



Chlorophyll *a* and macro-nutrient concentrations during the icebreaker *Shirase* cruise of the 58th Japanese Antarctic Research Expedition

Ryosuke MAKABE^{1,2,3*}, Shintaro TAKAO^{1,2**},
Kunio T. TAKAHASHI^{1,2} and Tsuneo ODATE^{1,2}

¹ National Institute of Polar Research, Research Organization of Information and Systems,
10–3 Midori-cho, Tachikawa, Tokyo 190-8518.

² Department of Polar Science, School of Multidisciplinary Sciences, SOKENDAI (The Graduate University for Advanced Studies), 10–3 Midori-cho, Tachikawa, Tokyo 190-8518.

³ Tokyo University of Marine Science and Technology, 4-5-7 Konan, Minato,
Tokyo 108-8477, Japan

*Corresponding author: Ryosuke Makabe (makabe@nipr.ac.jp)

**Current affiliation: National Institute for Environmental Studies, 16-2 Onogawa,
Tsukuba, Ibaraki 305-8506 JAPAN

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Abstract: Chlorophyll *a* concentration is the most common indicator of phytoplankton biomass, basically regulated by macro-nutrients and light intensity. Therefore, long-term monitoring of these parameters provides fundamental information on ecosystem changes with climate change. As part of the monitoring programs of the Japanese Antarctic Research Expedition (JARE), water temperature, salinity, chlorophyll-*a* concentration, macro-nutrients (nitrate, nitrite, phosphate, and silicate), and photosynthetically active radiation at the sea surface have been measured onboard the icebreakers *Shirase* and *Fuji* by JARE-7 during the 1965/66 season and by JARE-14 during the 1972/73 season, respectively. This report presents the latest data collected during the *Shirase* cruise in the 2016/17 season.

1. Background & Summary

The phytoplankton community is the main primary producer in the ocean ecosystem. Its productivity not only affects heterotrophic communities but also the air–sea CO₂ flux. Phytoplankton biomass is usually monitored based on chlorophyll-*a* concentrations in various coastal and oceanic regions. In the Indian Sector of the Southern Ocean, inter-annual changes in surface chlorophyll-*a*

reveal a less than 10-year cycle (Hirawake *et al.*, 2005)¹. This means that frequent observations of chlorophyll *a* are needed to understand the ecosystem responses to long-term climate changes (e.g., global warming) and decadal environmental changes (e.g., El Niño and Southern Annular Mode).

“Biological Oceanography” was included in the routine observations of the Japanese Antarctic Research Expedition (JARE). These routine observations have been renamed “Marine Ecosystem Monitoring” since JARE-38. Chlorophyll-*a* concentrations have been measured onboard the icebreakers *Shirase* and *Fuji* by JARE-7 during the 1965/66 season and by JARE-14 during the 1972/73 season, respectively, as part of routine observations. The abundance of chlorophyll *a* was closely related to water column structure (e.g., temperature and salinity) and macro-nutrients (nitrate, nitrite, silicate, and phosphate).

This report documents the phytoplankton chlorophyll-*a* concentrations, water temperature, salinity, and macro-nutrients measured during a cruise by the icebreaker *Shirase* as part of the JARE-58 during the austral summer of 2016/17. The chlorophyll-*a* concentration was measured in two series: (1) spatial variations in chlorophyll-*a* at the surface water along a cruise track, and (2) vertical profiles of chlorophyll-*a* in the Indian sector of the Southern Ocean. Similar datasets collected previously by JARE have been published in JARE Data Reports (e.g., Takamura *et al.*, 2016)².

2. Study sites

Field sampling was performed from Fremantle to Sydney during the *Shirase* cruise as part of the 58th JARE. Surface waters from the underway pump, of which the inlet was located at a depth of 8–9 m, were sampled twice daily along the cruise track outside of the Exclusive Economic Zone of Australia (Fig. 1). Vertical water sampling was conducted at 10 stations (L1–10) located in meridional transects along 110°E and 150°E (Fig. 1).

3. Materials and methods

3.1. Temperature, salinity, and *in situ* chlorophyll fluorescence

Temperature and salinity of the surface water, collected by the underway pump, were quasi-continuously measured by sensor probes (SBE 38 for temperature and SBE 45 for salinity; Sea-Bird Scientific, Bellevue, WA, USA). *In situ* chlorophyll fluorescence of the same water was measured with a fluorometer (WETStar, ex: 460 nm/em: 695 nm, Sea-Bird Scientific). The sensors were calibrated by Sea-Bird Scientific during the last boreal summer. All sensor data were collected once per minute.

Vertical profiles of temperature and salinity were determined at 10 vertical stations using a conductivity-temperature-depth (CTD) memory probe (SBE19 plus, Sea-Bird Scientific) attached to a water sampler with six 4-L bottles (SBE 55 ECO, Sea-Bird Scientific). The data were downloaded from the CTD to a laptop computer immediately after each cast. The CTD sensor was calibrated by

Sea-Bird Scientific during the last boreal summer. The salinity data in this report were not corrected by the bottle salinity data measured by the salinometer.

3.2. Chlorophyll *a*

Surface seawater was collected twice daily (day and night without the midnight sun) during the cruise from water that was continuously pumped through the vessel from an intake in the hull. Surface seawater was collected using a plastic bucket at stations where vertical water sampling was performed. Vertical water samples were collected over the upper 100 m of the water column using six Niskin bottles attached to the water sampler. The water samples were collected in two dark bottles (ca. 300 mL) for bulk measurements using glass-fiber filter (Whatman, GF/F) and size-fractionated measurements to determine the phytoplankton size composition using membrane filters (pore size: 10 and 2 μm) and a Whatman GF/F. The filters were immediately soaked in N, N-dimethylformamide (Suzuki and Ishimaru, 1990)³, and the pigments were extracted for more than 24 hours. The samples were stored (-18°C) until onboard analysis. Concentrations of chlorophyll-*a* were determined fluorometrically (Welschmeyer, 1994)⁴ with an onboard fluorometer (10-AU; Turner Design, Sunnyvale, CA, USA). The fluorometer was calibrated against a chlorophyll-*a* standard (Fujifilm Wako Pure Chemical Corp., Osaka, Japan) at a laboratory on-land before the cruise, using a spectrophotometer and the specific absorption coefficient of chlorophyll *a* (Porra *et al.*, 1989)⁵. The fluorometer calibration results are shown in [Fig. 2](#). The fluorescence of all samples was higher than the minimum fluorescence during calibration (0.302).

3.3. Macro-nutrients

Seawater to determine macro-nutrient contents was collected at the time when seawater was sampled for chlorophyll *a*. The sampled water was stored (-18°C) until analysis in a land laboratory. The analytical method after melting the frozen samples was performed according to (Shimada *et al.*, 2020)⁶. The coefficients of variation calculated from five replicates of nitrate, nitrite, silicate, and phosphate were 0.18%, 0.29%, 0.16%, and 0.13%, respectively.

3.4 Photosynthetically active radiation

Photosynthetically active radiation (PAR) was measured at the sea surface using a Pocket-size PAR logger (DEFI-L, JFE Advantech Co., Ltd., Tokyo, Japan) mounted on the navigation bridge deck of the ship. The logger has a detection limit and accuracy of $0.2 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $\pm 4.0\%$ ($0\text{--}2000 \mu\text{mol m}^{-2} \text{s}^{-1}$), respectively.

4. Data records

[Figures 3a](#) and [3b](#) present the vertical profiles of water temperature and salinity. [Figures 4a](#) and [4b](#) present the vertical profiles of chlorophyll-*a* concentration and size composition. [Figures 5–8](#) present the vertical profiles of the macro-nutrients. [Figures 9–12](#) present temperature, salinity, and chlorophyll fluorescence according to the underway monitoring sensors and PAR at the sea surface. [Figures 13–16](#) present chlorophyll-*a* concentrations, size composition, and macro-nutrients of the water collected from the underway pump. All measurements are presented in three data files, named “JARE58_CTD”, “JARE58_Ch&Nuts”, and “JARE58_Underway_sensors”. The fields in the datasheets in the three files are:

CTDPRS – Pressure (dbar) of the data collected

CTDTMP – Temperature (°C)

CTDCND – Conductivity (s/m)

CTDSAL – Salinity

THETA – Potential temperature (°C)

SIGT – Sigma-t (kg m^{-3})

CRUISE – Cruise code of the vessel

SHIP – Name of the ship on which the sampling was conducted

STNNBR – Name of the station on which the sampling was conducted

DATE – Sampling date

TIME – Sampling time (UTC)

LATITUDE – Decimal latitude of the sampling station (negative value for South)

LONGITUDE – Decimal longitude of the sampling station (positive value for East)

DEPTH – Sampling depth (m)

SIG0 – Sigma- θ (kg m^{-3})

CHL BULK – Total chlorophyll-*a* concentration ($\mu\text{g l}^{-1}$)

CHL 10UM – Composition of chlorophyll-*a* in the $>10 \mu\text{m}$ fraction (%)

CHL 2UM – Composition of chlorophyll-*a* in the $2\text{--}10 \mu\text{m}$ fraction (%)

CHL GF/F – Composition of chlorophyll-*a* in the $< 2 \mu\text{m}$ fraction (%)

NITRAT – Nitrate concentration ($\mu\text{mol l}^{-1}$ or $\mu\text{mol kg}^{-1}$)

NITRIT – Nitrite concentration ($\mu\text{mol l}^{-1}$ or $\mu\text{mol kg}^{-1}$)

SILCAT – Silicic acid concentration ($\mu\text{mol l}^{-1}$ or $\mu\text{mol kg}^{-1}$)

PHSPHT – Phosphate concentration ($\mu\text{mol l}^{-1}$ or $\mu\text{mol kg}^{-1}$)

FLUOR – Chlorophyll fluorescence determined by a sensor ($\mu\text{g l}^{-1}$)

PAR – Photosynthetically active radiation ($\mu\text{mol m}^{-2} \text{s}^{-1}$) at the sea surface

5. Author contributions

R. Makabe processed and analyzed the samples and wrote the manuscript. T. Odate and K.T. Takahashi directed the monitoring program. S. Takao carried out the nutrient analysis in the land laboratory and analyzed the sensor data.

