

Zooplankton ETS activity and respiration in the Catalan Sea (Western Mediterranean)

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SUMMARY: Zooplankton biomass, ETS activity and direct measurements of respiration were compared in a study of the Catalan Sea during the summer stratification period, in and around the deep chlorophyll maximum. The pattern of vertical distribution of zooplankton biomass differed from that found on previous cruises, but some trends in the horizontal were similar (minimum integrated values coinciding with ascending deep waters). Over the Catalan shelf the ETS activity averaged $0.09 \mu\text{eq h}^{-1} \text{ l}^{-1}$. The potential respiration, stoichiometrically calculated from the ETS activity, is $0.5 \mu\text{O}_2 \text{ h}^{-1} \text{ l}^{-1}$. Seaward of the frontal system on the shelf the rates decreased 50 % and then increased to $0.5 \mu\text{O}_2 \text{ h}^{-1} \text{ l}^{-1}$ on the eastern side of the divergence that occurs in the middle of the Catalan Sea. The zooplankton ETS activity did not increase in the chlorophyll maximum. A comparison of the ETS activity in the net and bottle samples suggests a difference in the capture efficiencies by both sampling methods. Physiological measurements of respiration were made on board and compared with ETS activity. A wide range of respiration/ETS ratio (1.60-3.38) was found; the correlation coefficient of respiration on ETS activity was 0.64.

Key words: zooplankton, ETS, respiration, frontal systems, Western Mediterranean.

INTRODUCTION

The flow of energy through the different compartments of an ecosystem is of prime importance in plankton production models. The rate of oxygen consumption by zooplankton represents the minimal food requirements of the first level of consumers and an estimate of the amount of energy (and hence the proportion of primary production) necessary to maintain the structure and activity of zooplankton populations (PACKARD, 1979; ALCARAZ, 1988). Although direct measurements of zooplankton respiration are technically simple, the incubations are too long for routine measurements (i.e., time series, horizontal sections, or vertical profiles). On the other hand, electron transport system (ETS) activity is also a simple measurement of metabolism, but in addition it is very sensitive and can predict the zooplankton respiration rate to within $\pm 34\%$ (KING & PACKARD, 1975). So, at times, it can be useful for some types of oceanographic studies.

In the Western Mediterranean, the development

of heterogeneities in the vertical distributions of phyto and zooplankton during the summer stratification period (ESTRADA, 1985; ALCARAZ, 1985), and the existence of a frontal system (a zone of ascension of deep water coupled with two hydrographic fronts, one at the Catalan side and the other at the Balearic side) approximately midway between Barcelona and the Balearic islands, have important consequences from the ecological point of view (ESTRADA & MARGALEF, 1988).

The characteristics of the deep phyto and zooplankton layers and the role of the frontal systems in the productivity of the Western Mediterranean have been studied in a series of cruises. Some aspects have been already discussed by ESTRADA (1985 a, b); MARGALEF & ESTRADA (1987); ESTRADA & MARGALEF (1988); ALCARAZ (1985, 1988), amongst others.

The purpose of this paper is to study the characteristics and interrelationships of the zooplankton biomass, respiration, and ETS activity across the frontal system in the Catalan Sea.

MATERIAL AND METHODS

The area was sampled during the PEP-86 cruise (13-24 June, 1986). Eight stations on a transect from Barcelona to the channel between the islands of Majorca and Minorca were occupied (Fig. 1). For the zooplankton biomass and metabolism studies, 6 sample depths were chosen from temperature, salinity and chlorophyll *a* profiles. Water samples were taken at each depth by means of twin 15 l Perspex VAN DORN-type bottles. The samples were then reverse-flow filtered by gravity through 6 cm diameter, 200 μm -mesh nylon filters (ALCARAZ, 1985). The zooplankton retained by the two filters was immediately washed off with 75-100 ml of filtered seawater and transferred to 2.5 cm \varnothing GF/F glass fibre filters.

The filters for the zooplankton biomass were desiccated and stored. Later they were analysed with a PERKIN-ELMER CHN analyzer according to FRAGA (1976). The biomass was expressed as μg at $\text{N}_2 \text{ l}^{-1}$. The filters for ETS activity were folded, placed in cryo-vials and frozen in liquid nitrogen until the analysis could be run, usually between 1 and 12 hours after sampling. These bottle samples are designed as ETS_B . ETS activity was measured and temperature corrected according to PACKARD (1979) and KING & PACKARD (1975), and the results expressed as *in situ* potential respiration on a volume basis ($\mu\text{l O}_2 \text{ l}^{-1} \text{ h}^{-1}$) and as biomass-specific rates ($\mu\text{l O}_2 \mu\text{g}$ at $\text{N}_2^{-1} \text{ h}^{-1}$), taking as zooplankton biomass the N_2 values from bottle samples.

