Phytoplankton biomass, P-I relationships and primary production in the Weddell Sea, Antarctica, during the austral autumn

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Abstract An investigation into the changing phytoplankton biomass and total water column production during autumn sea ice formation in the eastern Weddell Sea, Antarctica showed reduced biomass concentrations and extremely low daily primary production. Mean chlorophyll-a concentration for the entire study period was extremely low, 0.15 ± 0.01 mg.m⁻³ with a maximum of 0.35 mg.m⁻³ found along the first transect to the east of the grid. Areas of low biomass were identified as those either associated with heavy grazing or with deep mixing and corresponding low light levels. In most cases phytoplankton in the < 20-μm size classes dominated. Integrated biomass to 100 m ranged from 7.1 to 28.0 mg.m⁻² and correlated positively with surface chlorophyll-a concentrations. Mean $P_{B_{\text{max}}}$ (photosynthetic capacity) and $z^b$ (initial slope of the photosynthesis-irradiance curve) were 1.25 ± 0.19 mgC.mgChl a⁻¹.h⁻¹ and 0.042 ± 0.009 mgC.mgChl a⁻¹.h⁻¹.(btmol.m⁻².s⁻¹)⁻¹ respectively. The mean index of photoadaptation, $I_k$, was 32.2 ± 4.0 μmol.m⁻².s⁻¹ and photoinhibition was found in all cases. Primary production was integrated to the critical depth ($Z_{cr}$) at each production station and ranged from 15.6 to 41.5 mgC.m⁻².d⁻¹. It appears that, other than grazing intensity, the relationship between the critical depth and the mixing depth ($Z_{mix}$) is an important factor as, ultimately, light availability due both to the late season and growing sea ice cover severely limits production during the austral autumn.

Introduction

Satellite remote sensing is the only practical method of estimating ocean primary production on a global scale. Algorithm development to interpret remotely sensed images depends on data relating the optical properties of the water column to phytoplankton community structure, production and physiology. Bio-optical provinces may then be set for the simplification of ocean systems based on their predictability and bio-physical characteristics. Insight into phytoplankton production is also important for trophodynamics, investigating carbon flux in the oceans and in particular...
the absorption of CO₂ from the atmosphere. The seasonal variation in production and in the light environment must be well understood for effective interpretation of year-round remotely sensed data and the establishment of bio-optical provinces.

Phytoplankton biomass is highly variable seasonally in both Arctic and Antarctic ecosystems. Summer chlorophyll-a concentrations in both systems may vary from <1 mg.m⁻³ to more than 25 mg.m⁻³ under exceptional bloom conditions. Winter concentrations are consistently <1 mg.m⁻³ (Whittaker 1982; El-Sayed 1984; Smith 1987; Brightman and Smith 1989). Recent estimates of total global oceanic primary production range from 31 gigatons C yr⁻¹ (Tréguer and van Bennekum 1991) to 51 gigatons C yr⁻¹ (Martin et al. 1987; Knauer 1993). The Antarctic marginal ice zone and ice edge are relatively unproductive, making up about 4% of the surface area of the world’s oceans but producing less than 1% of the total production, most of which takes place during 5 months of the year only (Smith et al. 1988; Tréguer and van Bennekum 1991).

At the ice edge, increased water-column stability due to ice melt in early summer is thought to enhance phytoplankton production and, as a result, high standing crops (> 5 mg.m⁻³) are found in the marginal ice zone (MIZ). Zooplankton grazing and an increase in wind stress leading to deep mixing are usually responsible for the often rapid decline of these spatially and temporarily patchy blooms in late summer and primary production is effectively retarded for most of the year.

