Seasonal cycle of phytoplankton community structure and photophysiological state in the western subarctic gyre of the North Pacific

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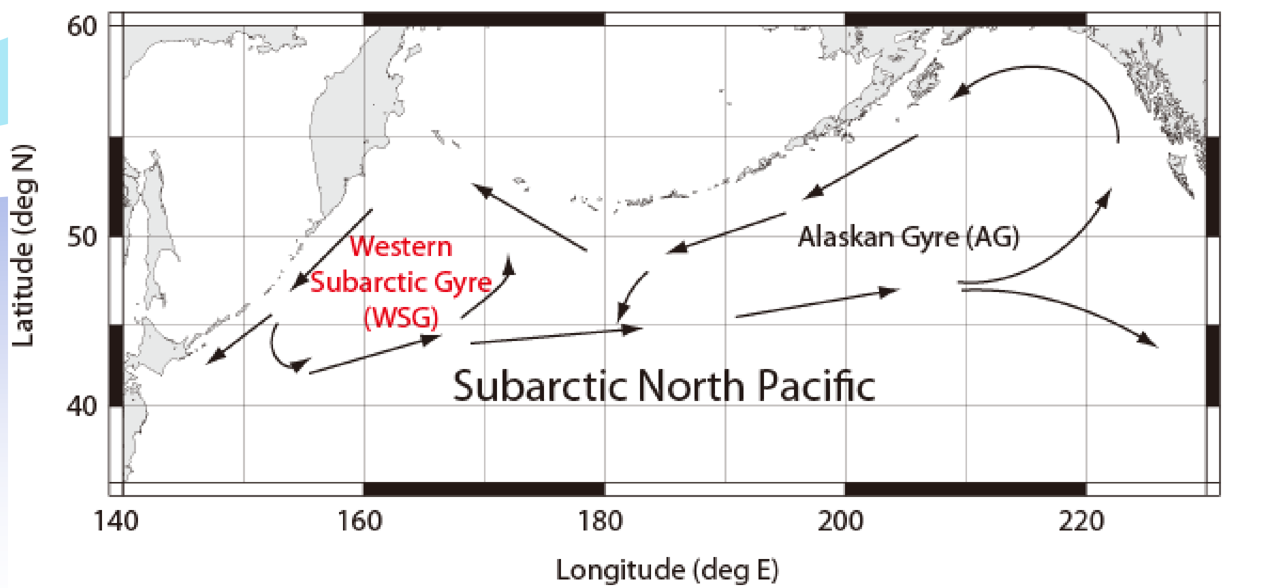
Introduction



Subarctic North Pacific: High Nutrient–Low Chlorophyll (HNLC) region

Alaskan Gyre:

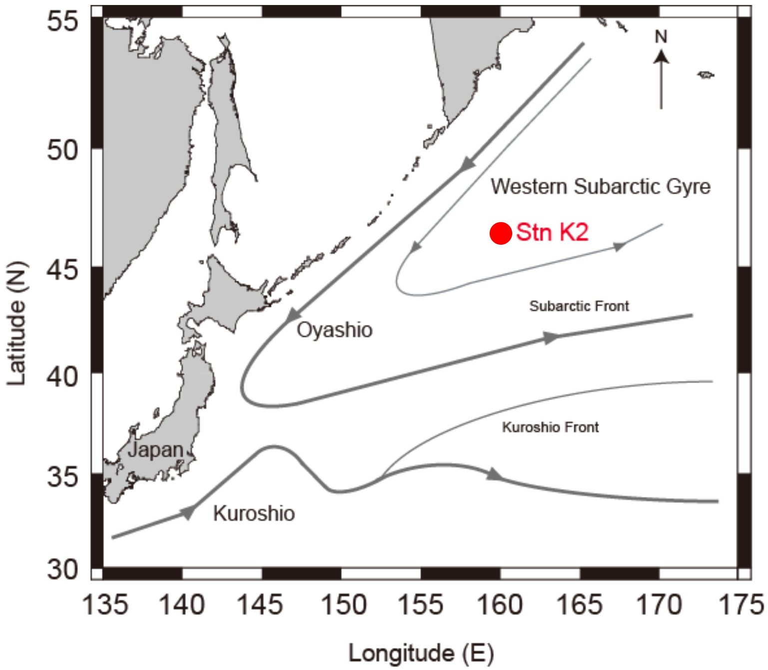
Chl *a* concentration is nearly constant throughout the year (Welschmeyer et al. 1993, Wong et al. 1995).

Western Subarctic Gyre:

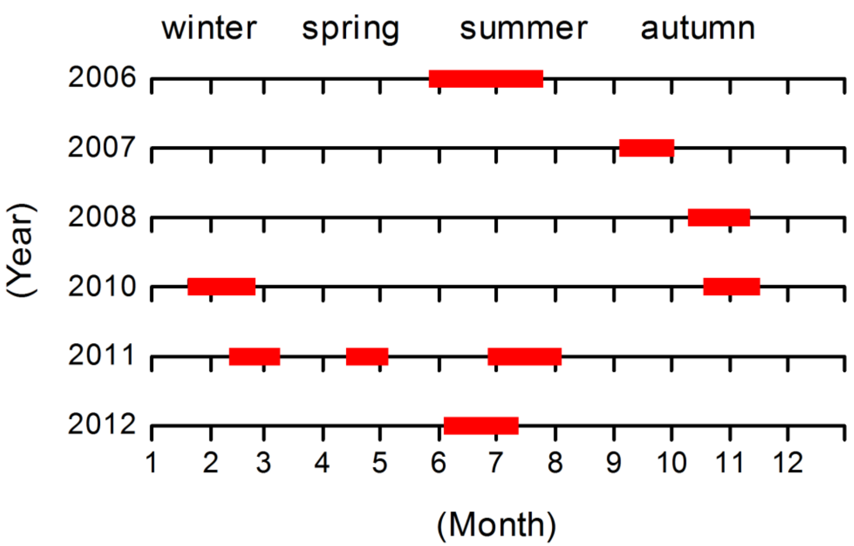
High Chl *a* concentrations (phytoplankton blooms) have been observed from late spring to early summer (Obayashi et al. 2001, Imai et al., 2002).

