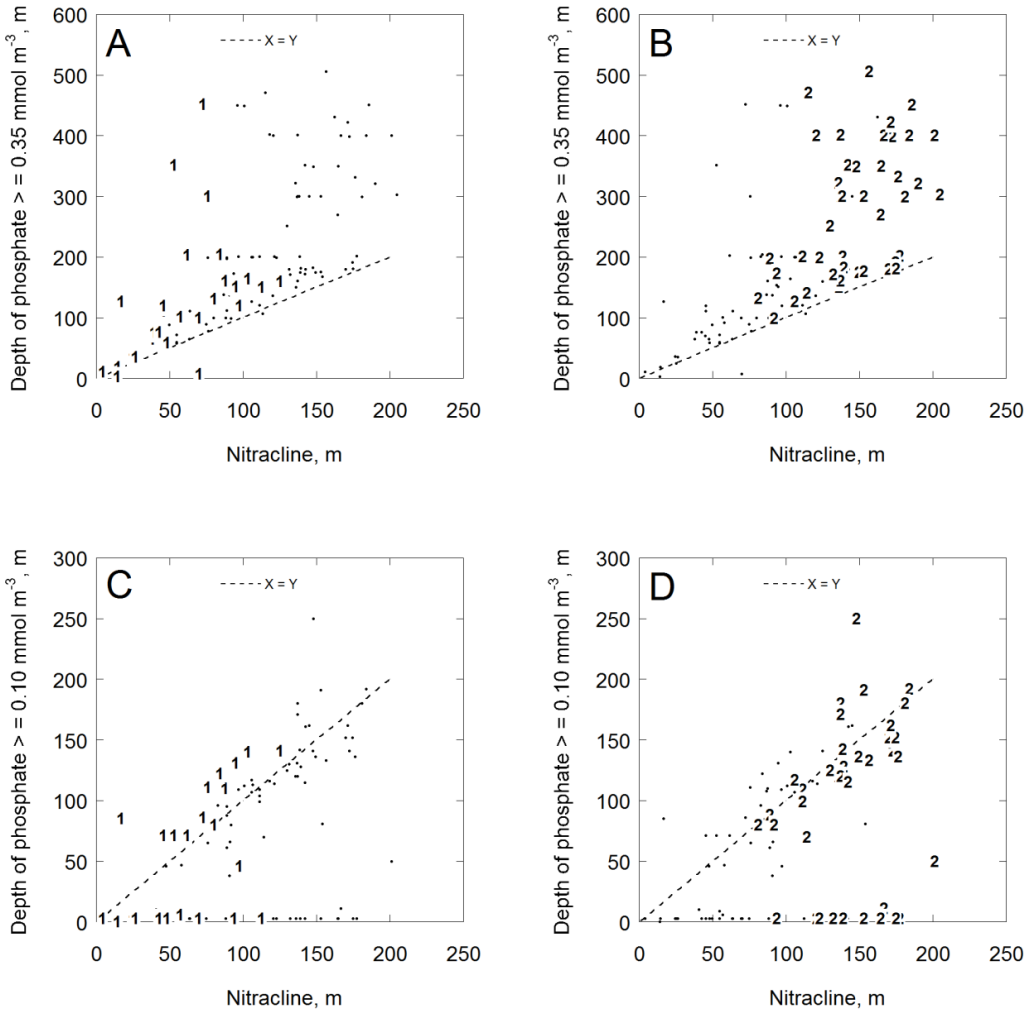

Fig. S5. – Relationships between the nitracline depth and the shallower depth with phosphate concentrations equal to or exceeding 0.35 mmol m^{-3} (A, B) or 0.10 mmol m^{-3} (C, D). Stations with DCM more than 10 m deeper than the nitracline are marked with "1" and those with DCM more than 10 m shallower than the nitracline are marked with "2" (the 10 m absolute difference between DCM and nitracline was adopted to account for uncertainties in the sampling depths).