Decreased irradiance and daylength, low ambient temperatures and, in some cases, suboptimal trace metal concentrations (e.g. iron) have also been considered to be limiting factors throughout autumn, winter and early spring (Jacques 1983; Harrison and Platt 1986; de Baar et al. 1990; Martin et al. 1990; Tilzer 1994). Ambient light varies between less than 1 mol.m⁻².d⁻¹ south of 65°S in the winter to over 70 mol.m⁻².d⁻¹ in the same area during summer (Bishop and Rossow 1991). Photoperiod varies from 0 h in winter to 24 h in mid-summer and low ambient temperatures limit growth all year round (Neori and Holm-Hansen 1982; Tilzer et al. 1985; Sakshaug and Sæstad 1991).

During ice formation in late autumn motile algal species may actively enter the ice while other species may be scavenged during ice crystal formation and then entrained into the surface ice layer. Both processes result in diminished water column concentrations of phytoplankton (Ackley 1982; Garrison et al. 1983; Horner et al. 1988; Syverson and Kristiansen 1993; Gleitz et al. 1994). Ice formation during autumn may occur in varying ways under different physical conditions: as ambient temperatures decrease, a thin surface layer of “grease ice” is formed, or, if windy conditions prevail, small “pancakes” of ice are formed, which grow larger and fuse with one another or become rafted during strongly convergent ice conditions (Ackley 1982; Garrison et al. 1983; Lange et al. 1989). In both instances cells are entrapped in the ice and thereby removed from the water column.

Plankton dynamics during winter conditions in the Southern Ocean are relatively poorly understood owing mainly to prohibitive weather conditions and extensive ice cover that restricts access to most survey vessels, particularly close to the Antarctic shelf. Nevertheless, production studies for this region during autumn and winter need to be made to enhance our understanding of the seasonal role of the Southern Ocean in terms of primary production and as a potential sink for atmospheric CO₂.

The aim of the (ANT X/3) cruise of the RV Polarstern in April–May of 1992 was to investigate the onset of sea ice formation and its effect on biological activity both within the ice as well as in the underlying water column. Here we investigate the changing biomass of phytoplankton in relation to the hydrographic conditions prevailing during sea ice formation. Integrated water column production was calculated using parameters derived from photosynthesis-irradiance (P-I) experiments.

Materials and methods

Study area and hydrography

Five oceanographic (physical and biological) transects and a single physical transect arranged in a grid pattern were carried out during the third leg of the tenth Antarctic expedition of RV Polarstern, which took place during the austral autumn (6 April–6 May) of 1992 (Fig. 1). The grid was located between latitudes 67° 30’S and 71° 30’S and longitudes 4°W and 12°W and designed to provide repeated crossings of the Antarctic slope front (ASF) (Jacobs 1991) and the marginal ice zone (MIZ), covering a total area of 65 x 10⁴ km². Temperature, salinity and fluorescence profiles to a maximum depth of 500 m were determined at 55 stations using a ‘BIOROSI’ equipped with twelve 15-l Niskin bottles, a CTD (ME 98) and a fluorometer. Water samples were collected from the Niskin bottles (triggered at standard depths: 0, 10, 20, 30, 50, 70, 100, 150, 200, 250, 500 m) and analysed for O₂, CO₂/alkalinity, nutrient, chlorophyll-a and particulate organic carbon and nitrogen (POC and PON). In addition to the Bi-Rosette, a CTD (Bathysonde LS200 of Salzgitter Elektronik) was used for the hydrographic profiles carried out at the same stations as the biological work.

A Secchi disc was used to estimate underwater light attenuation while photosynthetically available radiation (PAR, 400–700 nm) was measured with an Li Cor LI-193SA spherical quantum sensor so that 15-min PAR means were logged throughout the day to a Li Cor LI-1000 Data Logger. Submarine PAR was calculated using various models (Cox and Munk 1956; Brock 1981; Kirk 1983; Campbell and Arrup 1989; Bishop and Rossow 1991) accounting for declination of the sun, zenith angle and reflective losses at the sea surface depending on measured average cloud cover and wind speed (Dentler and Sonnabend 1993).

Chlorophyll-a and primary production

Chlorophyll-a concentrations at standard depths were determined by filtering 2-l samples through 25-mm Whatman GF/F filters that