In this study, we examined the seasonal variations in phytoplankton composition and physiological state in the WSG as well as environmental factors.

Observations



Time-series station K2 (47ºN, 160ºE) in WSG

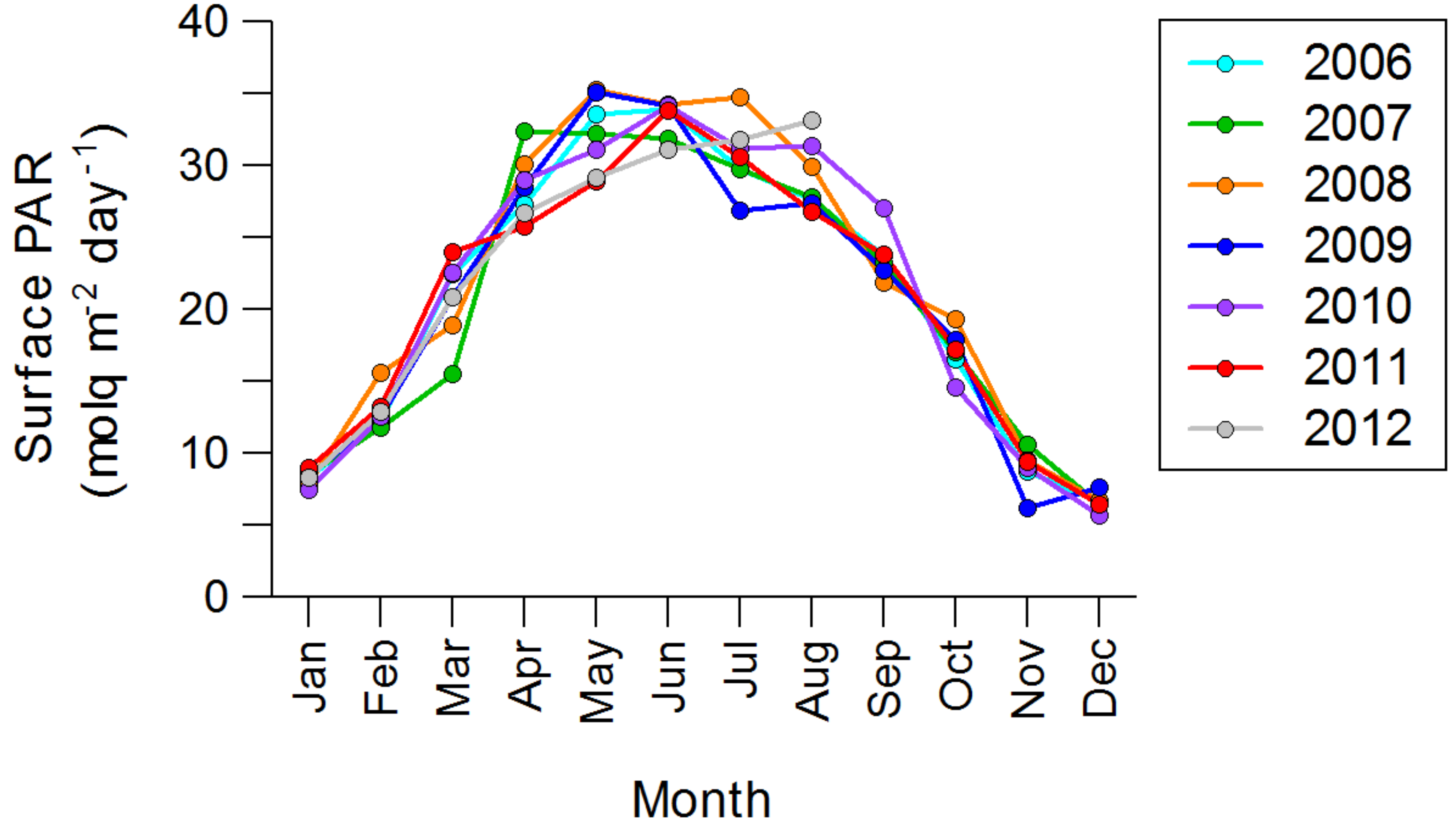


9 cruises of R/V "MIRAI" in the western North Pacific from 2006 to 2012

Measurements:

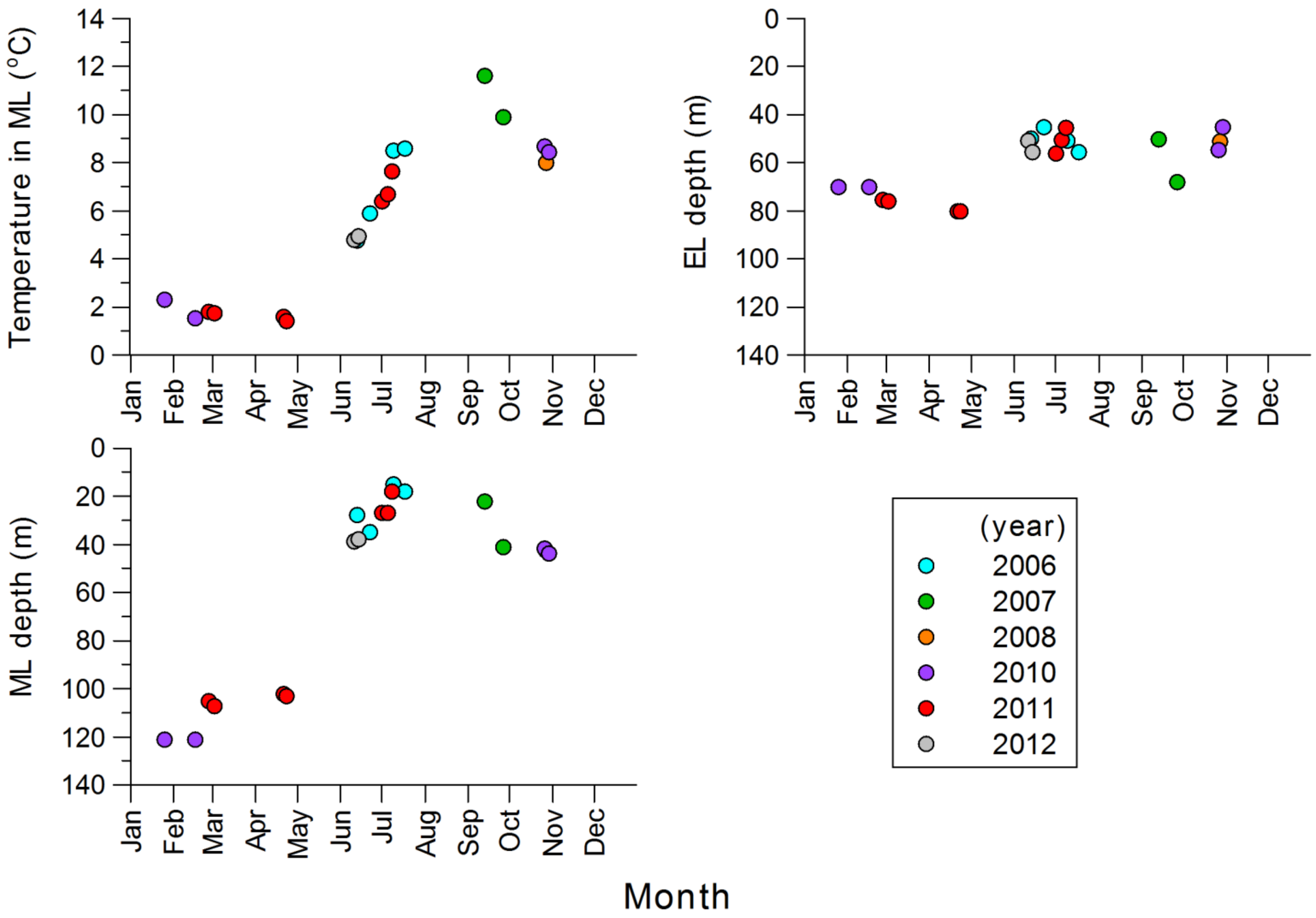
- Pigment concentrations [HPLC]
- Taxonomic composition [CHEMTAX program (Mackey et al.1997), Microscopy]
- Physiological state [Fast repetition rate fluorometer (FRRF)]
- Environmental factors [Temperature, Salinity, Irradiance, Nutrients (N, P, Si), etc.]