6. Competing interests

The authors declare no competing financial interests.

7. Figures

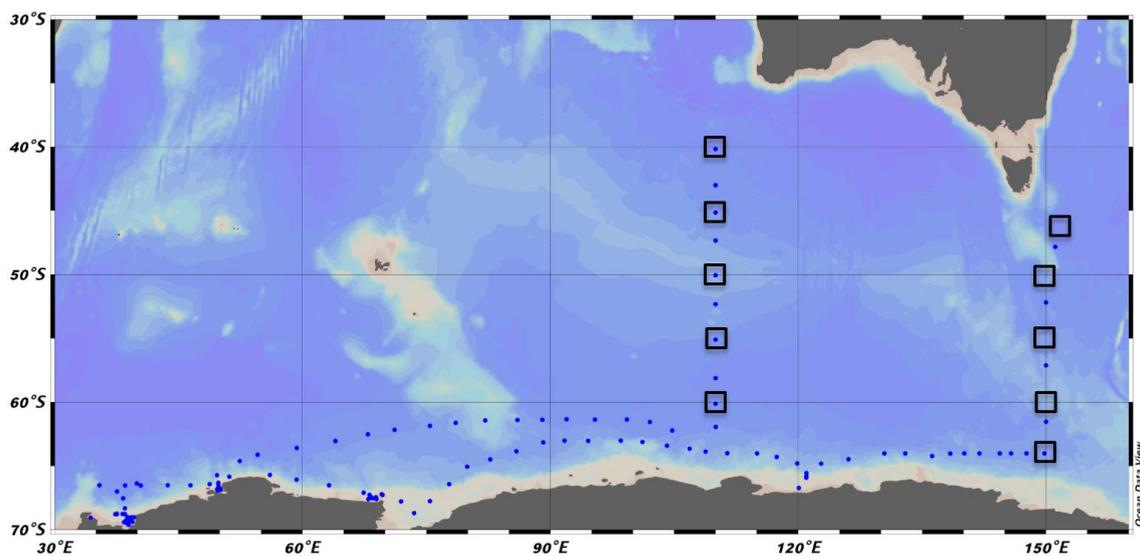


Fig. 1. Location of the sampling sites during the JARE-58 cruise. Open squares and blue circles indicate the vertical and underway sampling stations, respectively.

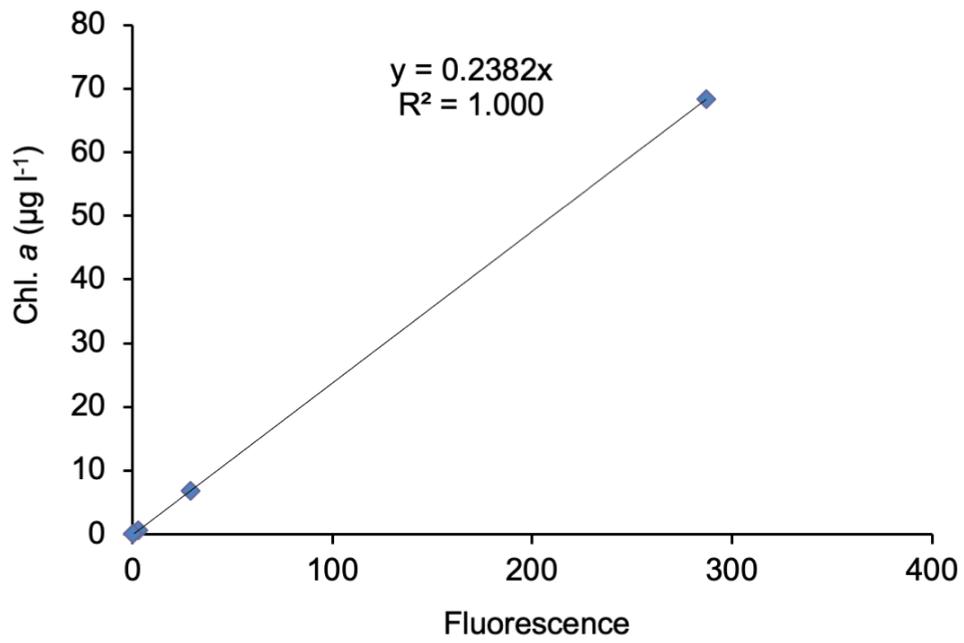


Fig. 2. Correlation between chlorophyll-*a* and fluorescence during calibration of the fluorometer.

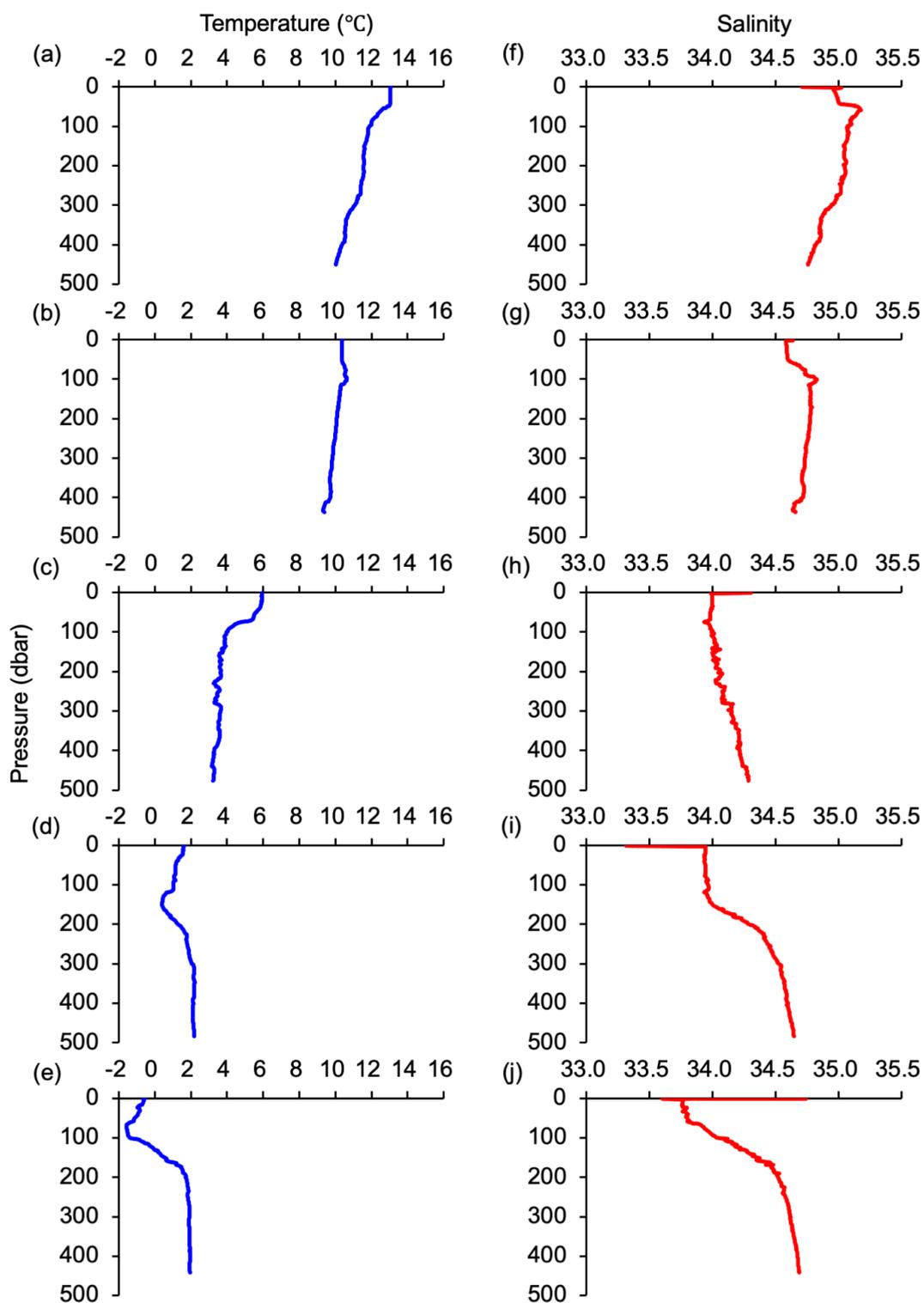


Fig. 3a. Vertical profiles of temperature and salinity at L01 (a, f), L02 (b, g), L03 (c, h), L04 (d, i), and L05 (e, j) along 110°E during December 2016.