Net zooplankton respiration and ETS measurements

Net zooplankton samples were taken between 70 m depth or 100 m depth to the surface with a WP2 net fitted with 250 μm nylon netting. For the ETS measurements, the whole sample or 1/5 aliquots, depending on the zooplankton abundance, were transferred by filtration onto GF/F glass fibre filters, placed in cryo-vials and frozen in liquid nitrogen until analysis. The ETS results were expressed as before, using the bottle plankton nitrogen to normalize the measurements for biomass.

For the respiration measurements, a separate net haul was made using a non-filtering cod end. The zooplankton were transferred into several 1 l jars, diluted with aerated filtered seawater and allowed to acclimatize for 1-2 h at the experimental temperature and dim light. Aliquots of the diluted samples were added to 250-500 ml beakers filled with the same air-saturated water used for dilution. Respiration was then measured by oxygen difference (ALCARAZ, 1988), using the Winkler method (STRICKLAND & PARSONS, 1972). Flasks with and without zooplankton were stoppered without trapping air bubbles.

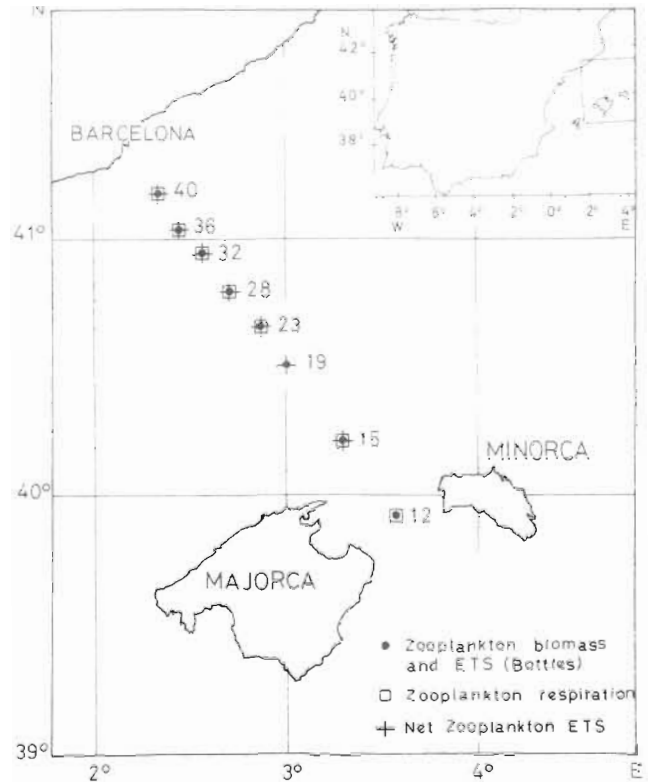


FIG. 1. — Location of the stations on the section studied during the PEP-86 cruise.

covered with aluminium foil and incubated for 12-24 h at $17 \pm 0.1^\circ\text{C}$. Samples for oxygen analysis were siphoned off through 200 μm nylon netting to prevent loss of the organisms. After drawing the oxygen samples, the organisms were transferred by filtration onto GF/F glass fibre filters, desiccated and analysed as in the case of zooplankton biomass. O_2 consumption was expressed as $\mu\text{l O}_2 \text{ l}^{-1} \text{ h}^{-1}$ and $\mu\text{l O}_2 \mu\text{g}$ at $\text{N}_2^{-1} \text{ h}^{-1}$.

RESULTS AND DISCUSSION

The hydrographic features, mainly temperature and density (σ_t) distribution along the transect were similar to those found during the summer stratifi-

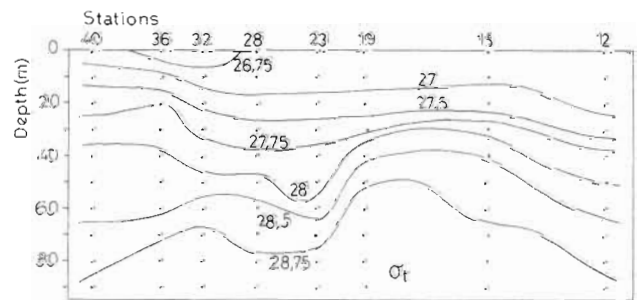


FIG. 2. — Distribution of σ_t values along the transect.

cation period on preceding cruises (PEP-82 and PEP-83; ESTRADA, 1985 a, b; ALCARAZ, 1988), with a divergence zone approximately midway between Barcelona and Majorca (Fig. 2).