Monthly mean of sea-surface daily PAR around stn K2

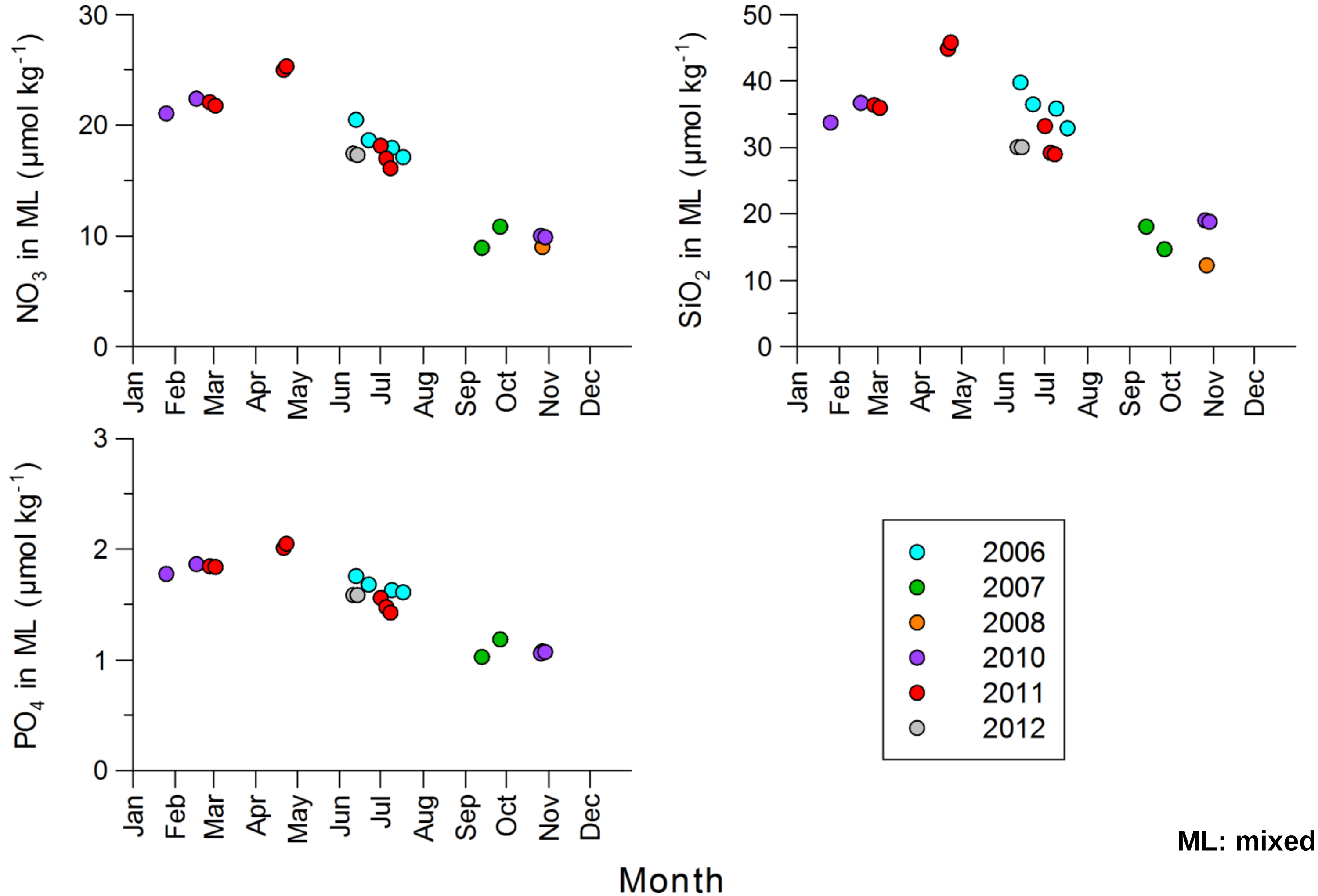


(from NASA MODIS satellite image data)

Temperature, Mixed layer (ML) & Euphotic layer (EL) depths



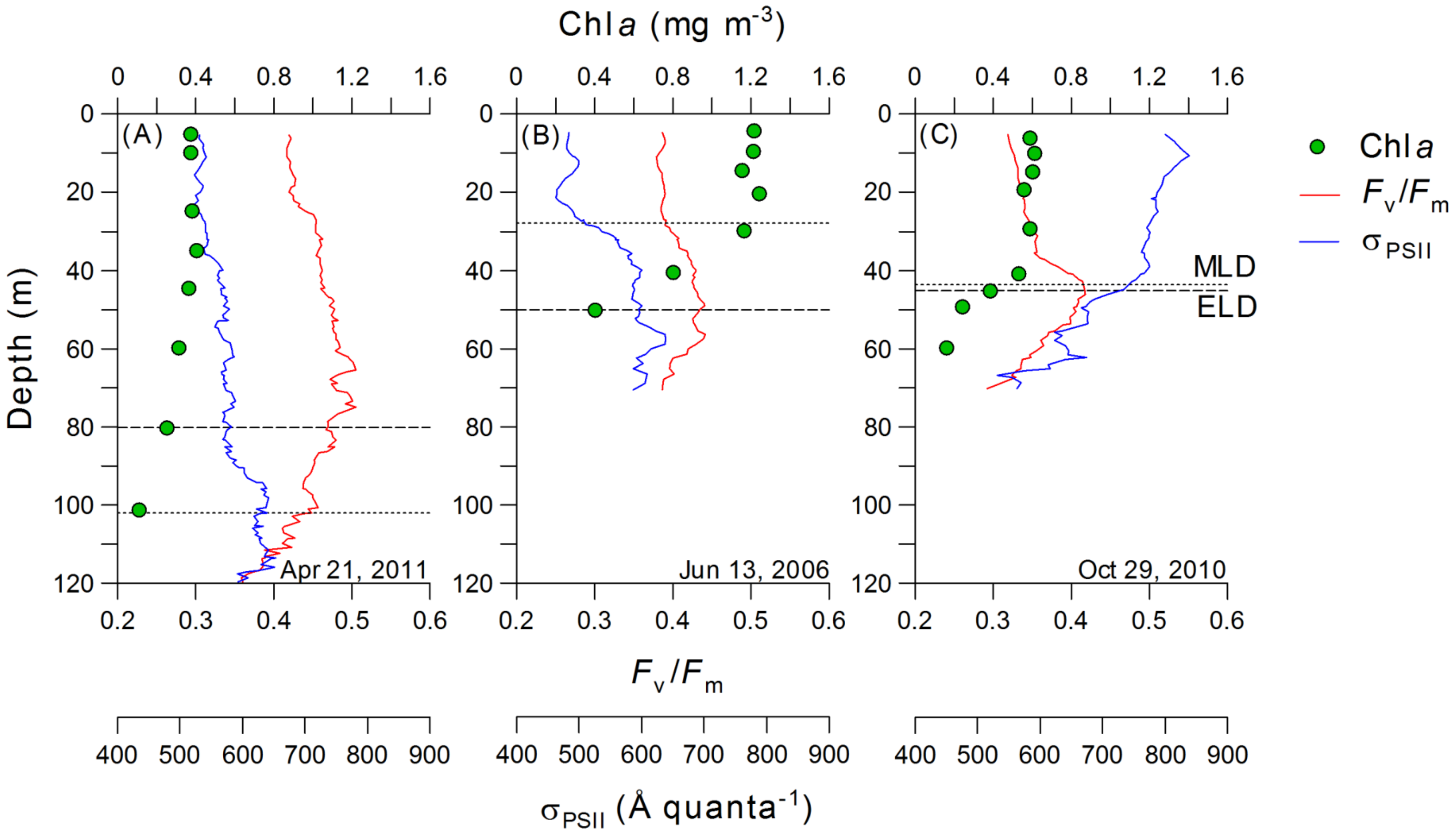
Nitrate, Phosphate, Silicate



ML: mixed layer

Macronutrients in the ML were not depleted throughout the year.