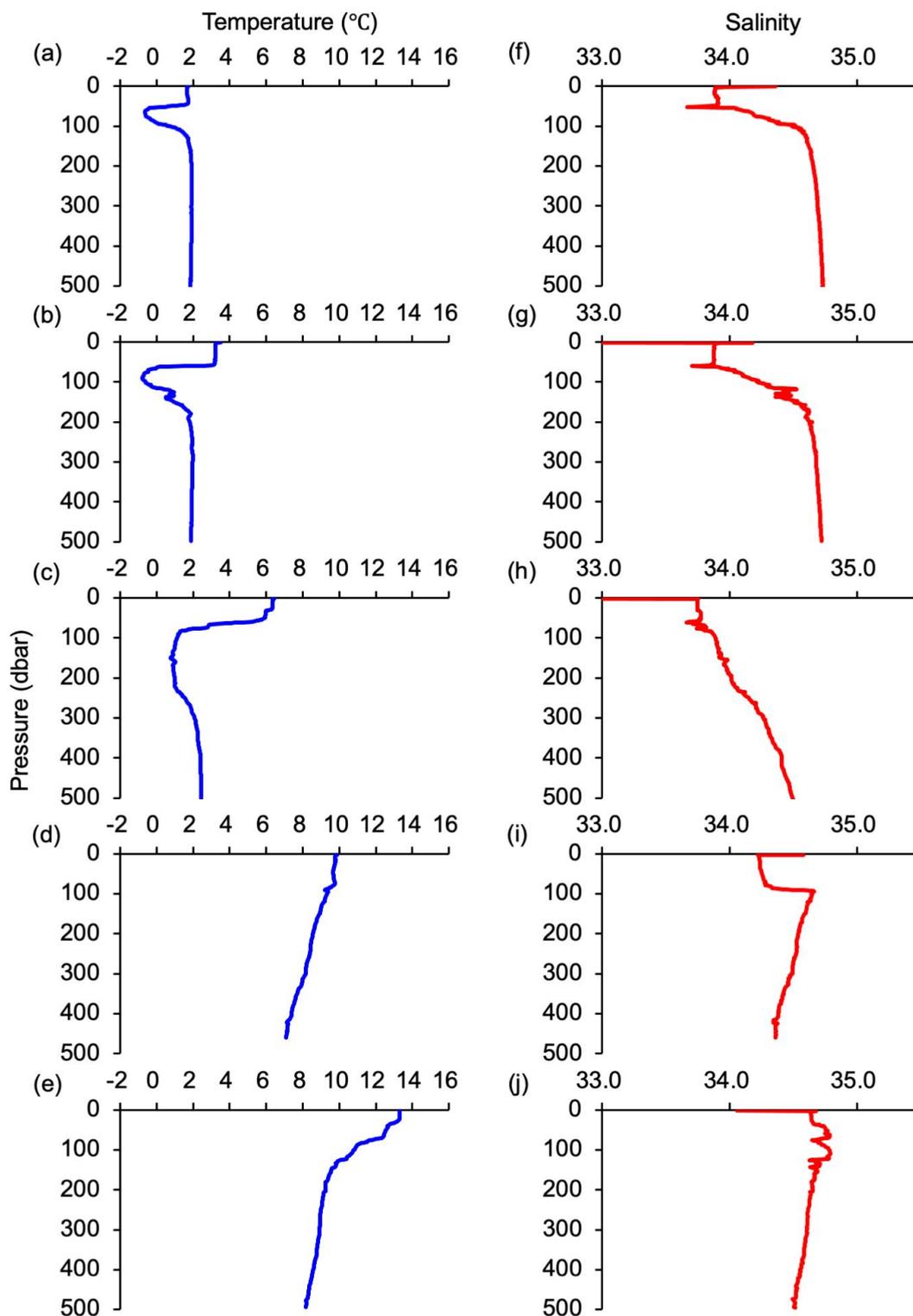


Fig. 3b. Vertical profiles of temperature and salinity at L06 (a, f), L07 (b, g), L08 (c, h), L09 (d, i), and L10 (e, j) along 150°E during March 2017.

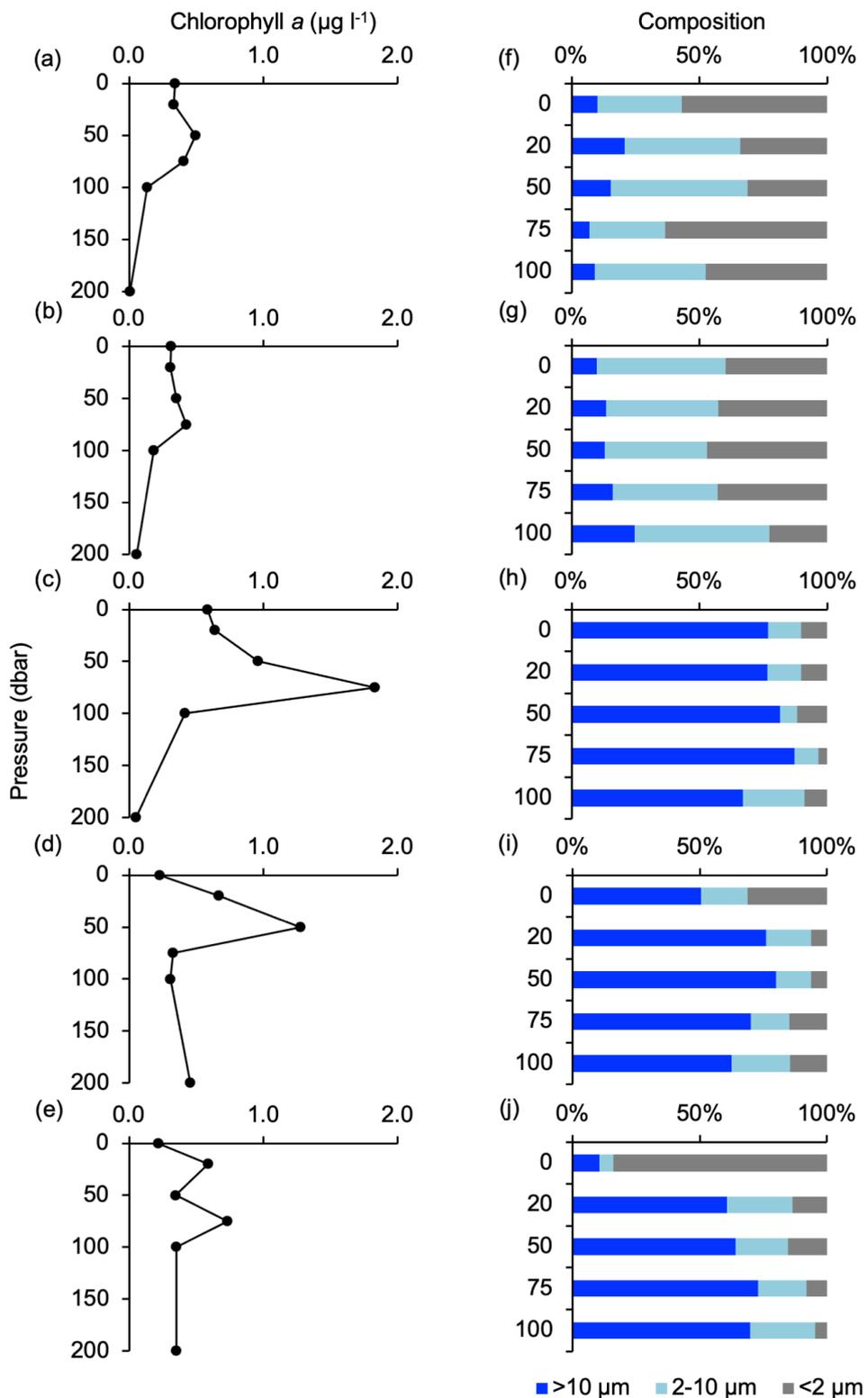


Fig. 4a. Vertical profiles of chlorophyll-*a* and the size composition at L01 (a, f), L02 (b, g), L03 (c, h), L04 (d, i), and L05 (e, j) along 110°E during December 2016.

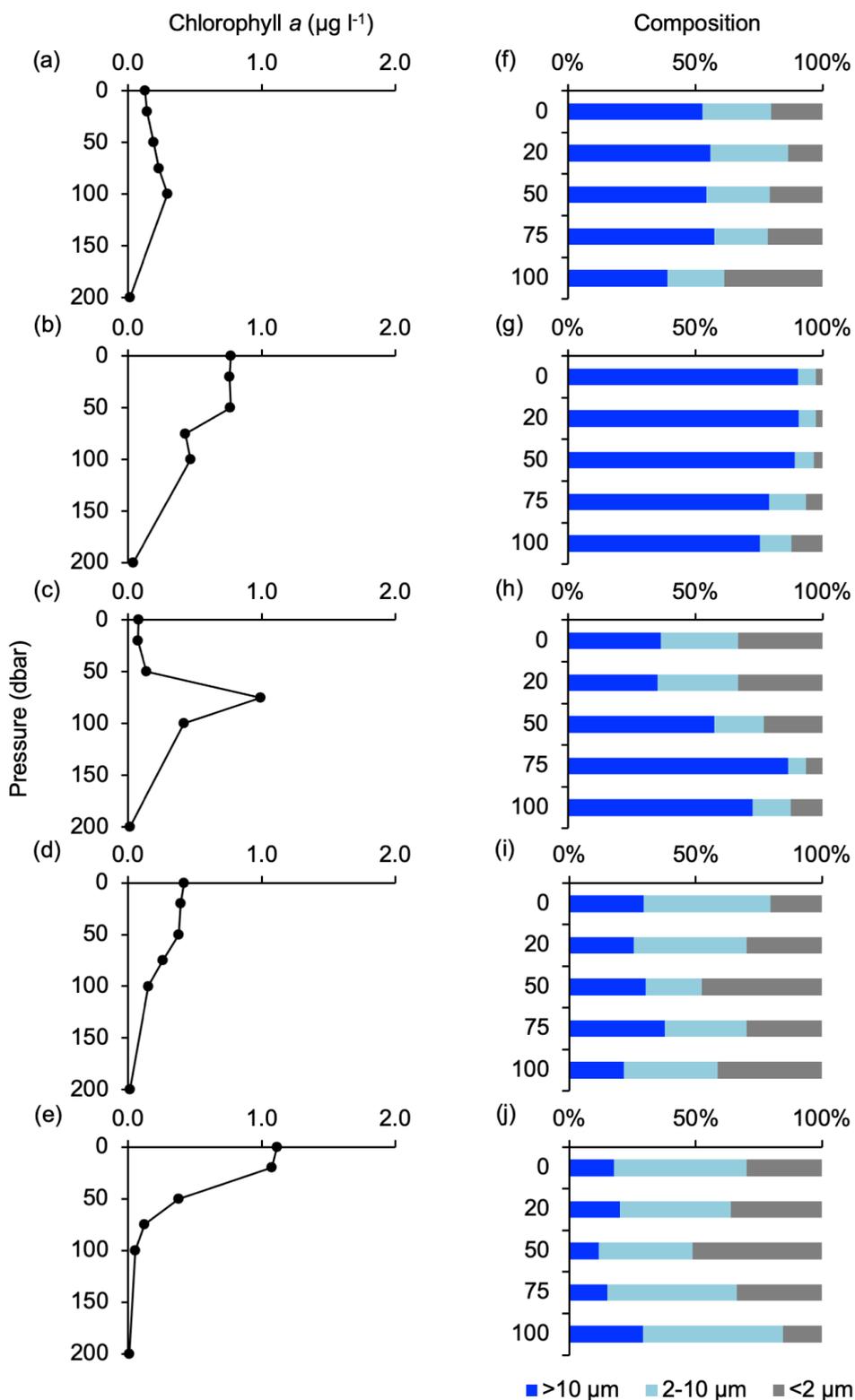


Fig. 4b. Vertical profiles of chlorophyll-*a* and the size composition at L06 (a, f), L07 (b, g), L08 (c, h), L09 (d, i), and L10 (e, j) along 150°E in March 2017.

