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ONR Grant #N00014-90J-1240
OSU Acct #30-262-3104

Dear Eric:

In order to complete my ONR Grant entitled "Marine Light-Mixed Layer: Zooplankton Grazing", I am sending three (3) copies of the Final Technical Report to you with copies distributed as indicated below.

Sincerely,

Timothy J. Cowles
Professor

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Final Technical Report

ONR Grant # N00014-90J-1240

Timothy J. Cowles, Principal Investigator

Marine Light-Mixed Layer: Zooplankton Grazing

The main objectives of this project were guided by the objectives of the Marine Light-Mixed Layer program:

- To evaluate the mechanisms by which physical forcing manifests itself in the functioning of marine ecosystems and thereby influences the bioluminescent signal and optical characteristics;

- To develop predictive capabilities of the space/time variability of bioluminescence and optical properties through the use of theoretical models and inferences from primary environmental characters.

Our specific objectives were to quantify the impact of major crustacean grazers on the optical characteristics of the water column, and to determine the finescale distributional patterns of major bioluminescent and grazing zooplankton.

We obtained zooplankton samples from discrete layers within the upper 120m of the water column during the spring and summer of 1991 at 59°N, 21°W, using a submersible pumping system. In addition, we measured the grazing rate of the dominant copepods using gut fluorescence and evacuation rate techniques. We found that the mesozooplankton in the upper 100 m at 59°N, 21°W were dominated by the copepodite stages of *Calanus finmarchicus* in both May and August 1991(Table 1a,b). Abundance of *C. finmarchicus* in the upper 20 m of the water column was 800 m^{-3} in May and 200 m^{-3} in August. Although hydrographic conditions changed from well mixed to stratified between May and August, the fine-scale vertical distribution pattern of *C. finmarchicus* was essentially the same during these two surveys of the Marine Light-Mixed Layers site. Copepodite stage five (CV) comprised a larger fraction of the population in August compared to May, however. Gut evacuation experiments with *C. finmarchicus* indicated that late copepodite and adult female life stages had evacuation rates of approximately 4% h^{-1} in both May and August (Tables 2, 3). Although these evacuation rates are consistent with others measured for *Calanus*, the relatively low biomass in the upper 100 m resulted in an estimated daily grazing impact by *Calanus* of less than 5% of the phytoplankton standing stock in May, and less than 1% in August (Figure 1). The ingestion rates we measured suggest that the total grazing impact of all mesozooplankton grazers is less than 10% of daily primary production. These relatively low ingestion rates on phytoplankton provide these copepods with less than half of the total daily carbon intake required to balance estimated rates of respiration and growth in the field (Table 4). In order to balance these metabolic costs, we estimate that the mesozooplankton would need to ingest the equivalent of at least 100% of the estimated microzooplankton/protist daily production (Table 5).

Table 1a. Numerically Dominant Mezozooplankton at 59° N, 21°W in May and August 1991.

Taxon	May 24 ($59,279\ m^{-2}$), % Total	August 28 ($12,320\ m^{-2}$), % Total	August 30 ($10,688\ m^{-2}$), % Total	September 1 ($9,788\ m^{-2}$), % Total
Calanus finmarchicus	93	38	45	37
Unidentified copepodites	-	23	19	16
Paracalanus cf. *parvus*	-	13	10	3
Pteropods	< 1	6	6	8
Euchaeta norvegica	2	4	2	4
Scolecithricella minor	< 1	3	9	15
Ostracods	< 1	2	1	6
Euphausiids	3	1	2	< 1
Hyperiid amphipods	< 1	5	2	2
Polychaetes	< 1	< 1	< 1	< 1
Chaetognaths	< 1	< 1	< 1	< 1

Taxonomic groups are listed with their respective percentage of total integrated numbers m^{-2} in the upper 100 m.

Table 1b. Dominant Mezozooplankton at 59° N, 21°W in May and August 1991.