The vertical distribution of chlorophyll showed the existence of a deep maximum between 50 and 70 m depth, shallower than that observed at the end of the stratification period (70-100 m depth at the end of August, PEP-82; ESTRADA, 1985). During the present cruise, this maximum was more diffuse and the concentration gradients were weaker than in preceding years, as corresponding to an initial phase of the development of the chlorophyll maximum (Fig. 3).

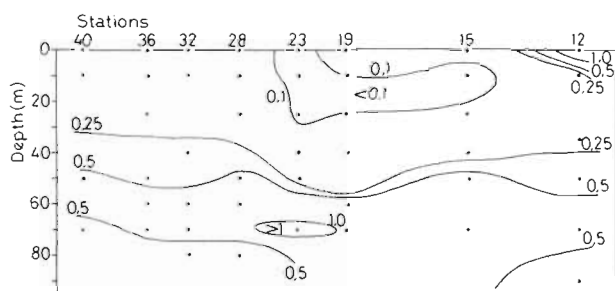


FIG. 3. — Distribution of chlorophyll *a* ($\mu\text{g l}^{-1}$) along the transect.

Vertical distribution of zooplankton biomass and ETS activity

The pattern observed in the vertical distribution of zooplankton biomass ($\mu\text{g at N}_2 \text{l}^{-1}$, Fig. 4) bears no relationship with the chlorophyll distribution (Fig. 3). The vertical structure did not follow a consistent pattern and the deep maximum observed later in the year could only be identified near Majorca I. (st. 15 and 12). The lack of correlation between chlorophyll and zooplankton in comparison to previous years (PEP-82 and PEP-83; ESTRADA, 1985; ALCARAZ, 1985, 1988) could possibly be due to the youth of the deep chlorophyll maximum. The previous cruises sampled it later in the year. The mean integrated zooplankton biomass ($\bar{X} = 0.079$; s.e. = $0.0038 \mu\text{g at N}_2 \text{l}^{-1}$, Table I) was significantly higher than in previous years ($\bar{X} = 0.060$; s.e. = $0.004 \mu\text{g at N}_2 \text{l}^{-1}$,

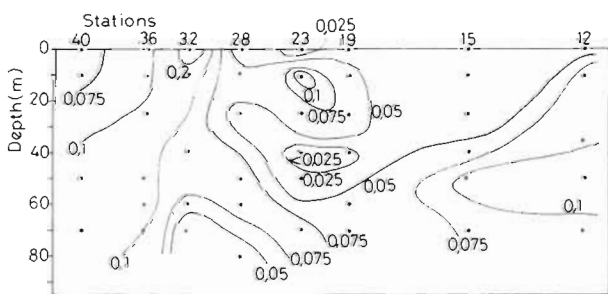


FIG. 4. — Distribution of zooplankton biomass ($\mu\text{g at N}_2 \text{l}^{-1}$) along the transect.

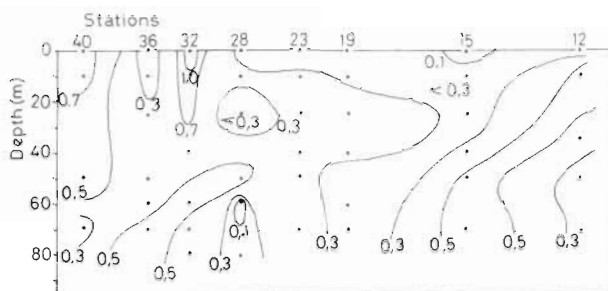


FIG. 5. — Distribution of potential respiration calculated from ETS_B ($\mu\text{l O}_2 \text{l}^{-1} \text{h}^{-1}$) along the transect.

PEP-82; ALCARAZ, 1985; $\bar{X} = 0.057$; s.e. = $0.0032 \mu\text{g at N}_2 \text{l}^{-1}$, PEP-83; ALCARAZ, 1988), but the horizontal distribution along the transect was similar to the distribution on previous cruises; the minimum integrated values occurred in the zone of deep water ascension (ALCARAZ, 1985).

The distribution of *in situ* potential respiration calculated from ETS activity (ETS_B , $\mu\text{l O}_2 \text{l}^{-1} \text{h}^{-1}$, Fig. 5) partly coincided with the zooplankton biomass distribution. In the deep chlorophyll maximum there was no increase in activity. However, the correlation between zooplankton biomass and ETS activity was low, although statistically significant ($r = 0.51$, $p < 0.01$). Variability of the sampling method (the coefficient of variation between bottle samples on a biomass basis was about 19 %, ALCARAZ, 1985, 1988), as well as metabolic differences due to taxonomic composition (KING & PACKARD, 1975; VERITY, 1985; ALCARAZ, 1988) and size differences (IKEDA, 1985) could cause this weak correlation.