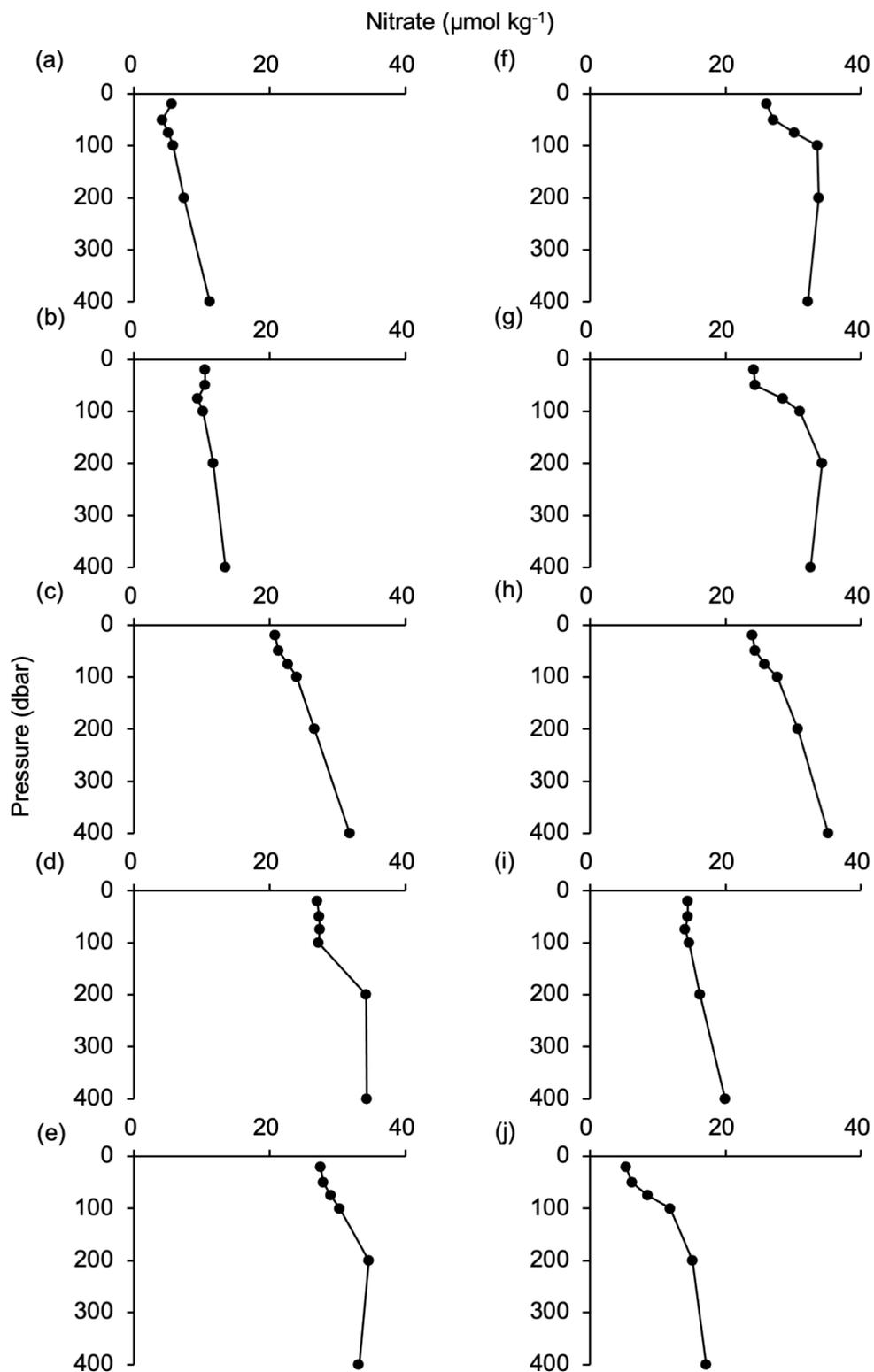


Fig. 5. Vertical profiles of nitrate at L01–L10 (a–j).

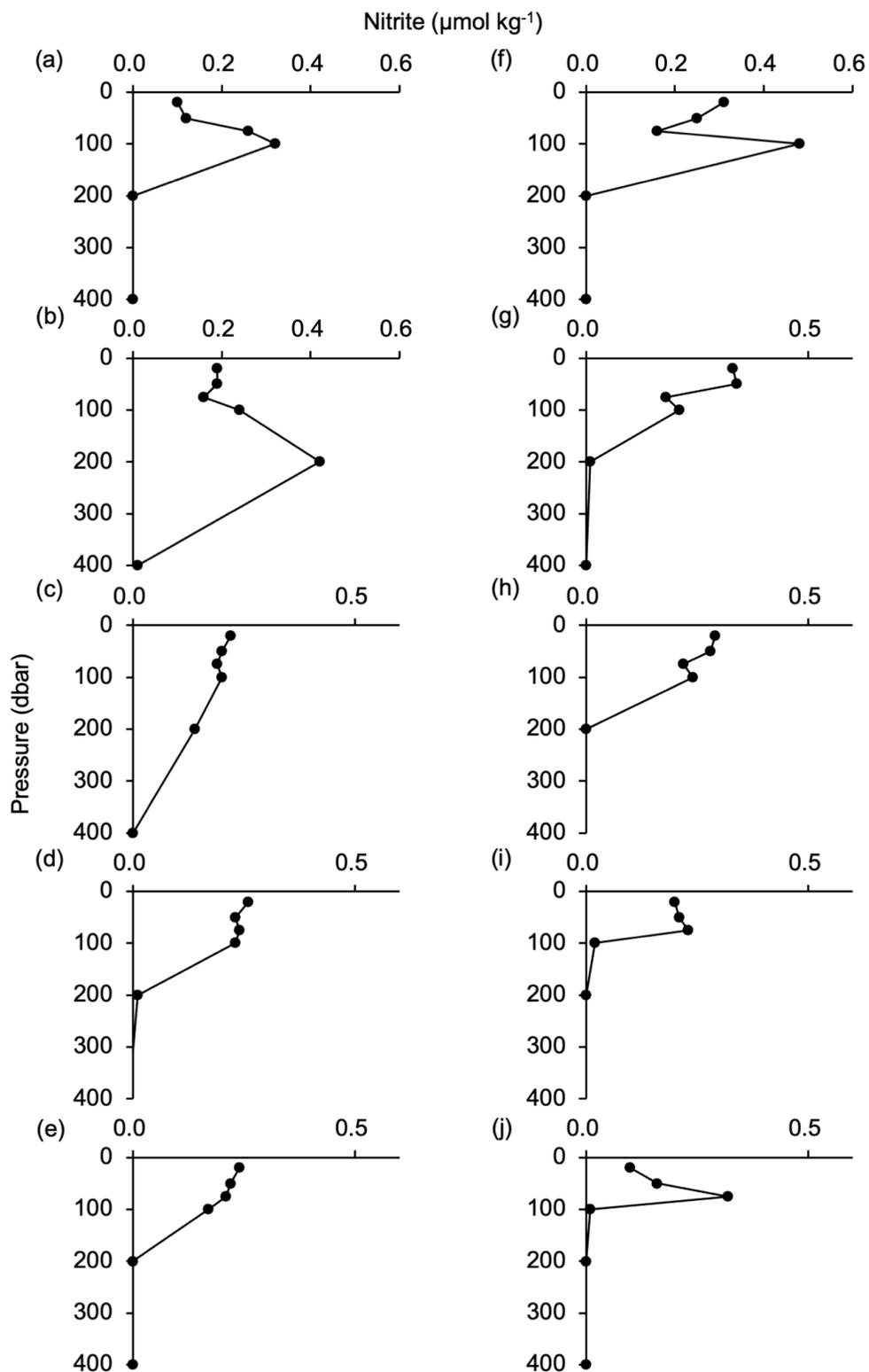


Fig. 6. Vertical profiles of nitrite at L01-L10 (a-j).