Taxon	May 24 ($2,275\ mg\ C\ m^{-2}$), % Total Biomass	August 28 ($936\ mg\ C\ m^{-2}$), % Total Biomass	August 30 ($965\ mg\ C\ m^{-2}$), % Total Biomass	September 1 ($671mg\ C\ m^{-2}$), % Total Biomass
Calanus finmarchicus	58	32	36	34
Euphausiids	30	24	46	33
Hyperiid amphipods	< 1	21	9	11
Euchaeta norvegica	10	15	3	13
Polychaetes	< 1	2	1	2
Unidentified copepodites	-	2	1	1
Pteropods	< 1	2	1	2
Chaetognaths	< 1	1	1	3

Groups are listed to show their respective contribution (as percent) to integrated biomass ($mg\ C\ m^{-2}$) in the upper 100 m. Carbon biomass was estimated to be 40% of dry weight biomass.

Table 2. Gut Evacuation Rates (GER), Initial Pigment Concentrations, and Ingestion Rates for *Calanus finmarchicus* at the MLML site in May and August 1991.

Calanus finmarchicus Stage	GER, % min^{-1} (±SD)		Initial Pigment, ng chl-*a* eq wt $copepod^{-1}$ (±SD)		Ingestion Rate ng chl-*a* eq wt $copepod^{-1}$ hr^{-1} (±SD)	
	May	August	May	August	May	August
C6 female	3.56	4.59 (1.21)	3.02	1.75 (0.75)	6.45	4.43 (1.25)
	n=1	n=6				
C5	4.0 (0.02)	3.99 (0.70)	1.62 (2.14)	1.45 (0.36)	3.87 (5.10)	1.45 (0.36)
	n=2	n=8				
C4	4.28 (1.06)	6.81 (0.41)	1.42 (1.42)	0.23 (0.07)	3.89 (5.53)	0.95 (0.33)
	n=3	n=3				
C3	3.63		0.604		1.32	
	n=1					

Incubation temperatures are May, 8-9°C; August, 11-13°C.

Table 3. Clearance Rates (mean ± SD) for *Calanus finmarchicus* in May and August, Based Upon Measured Gut Evacuation Rates (Table 2), 12 Hours Grazing per day (See Text), and the Approximate Average Pigment Content of the Mixed Layer (May 24 = 1.0 μg chl-*a* L^{-1}; August 28 = 2.0 μg chl-*a* L^{-1})

Stage	May ml $individual^{-1}$ d^{-1}	August ml $individual^{-1}$ d^{-1}
CVI female	77	26 ± 8
CV	46 ± 62	9 ± 2
CIV	47 ± 66	6 ± 2
CIII	16	8†
CII	10*	5†
CI	6*	3†

* Estimated based on body size relative to CIII.

† Assumed to be half the May clearance rate.

Table 4. Metabolic Costs Estimated for *Calanus finmarchicus* Based on Temperature Corrected Respiration Rate Based on Body Size [*Ikeda*, 1985] and an Estimated Growth Rate of 15% d^{-1} (See Text).

Calanus Stage	Body Weight, μg C	Respiratory Costs [*Ikeda*, 1985]*, % body C d^{-1}		Ingestion Needed to Balance Total Metabolic Costs, % body C d^{-1}		Measured Ingestion Assuming 12-hour Ingestion d^{-1}, % body C d^{-1}	
		8°C	12°C	8°C	12°C	May†	August‡
female	110	5.1	6.4	28.7	30.6	3.1	3.4 - 6.1
CV	70	5.4	6.9	29.2	31.4	0 - 6.4	1.7 - 3.2
CIV	33	6.2	7.8	30.3	32.7	0 - 12.3	2.1 - 4.3
CIII	13	7.2	9.1	31.7	34.5	4.5	nd
CII	5	8.4	10.7	33.5	36.7	nd	nd
CI	2	9.8	12.4	35.4	39.2	nd	nd