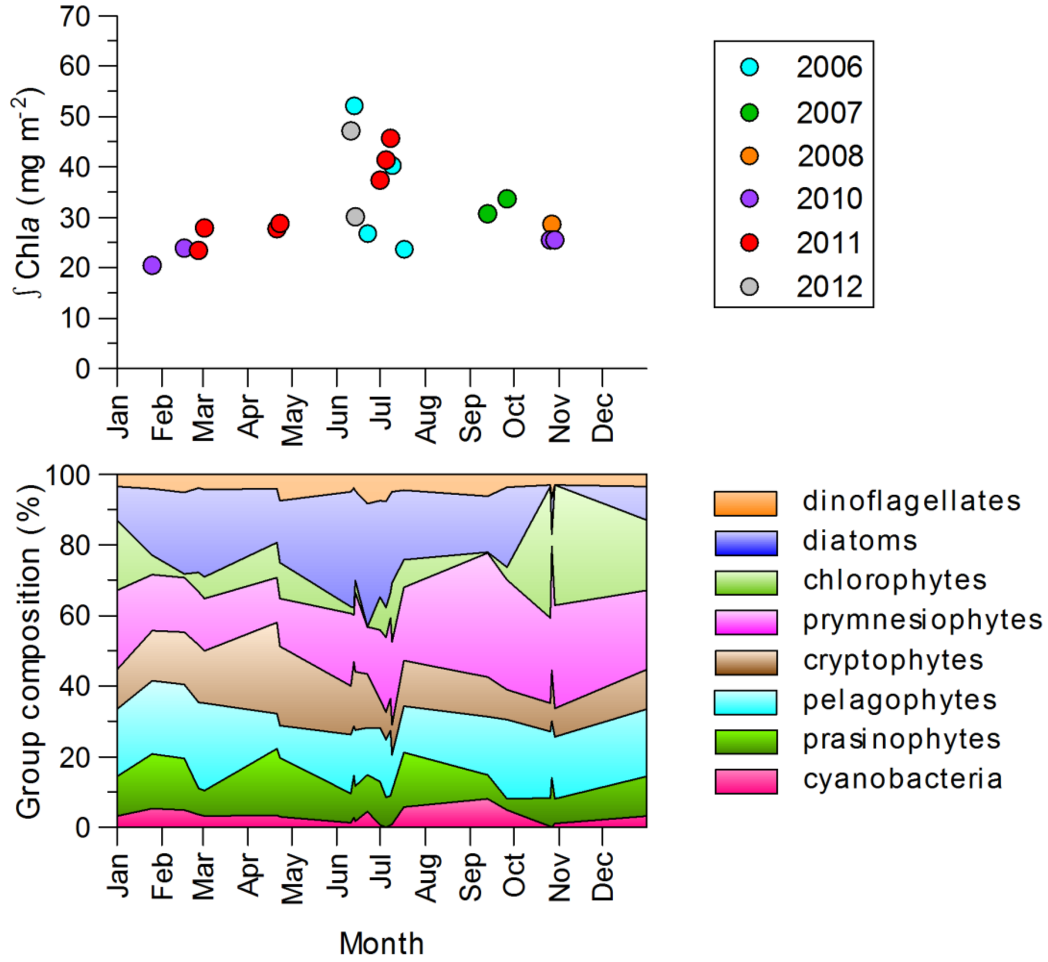
Vertical profiles of Chl *a*, F_v/F_m and σ_{PSII}



Chl *a* standing stock & Group Composition (by CHEMTAX)

Depth-integrated Chl *a* within the euphotic layer

Relative contribution (%) of each phytoplankton group to ∫Chla



Dominant groups

Jan-Apr : diatoms, pelagophytes, cryptophytes

Jun-Jul (blooms) : diatoms, prymnesiophytes

Sep-Oct : prymnesiophytes, chlorophytes

Main diatom species during the bloom period (by Microscopy)

	Bloom								
	2006				2011			2012	
Species	13 Jun	22 Jun	09 Jul	17 Jul	01 Jul	05 Jul	08 Jul	11 Jun	14 Jun
Centric diatoms									
Chaetoceros spp.					107	62	97	91	91
Thalassiosira spp.	90	203	255	91	460	491	437	120	164
Corethron criophilum					63	139	102	93	20
Pennate diatoms									
Fragilariopsis spp.	2771	1776	3378	1818	549	146	72	240	96
Neodenticula seminae	15	31	22	23	379	303	362	212	137
Nitzschia spp.	28	3	44					109	178
Pseudo-nitzschia spp.	165	75	364	72	2453	3821	4822	2	35
Thalassionema spp.					24	21	64		

(x 10^5 cells m^{-2})

Bloom-forming species of diatoms vary from year to year.

Table 2. Size and group composition (%) of the Chl *a* standing stock during prebloom, bloom, and postbloom periods based on conditions before and after the phytoplankton blooms. The group composition was calculated by using Eq. 1. Dino, dinoflagellates; Diato, diatoms; Pelago, pelagophytes; Prymne, prymnesiophytes; Crypto, cryptophytes; Prasino, prasinophytes; Chloro, chlorophytes; Cyano; cyanobacteria.