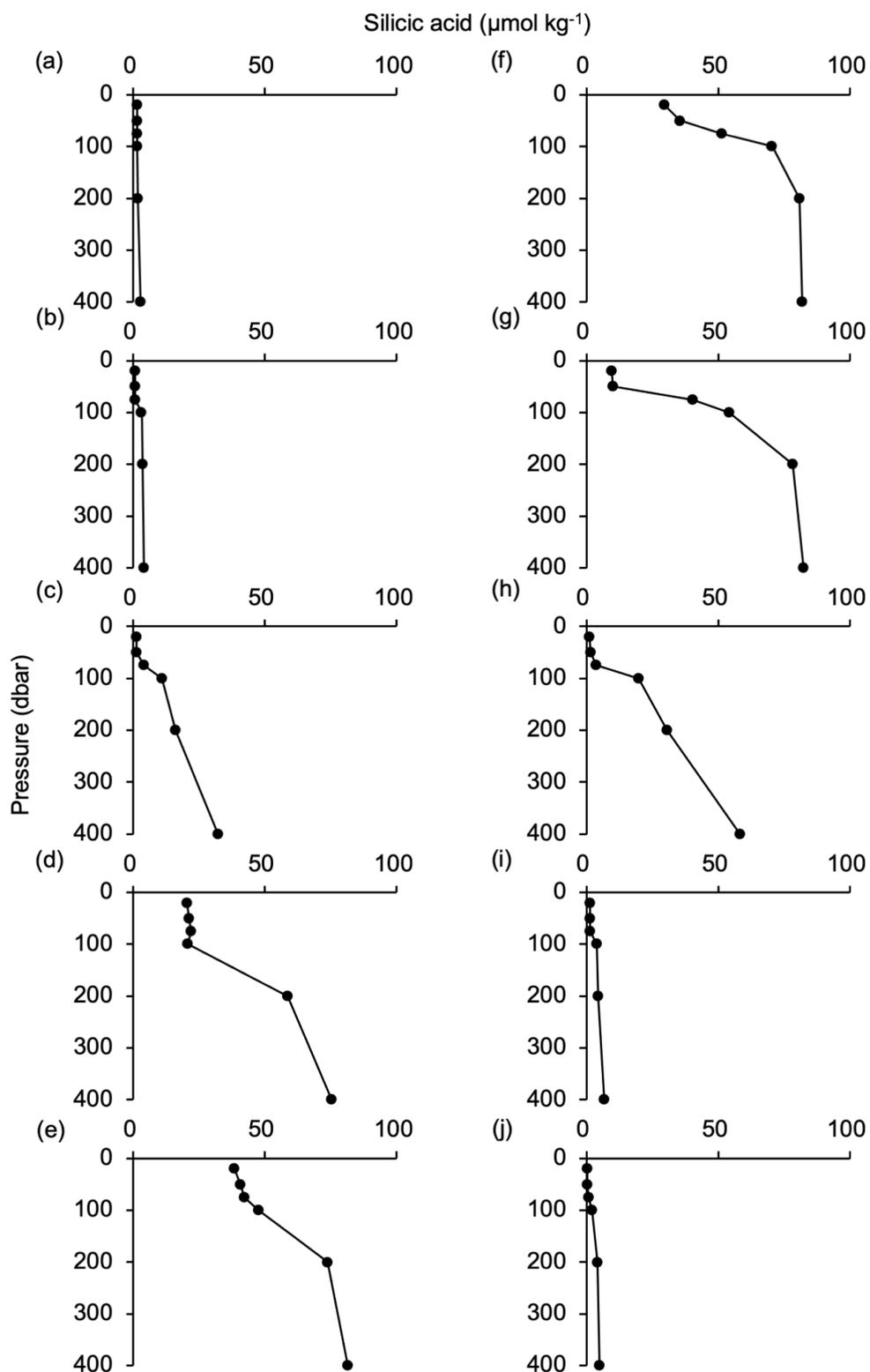


Fig. 7. Vertical profiles of silicic acid at L01-L10 (a-j).

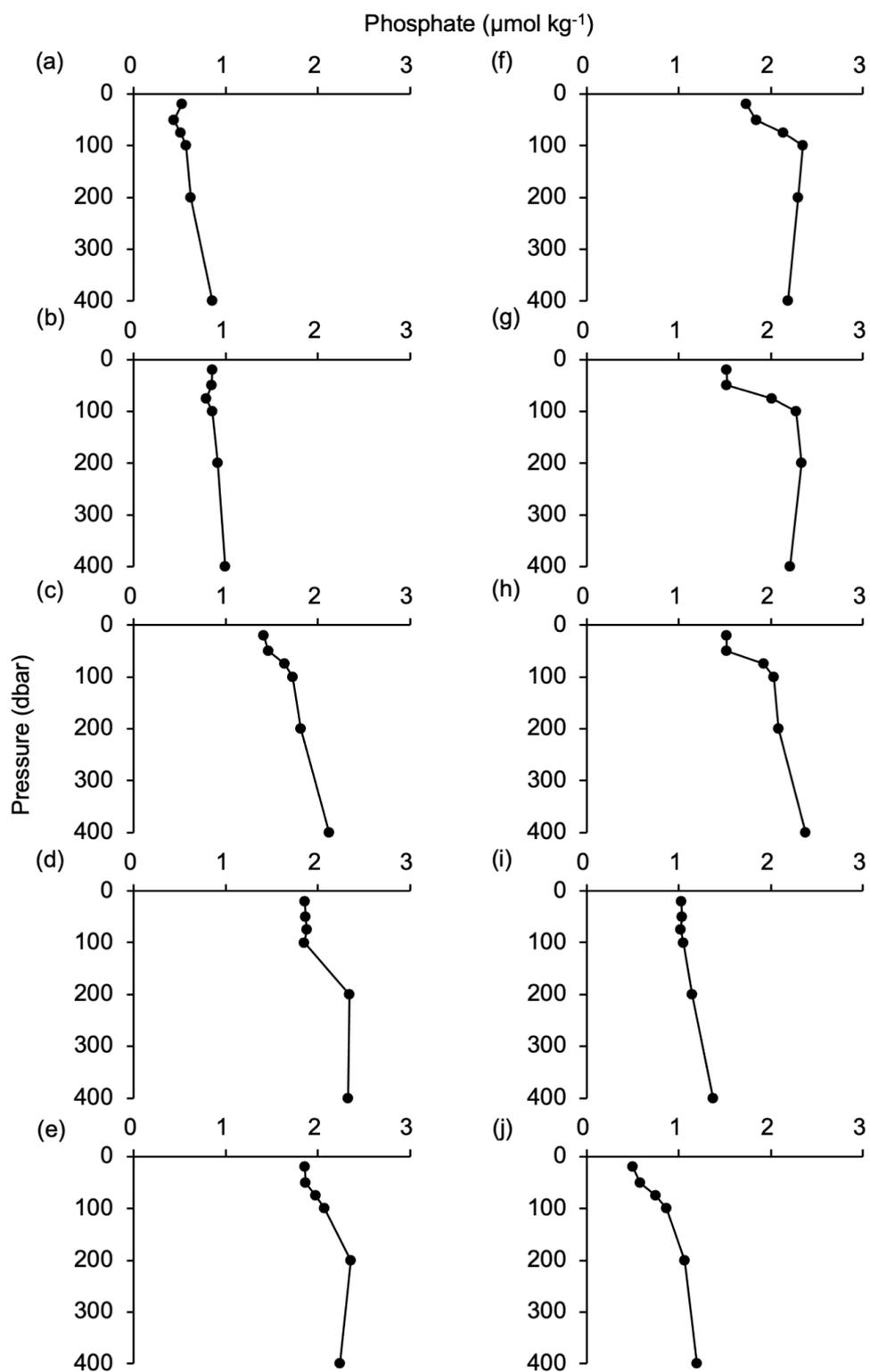


Fig. 8. Vertical profiles of phosphate at L01–L10 (a–j).

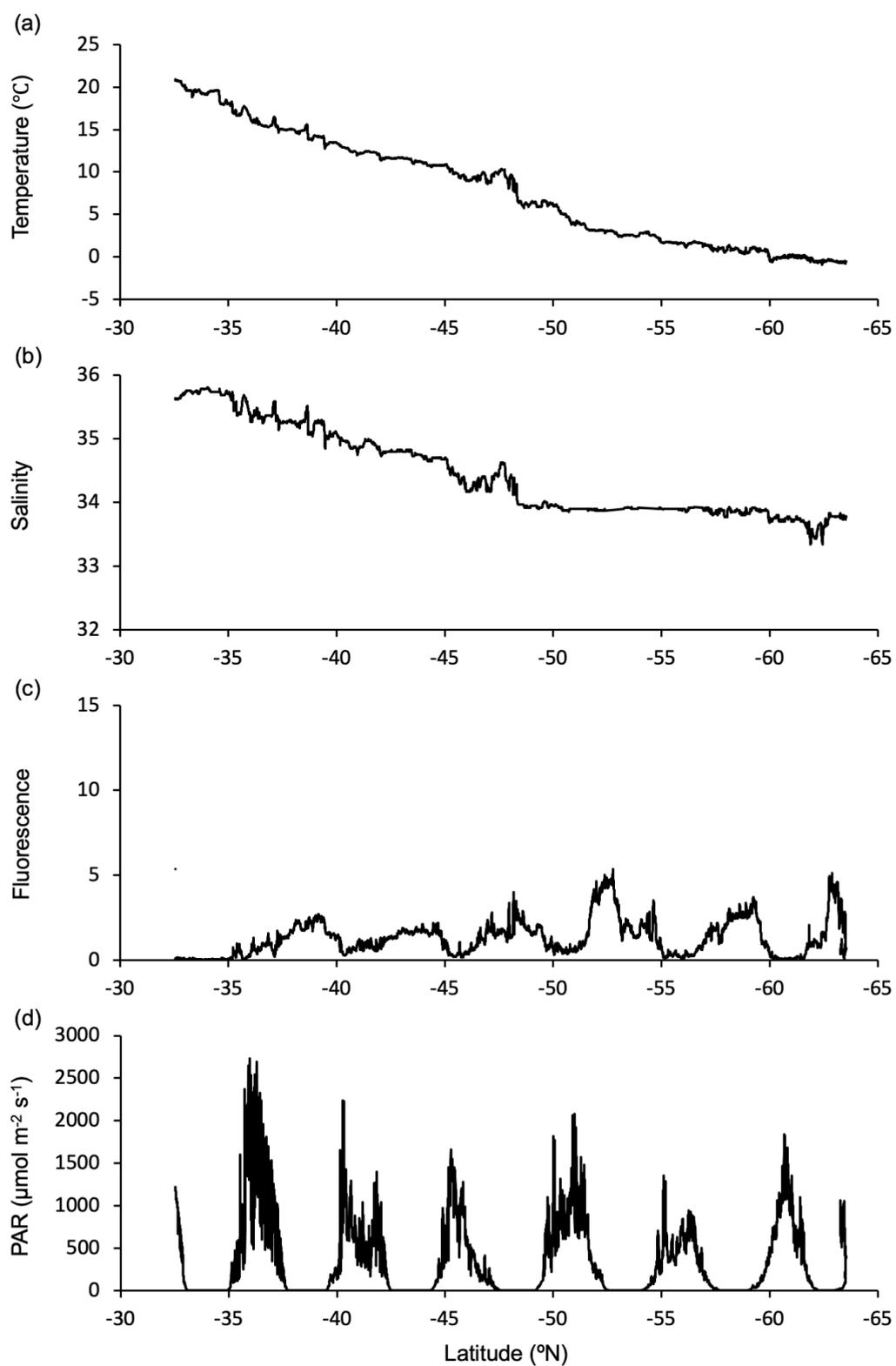


Fig. 9. Surface temperature (a), salinity (b), *in situ* fluorescence (c), and PAR (d) along 110°E during December 2016.