Estimated growth temperature was 8°C in May, 12°C in August. Ingestion needed to balance total metabolic costs (resp + growth (15% d^{-1}) assumes an assimilation efficiency of 70%. (nd = no data).
* $\ln R$ ($\mu L\ O_2\ h^{-1}$) = $0.5254 + 0.8354 \ln W$ (mg C) + $0.0601\ T$ (°C); assumes RQ=1, and conversion of O_2 to carbon using ratio of 12/22.4.
† based on C:chl conversion of 40 for May, 1991 [*Marra et al.*, this issue]
‡ based on C:chl conversion of 90 for August, 1991 (J.Marra, personal communication, 1993)

Table 5. Grazing Impact (% Primary Production d^{-1}) Assuming That the Mesozooplankton Herbivorous Biomass (see text) Was Ingesting Between 5% and 30% of Its Body Carbon d^{-1} from Phytoplankton.

Date	Daily Primary Production Grazed, %	
	If Mesozooplankton Ingested 5% Body C d^{-1}	If Mesozooplankton Ingested 30% Body C d^{-1}
May 24*	3 - 8	21 - 49
Aug 28†	1 - 2	6 - 12
Aug 30†	2 - 4	12 - 22
Sept 1†	1 - 2	6 - 11

Range of percent grazing impact based on mean ± s.d. of primary production estimates from in situ ^{14}C incubations.
*May primary production 1428 ± 564 mg C m^{-2} d^{-1} [*Langdon et al.*, this issue]
†August primary production 840 ± 240 mg C m^{-2} d^{-1} [*Langdon et al.*, this issue]

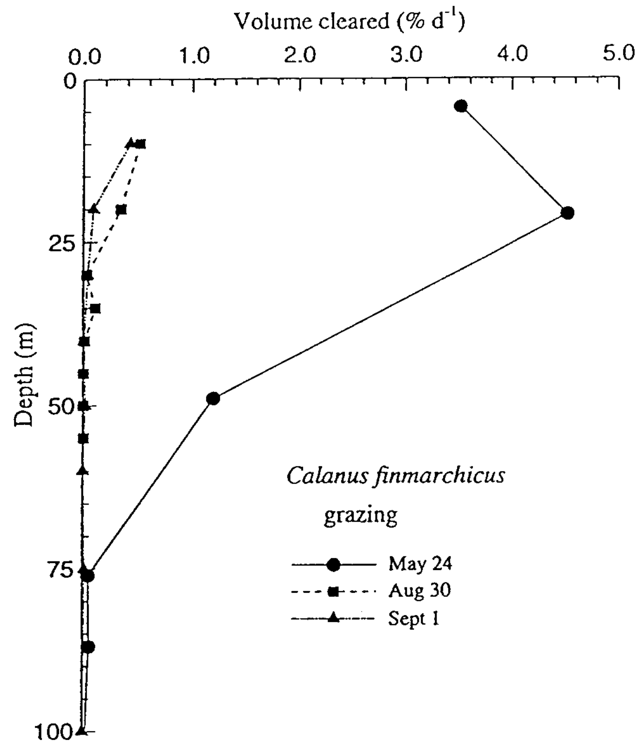

Figure 1. Vertical distribution of estimated grazing impact by all the stages of *C. finmarchicus* on May 24, August 30, and September 1, 1991. Grazing impact expressed as percentage of water column cleared per day. The low percentage numbers indicate that these dominant copepods do not have a significant impact on the phytoplankton population in the water column.

List of Publications and Presentations

Presentations:

Cowles, T.J. and L. Fessenden. Copepod grazing and fine-scale distribution patterns during the Marine Light-Mixed Layer Experiment. AGU Fall Meeting, San Francisco, CA, December, 1992

Publications:

Fessenden, L. and T.J. Cowles. 1994. Copepod predation on phagotrophic ciliates in Oregon coastal waters. Mar. Ecol. Prog. Ser. 107: 103-111.

Cowles, T.J. and L. Fessenden. (*in press*) Copepod grazing and finescale vertical distribution patterns in the Marine Light-Mixed Layer region. J. Geophys. Res.