			Size composition (%)			Group composition (%)							
Period	Date		>10 μm	3–10 μm	<3 μm	Dino	Diato	Pelago	Prymne	Crypto	Prasino	Chloro	Cyano
Prebloom	2010	25 Jan	22.7	17.5	59.8	4.1	19.0	20.6	15.9	14.2	15.6	5.4	5.2
		16 Feb	25.0	16.9	58.1	5.1	23.1	21.0	15.4	14.9	14.6	1.1	4.8
	2011	26 Feb	25.3	18.6	56.2	3.9	24.0	24.4	14.9	16.3	7.4	5.5	3.5
		02 Mar	26.3	17.5	56.3	4.4	24.8	24.7	15.0	14.7	7.3	5.9	3.1
		21 Apr	19.4	23.1	57.5	4.1	15.2	10.0	12.7	25.8	18.7	10.0	3.5
		23 Apr	22.1	26.2	51.7	7.6	17.4	9.0	13.4	22.5	16.8	10.3	3.0
Bloom	2006	13 Jun	18.1	27.7	54.1	4.0	33.7	13.9	13.4	18.3	11.7	2.1	2.8
		22 Jun	19.2	35.1	45.7	8.3	35.1	13.4	13.3	15.3	10.3	0.0	4.4
		09 Jul	29.1	21.9	49.0	5.0	25.7	10.2	23.3	8.5	9.5	16.8	0.9
		17 Jul	14.3	24.0	61.7	4.5	19.8	13.3	20.7	12.9	15.3	7.8	5.8
	2011	01 Jul	39.2	15.1	45.7	7.5	27.4	15.2	19.7	8.0	12.5	9.2	0.5
		05 Jul	43.3	17.5	39.3	7.7	30.0	16.3	21.2	7.9	8.4	8.5	0.1
		08 Jul	34.1	13.7	52.2	5.6	28.0	18.4	22.8	9.1	8.3	7.2	0.6
	2012	11 Jun	11.1	24.1	64.8	5.0	32.6	16.6	20.5	13.9	8.3	1.8	1.3
		14 Jun	7.7	17.9	74.4	4.8	25.3	15.9	22.5	16.5	9.9	3.3	1.7
Postbloom	2007	13 Sep	21.1	34.3	44.7	6.3	15.8	16.4	35.1	11.4	6.9	0.3	8.0
		26 Sep	17.5	27.6	54.8	3.8	22.6	22.4	31.2	8.4	3.3	3.5	4.8
	2008	27 Oct	12.8	26.3	61.0	6.8	10.2	16.1	35.1	14.4	13.9	3.5	0.0
	2010	26 Oct	7.2	18.8	74.0	3.1	0.4	19.0	24.1	8.1	7.9	37.1	0.3
		29 Oct	4.1	16.8	79.2	3.0	0.0	17.6	29.1	8.1	7.0	34.2	1.1

(Fujiki et al. 2014. LO)

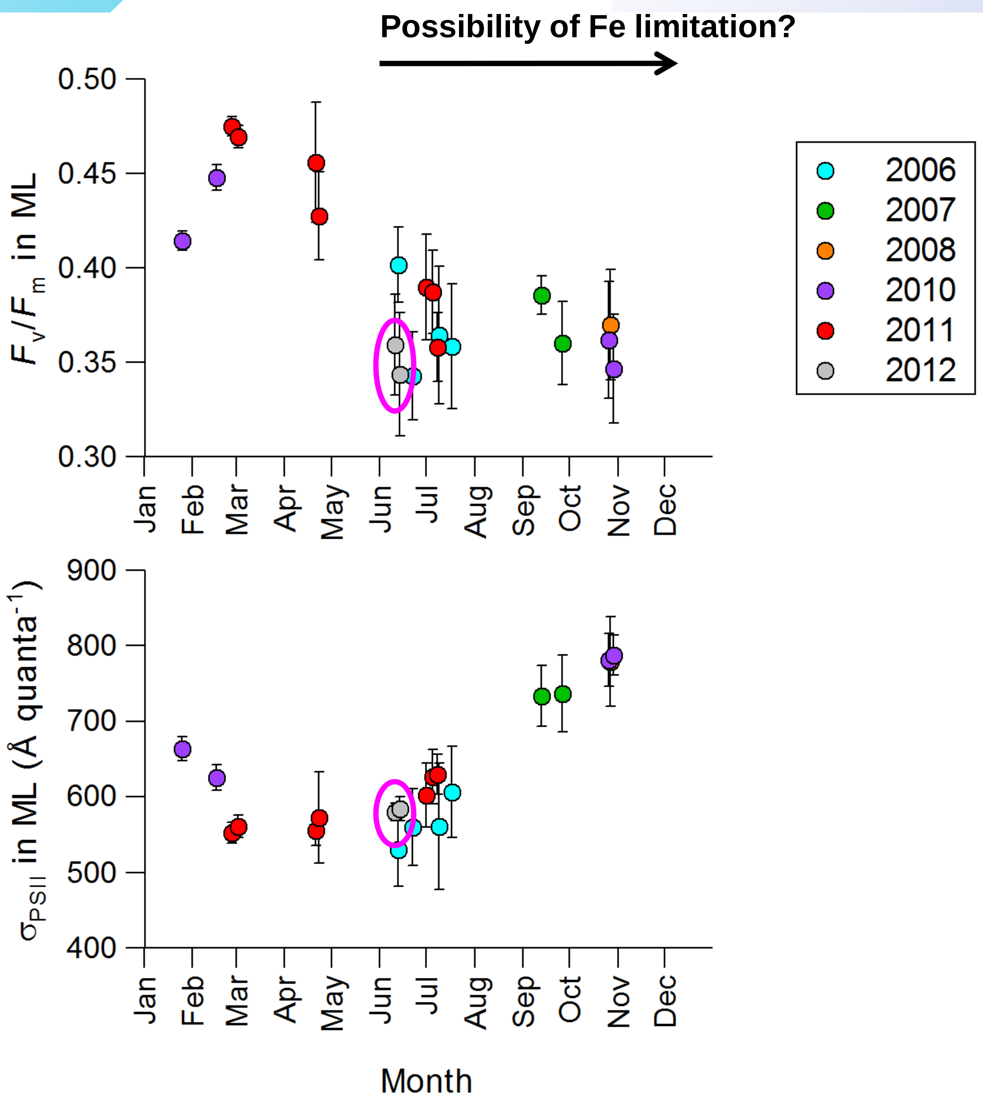
Physiological state [nighttime] (by FRRF)

F_v / F_m :