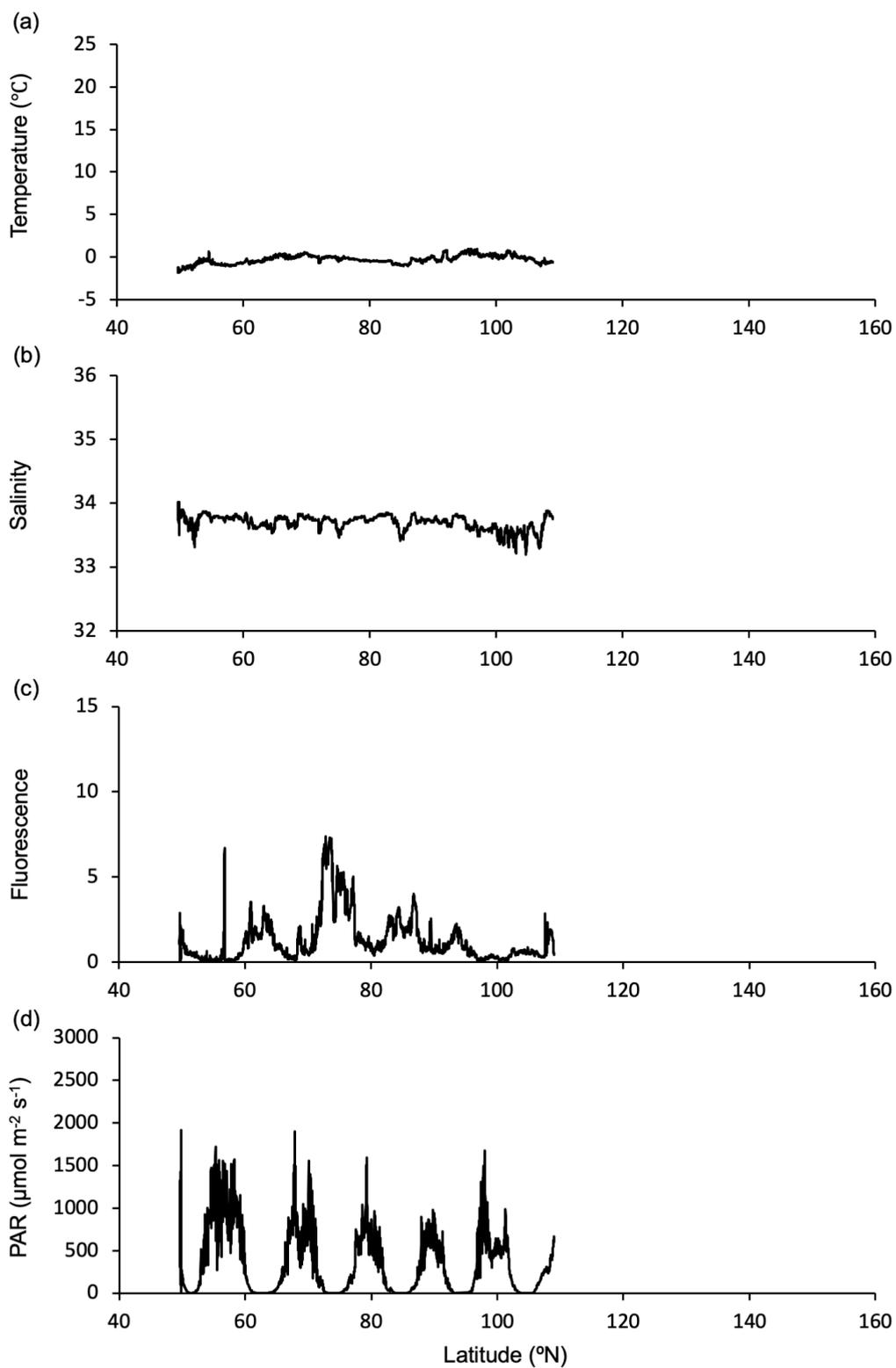


Fig. 10. Surface temperature (a), salinity (b), *in situ* fluorescence (c), and PAR (d) during L05 at the Syowa station section.

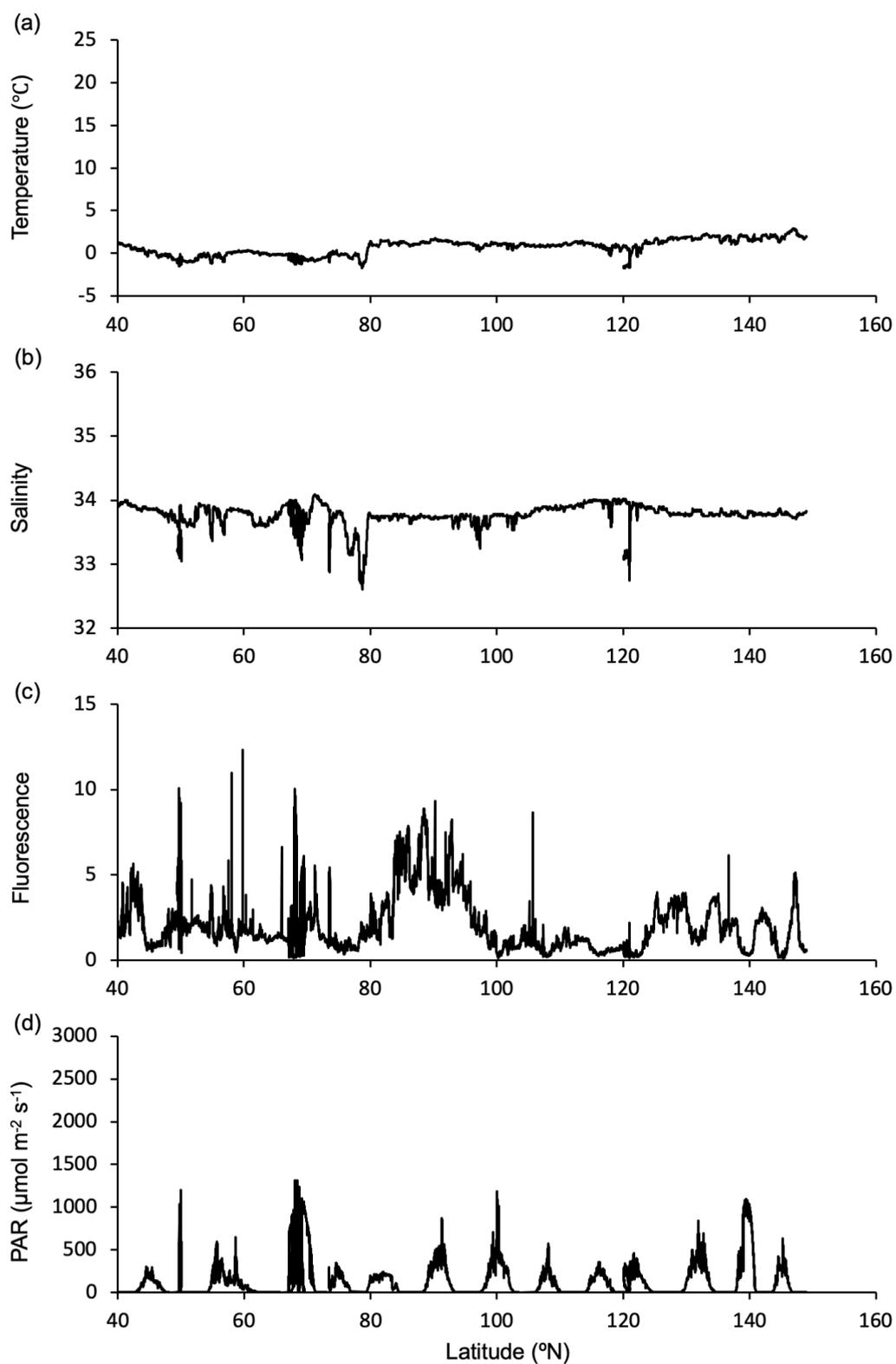


Fig. 11. Surface temperature (a), salinity (b), *in situ* fluorescence (c), and PAR (d) during Syowa station to L06 section.