Measured respiration rates and net ETS

The potential respiration rates from the net and depth integrated bottle samples were well correlated ($r = 0.93$, $n = 6$), but differed by a factor of 6, with the samples from bottles giving the greater activity

TABLE I. — Mean integrated values of zooplankton biomass ($\mu\text{g at N}_2 \text{l}^{-1}$), mean integrated Bottle ETS (ETS_B) and Net ETS (ETS_N) specific potential respiration rates ($\mu\text{l O}_2 \mu\text{g at N}_2 \text{l}^{-1} \text{h}^{-1}$), measured specific respiration (*R*) rates ($\mu\text{l O}_2 \mu\text{g at N}_2 \text{l}^{-1} \text{h}^{-1}$) and ratio measured respiration/potential ETS_N respiration rates (R/ETS_N) along the studied transect.

St	Zooplankton biomass	ETS_B	ETS_N	<i>R</i>	R/ETS_N
12	0.088	4.36	—	3.29	—
15	0.062	6.16	1.18	3.33	2.82
19	0.047	5.49	0.47	—	—
23	0.058	7.83	1.24	2.00	1.60
28	0.057	4.84	0.45	1.46	3.20
32	0.085	6.93	1.13	1.96	1.73
36	0.125	2.81	0.49	1.66	3.38
40	0.116	5.43	0.79	—	—
Mean	0.079	5.47	0.82	2.40	2.54
O	0.027	1.45	0.33	0.76	0.74

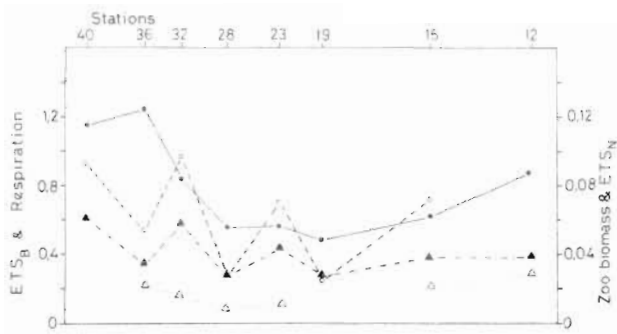


FIG. 6. — Spatial distribution of the mean integrated values of zooplankton biomass in $\mu\text{g at N, l}^{-1}$ (full circles); ETS_B potential respiration in $\mu\text{l O}_2 \text{ l}^{-1} \text{ h}^{-1}$ (full triangles), potential respiration in $\mu\text{l O}_2 \text{ l}^{-1} \text{ h}^{-1}$ as calculated from ETS_N (empty circles), and respiration in $\mu\text{l O}_2 \text{ l}^{-1} \text{ h}^{-1}$ (empty triangles).

(Table I). This suggests that, if the biochemistry is the same in the two samples, the plankton retained by 200 μm mesh-size are metabolically more important in the water column than the net plankton larger than 250 μm . On the other hand, higher capture efficiency of bottles in comparison to net tows (up to ten times higher: ALCARAZ, 1977) and the fact that specific net ETS potential respiration rates were calculated according to the mean integrated bottle zooplankton biomass, could be the reason for the differences between the two estimations.

The zooplankton respiration rates are presented in Table I. They are twice as high as those obtained during PEP-83 (ALCARAZ, 1985), when normalized to an incubation temperature of 17 $^{\circ}\text{C}$ ($Q_{10} = 1.89$; IKEDA, 1985). The maximum respiration rates were measured in the vicinity of Majorca (st. 12 and 15), where the deep zooplankton maximum was observed (Fig. 4).

The mean integrated values of zooplankton biomass, as well as the measured and potential respiration rates on a volume basis along the transect, have been represented in figure 6. Net and bottle potential respiration follow similar trends along the studied area, with minimum values in the zone of deep water ascent (st. 19) due to the low specific respiration rates there (Table I).

Relationships between respiration and potential respiration rates

To compare respiration with potential respiration only the net samples can be used because respiration was not measured on the bottle samples. From Table I it appears as if "potential respiration" is a misnomer because respiration is the larger of the two measurements. Although KING & PACKARD (1975) and BAMSTEDT (1980) found similar trends, the difference is disconcerting because the ETS method used in this work is more sensitive than previous ETS assays and so the two measurements should be much

closer. In any case, the wide range of values of the ratio measured/ ETS respiration rates obtained in the present cruise (1.6–3.38) indicates the existence of variability in both respiration and ETS activity which need to be identified if a more general and effective use of ETS activity is to be used as an estimator of metabolic activity in pelagic systems.

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