Photochemical efficiency

σ_{PSII} :

Effective absorption cross-section of photosystem II



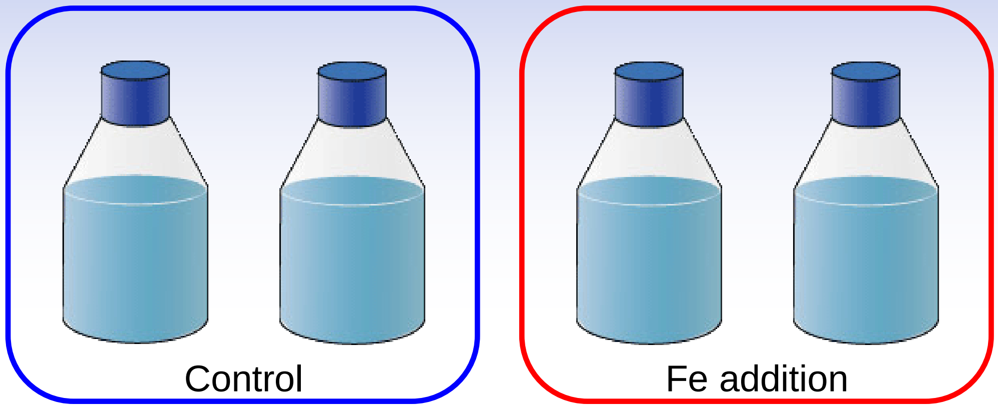
ML: mixed layer

The decrease in F_v/F_m and the increase in σ_{PSII} suggest that the growth of phytoplankton may be limited by iron.

Iron enrichment experiments (Methods)

14 June 2012 (bloom period), 5 m depth

acid-cleaned Niskin-X bottle



An acidified ferric chloride ($FeCl_3$) solution was spiked to the two bottles to add Fe concentration of 2 nmol L^{-1} (referred to Kudo et al. 2006).

acid-cleaned 1L polycarbonate bottles

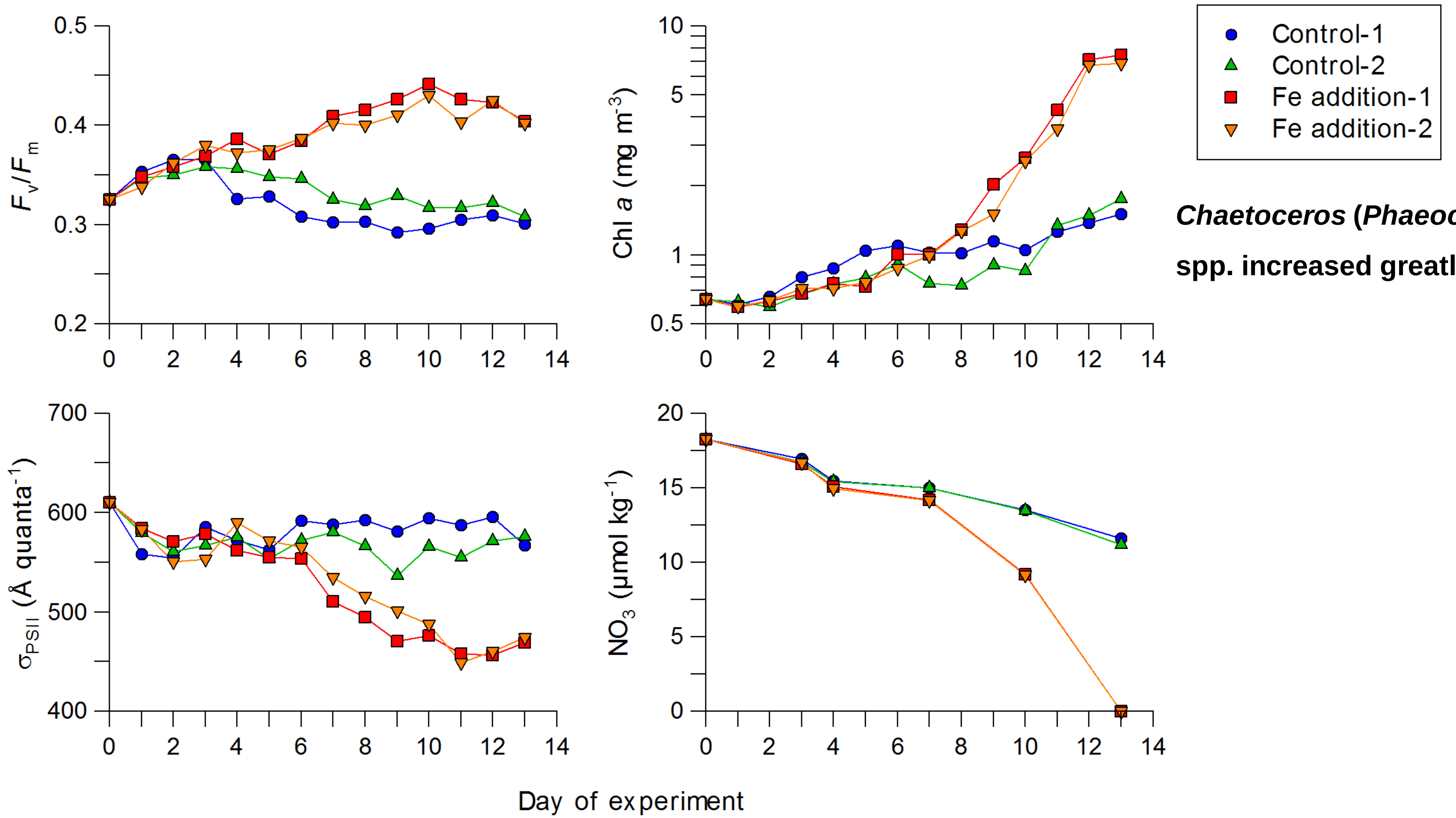
Onboard incubator

Light condition : 150 μmol quanta m^{-2} s^{-1} (14h:10h light/dark cycle)

Temperature : 5 ^oC

Period : two weeks

Iron enrichment experiments (Results)



***Chaetoceros* (*Phaeoceros*) spp. increased greatly**

The growth of phytoplankton has already been limited by iron in the bloom period.