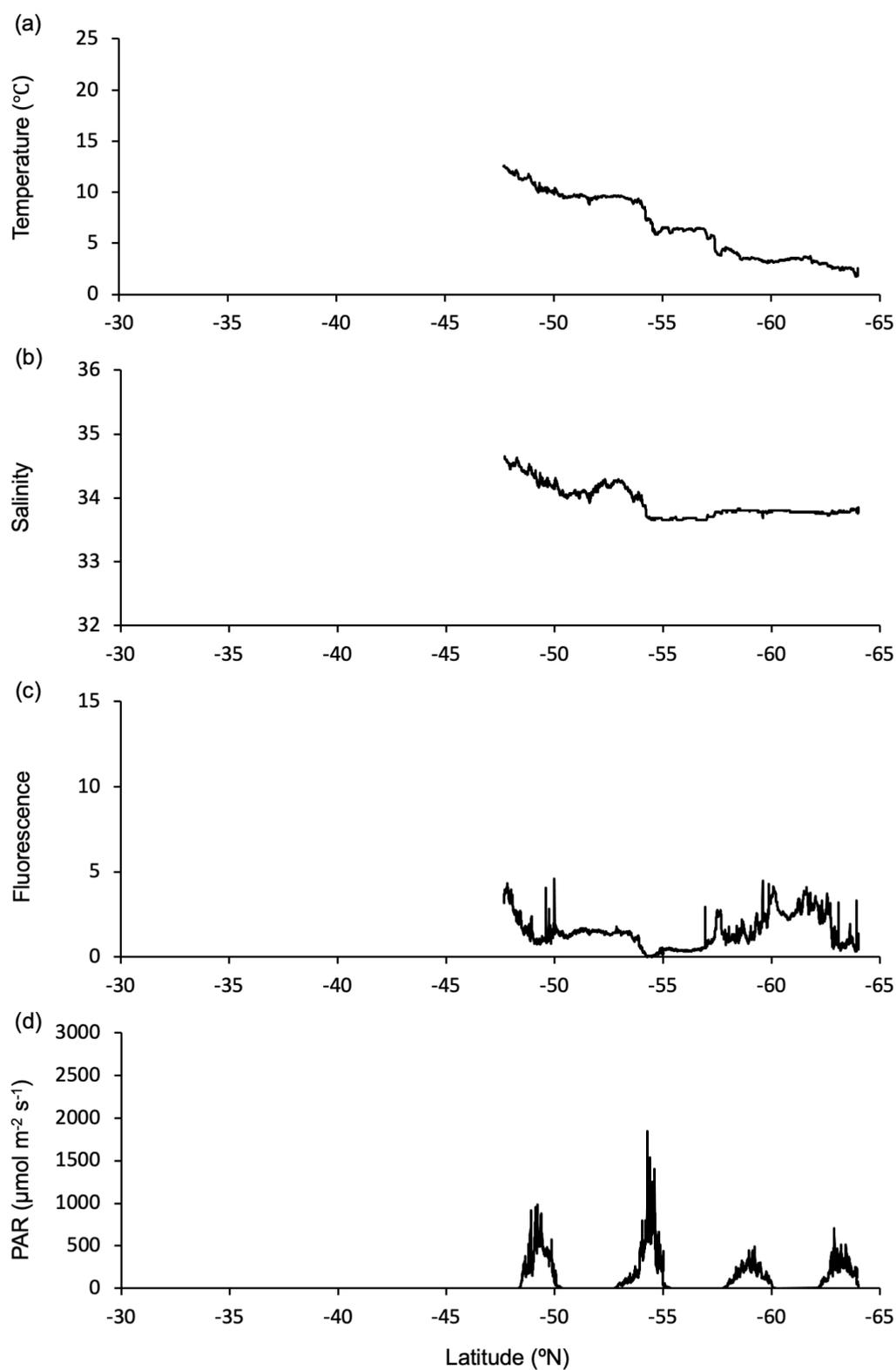


Fig. 12. Surface temperature (a), salinity (b), *in situ* fluorescence (c), and PAR (d) along 150°E during March 2017.

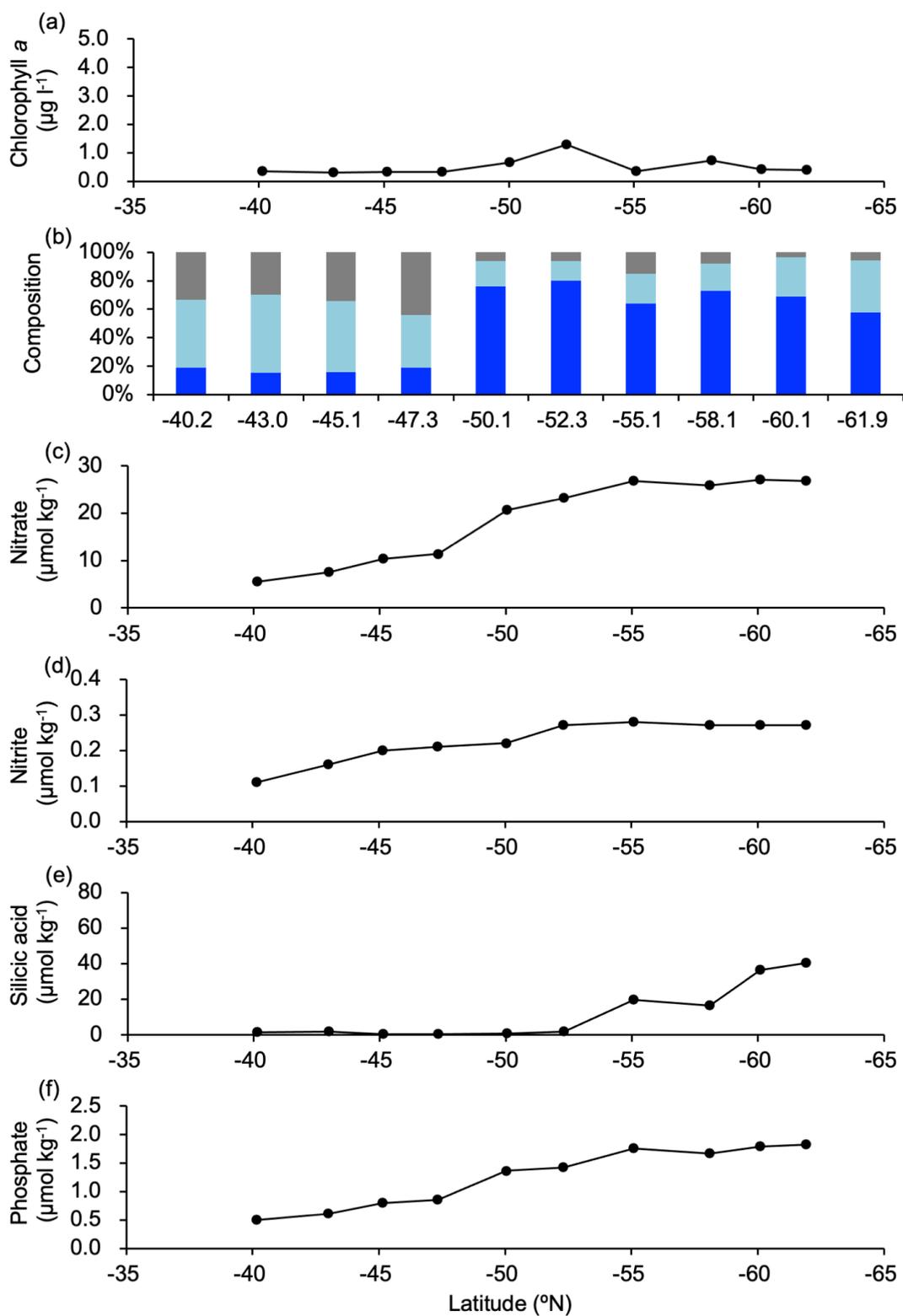


Fig. 13. Surface chlorophyll-*a* concentration (a), the size composition (b), and macro-nutrient concentrations (c–f) along 110°E during December 2016.

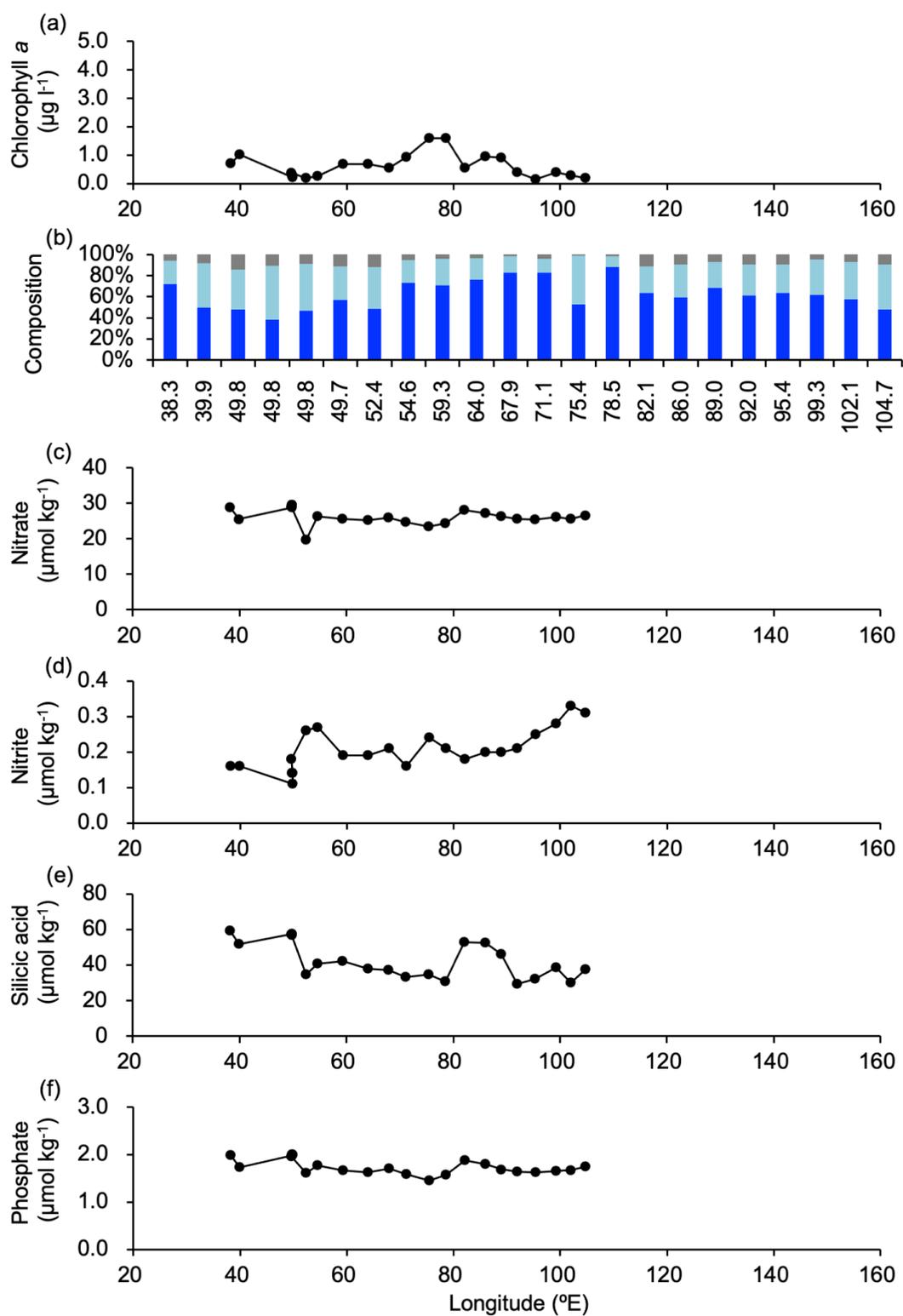


Fig. 14. Surface chlorophyll-*a* concentration (a), the size composition (b), and macro-nutrient concentrations (c–f) at L05 to the Syowa station section.

