Primary Productivity in a Cold Water Mass
and the Neighborhood Area Occurring off Enshu-Nada
in the Late Summer of 1989

AKIHIRO SHIOMOTO and SATSUKI MATSUMURA

High Latitudes Oceanography Section, Oceanography and Southern Ocean Resources Division,
National Research Institute of Far Seas Fisheries, Shimizu-Shi, Shizuoka 424, Japan

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Primary productivity off Enshu-nada was measured by the $^{13}$C method in September 1989. Primary productivity was estimated in a cold water mass developed off Enshu-nada for the first time. The obtained value was 469 mgC·m$^{-2}$·d$^{-1}$ and higher than those in the pelagic area of Kuroshio, but equivalent to those in the neritic and the Oyashio areas. It was indicated that cold water mass is the place where organic matter is produced actively. Extremely high chlorophyll $a$ of more than 5 µg·l$^{-1}$ were found in the cold water mass. The high productivity was due to high standing crop of phytoplankton. Furthermore, calculated light efficiency and quantum yield showed consistent increase with depth and showed a maximum at 10% light level. Both were larger on the coastal side than those on the oceanic side of the Kuroshio current.

1. Introduction

The measurements of primary productivity in the sea around the Japan Islands were actively carried out by the $^{14}$C method from the late 1950's to the early 1970's (Ichimura and Saijo, 1959; Saijo and Ichimura, 1960; Aruga and Monsi, 1962; Noda and Ichimura, 1967; Aruga et al., 1968; Aruga and Ichimura, 1968; Saijo et al., 1970; Shimura and Ichimura, 1972, 1973). The results obtained in those days supply the most useful information on primary productivity in the sea near Japan. There have been few measurements of primary productivity since then because the use of $^{14}$C in the natural environment has been strictly restricted in Japan. A stable isotope of carbon, $^{13}$C, has been developed for the determination of primary productivity since the late 1970's (Slawyk et al., 1977; Hama et al., 1983; Kanda et al., 1985a, b; Collos and Slawyk, 1986). However, there are still few data available about primary productivity determined by the $^{13}$C method in Japanese waters (Hama et al., 1983; Kanda et al., 1985b). It is not clear whether the primary productivity has changed over the last few decades. Therefore we began to determine primary productivity by the $^{13}$C method in the sea around the Japan Islands.

Cold water masses often appear off Enshu-nada (Yoshida, 1961; Nitani, 1969; Ishii et al., 1984). There are many studies on the physical aspects for these cold water masses (reviewed by Teramoto, 1972). Information on the effects of the cold water masses on fishery was also evaluated (Uda, 1961; Uehara, 1962; Igarashi and Sawada, 1969). However, there is hardly information on primary productivity in the cold water masses because of the sparse observation points in the past. Therefore, we arranged dense observation points to cover complex water masses off Enshu-nada. A type "N" cold water mass existed off Enshu-nada during the present sampling period (Department of Hydrography, Japan Maritime Safety Agency, 1989). Fortunately, we had a chance to determine primary productivity in the cold water mass.

Light is one of the most important factors controlling primary productivity in the sea. Many
studies on the conversion efficiency of light energy to chemical energy have been carried out in
the laboratory and in the field (e.g. Dubinsky and Berman, 1976; Welschmeyer and Lorenzen,
1981; Priscu, 1984; Laws et al., 1990). However, there have been few studies in Japanese waters
(Taguchi et al., 1977; Kishino et al., 1986; Takahashi et al., 1989). Therefore, we measured light
in the air and water simultaneously and calculated the light utilization efficiency and quantum
yield.

2. Materials and Methods
All samplings were conducted at stations off Enshu-nada during a cruise of the RV Shunyo
Maru (393.44 t) of the National Research Institute of Far Seas Fisheries, from September 1 to 16,
1989 (Fig. 1).
Primary productivity was measured by the simulated in situ methods using a $^{13}$C-technique
(Hama et al., 1983). Samples were taken from five depths corresponding to 100, 50, 30, 10 and
1% photon fluxes just above the sea surface, with a submersible pump (Terada ER-25B). To
determine the depths corresponding to these light levels, photon flux densities in the water
column were measured after the ship arrived at each station using a flat quantum sensor (Li Cor
model 1000). Subsamples (2 liters) were immediately sieved through a 200 μm mesh screen in
order to remove large zooplankton and dispensed into 2-1 polycarbonate bottles (two light bottles
and one dark bottle). Light was attenuated with a combination of black mesh screens. After the
addition of NaH$^{13}$CO$_3$, the bottles were placed in the incubator with circulating surface water.
The $^{13}$C enrichment was about 10% of the total inorganic carbon in ambient water. Incubation
experiments were started at about 0900 hours local time at Stas. 1, 7, 12 and 17 and at about 1500
at Stas. 4, 10 and 15. They were conducted for about 3 h and terminated by filtering the samples
onto precombusted 47 mm Whatman GF/F filters (450°C for 4 h) with gentle suction. Then the
filters were rinsed with a 3.5% NaCl solution. The filter papers were immediately frozen and

![Fig. 1. Location of sampling stations off Enshu-nada. Measurements of primary productivity were carried
out in the solid circles and only CTD casts at open circles. The arrow in the inset figure indicates the
direction of the Kuroshio current (Department of Hydrography, Japan Maritime Safety Agency, 1989).]