Iron supply process to the WSG

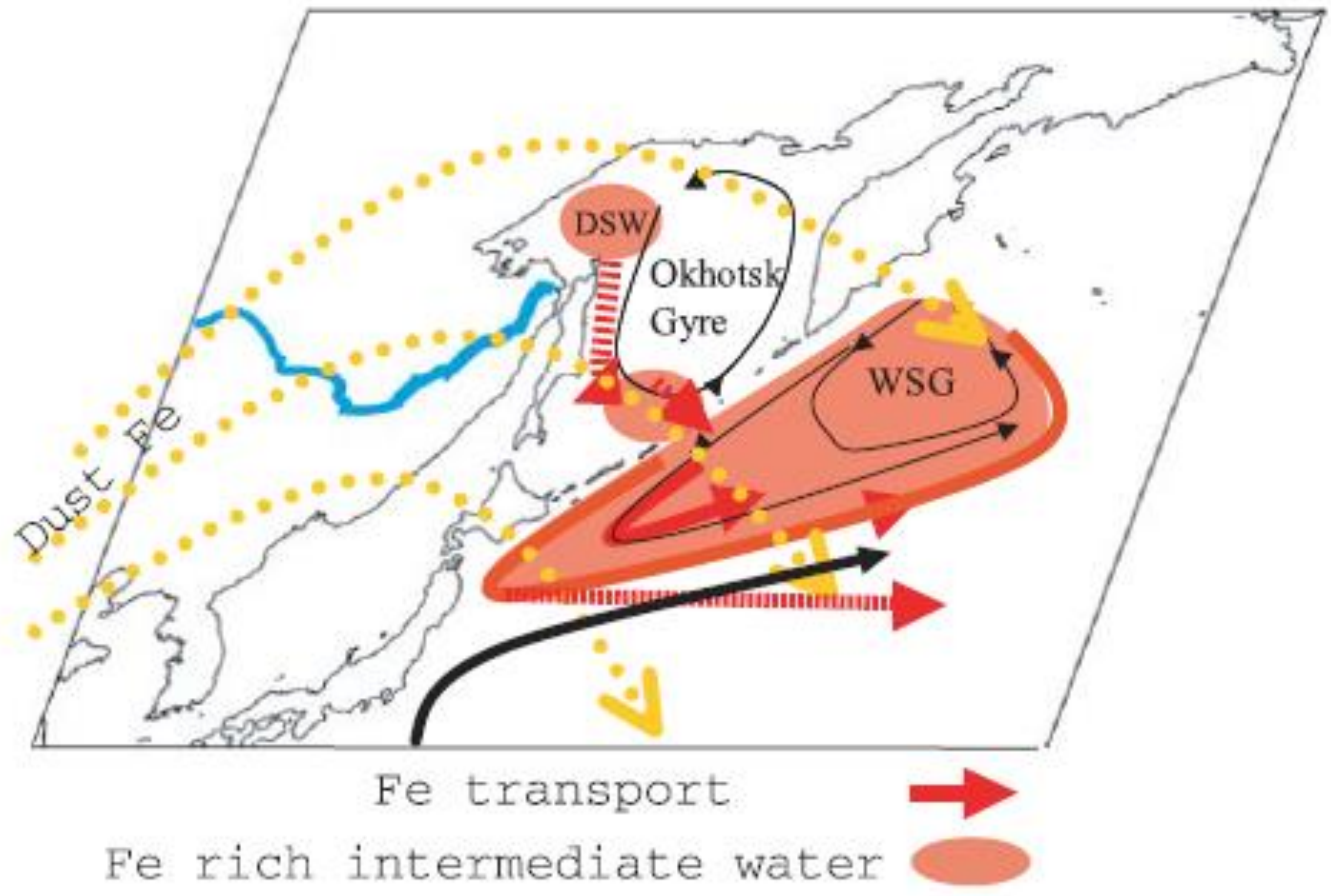


Figure 13. Schematic of iron supply process proposed in this study. Water ventilation processes in this region control the transport of dissolved and particulate iron through the intermediate water layer from the continental shelf of the Sea of Okhotsk to the wide area of the WSP.

(Nishioka et al. 2007. JGR)

Summary

- The transient increases in Chl *a* concentrations, mainly due to diatoms and prymnesiophytes, have been observed in early summer (June and July) when the ML depth shoaled.

- Although the concentrations of macronutrients (NO_3, PO_4 and SiO_2) still remained high in autumn, Chl *a* concentrations were relatively low and constant. At this time, the dominance of prymnesiophytes and/or chlorophytes was relatively enhanced.

- The values of F_v/F_m in the ML were relatively high in winter and spring, but had already declined in early summer when the blooms occurred. The values of σ_{PSII} were relatively high in autumn.

- In the bloom period, Fe addition caused an improvement in physiological state and resulted in a large increase in Chl *a* concentration.

Factors controlling the phytoplankton community in the WSG

- Seasonal cycle of the phytoplankton community and photophysiological state in the WSG is controlled primarily by Fe, along with light and temperature limitation in the winter and early spring.

- Fe supplied from subsurface intermediate waters should be considered an important source of Fe, along with aeolian dust inputs, for the seasonal blooms of phytoplankton in the WSG.

- Fe availability may plays an important role in regulating the magnitude and duration of blooms.