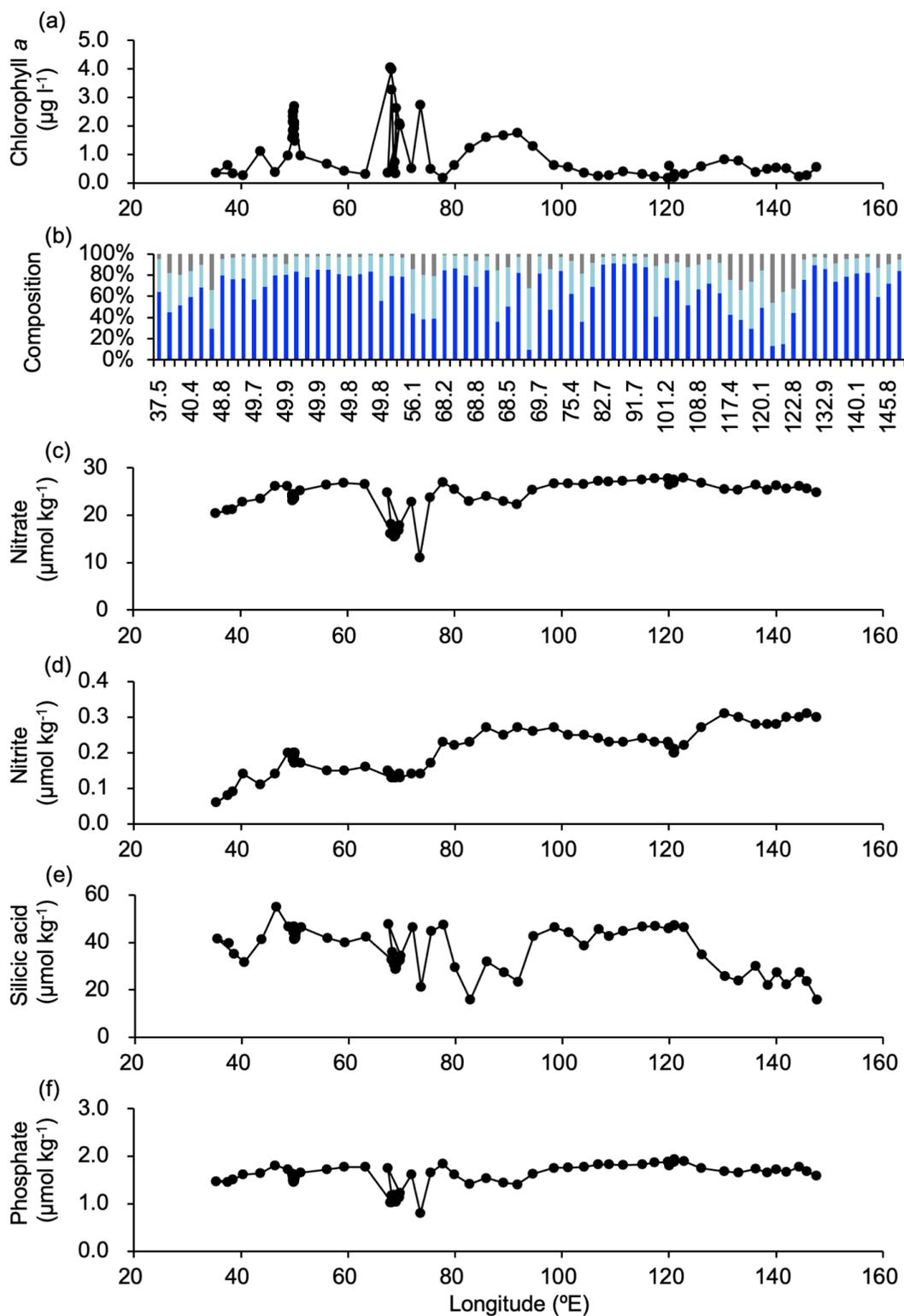


Fig. 15. Surface chlorophyll-*a* concentration (a), the size composition (b), and macro-nutrient concentrations (c–f) at the Syowa station to the L06 section.

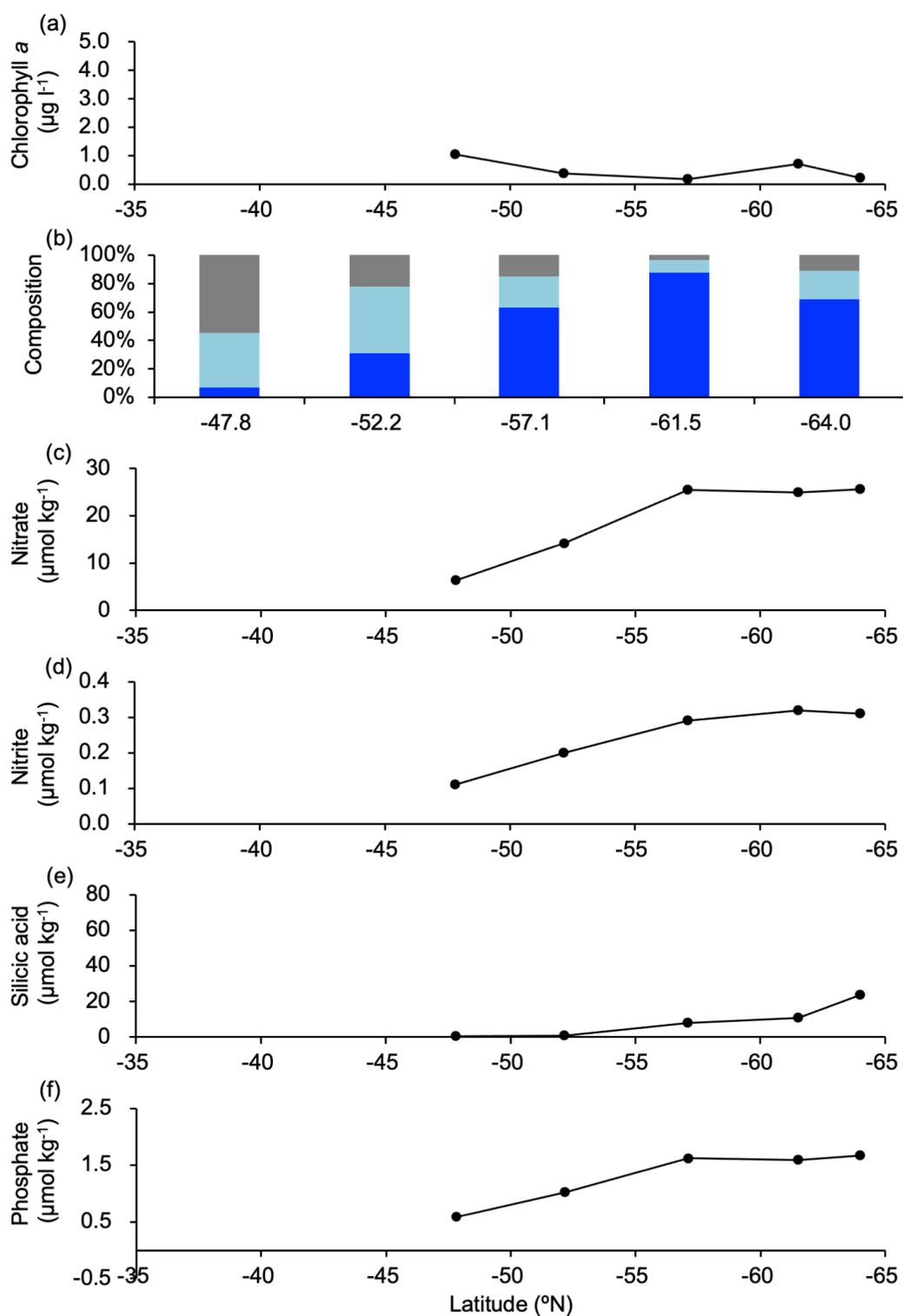


Fig. 16. Surface chlorophyll *a* concentration (a), size composition (b), and macro-nutrient concentrations (c–f) along 150°E during March 2017.

8. Table

Table 1. Dates and locations of the 10 stations.

Station	Date (UTC)	Time (UTC)	Latitude (DEG N)	Longitude (DEG E)
L01	04/12/2016	0:57	-40.15344	109.99729
L02	05/12/2016	0:55	-45.13812	109.99688
L03	06/12/2016	0:59	-50.04690	109.99577
L04	07/12/2016	0:59	-55.07686	109.98606
L05	08/12/2016	0:59	-60.10358	109.98838
L06	12/03/2017	21:53	-63.91445	149.99754
L07	13/03/2017	21:58	-59.85861	149.98121
L08	14/03/2017	21:58	-54.97263	150.01020
L09	15/03/2017	21:56	-50.01308	150.00326
L10	16/03/2017	21:51	-45.97918	152.01033

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Data Citations

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