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Note

Elemental composition (C, H, N) of the euphausiid *Euphausia pacifica* in Toyama Bay, southern Japan Sea

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The euphausiid *Euphausia pacifica* is distributed widely in the northern North Pacific and its marginal seas, including the Bering Sea, Okhotsk Sea, and Japan Sea (Brinton 1962), and is the most dominant component of the zooplankton biomass in the top 500 m in Toyama Bay, southern Japan Sea (31.1%, annual mean; Hirakawa et al. 1992). *E. pacifica* lives 1 to 2 years and its life history pattern varies geographically (Brinton 1976). As an example, *E. pacifica* off southern California spawn and grow in almost all seasons of the year, but those in Toyama Bay spawn and grow actively only for the first half of the year due to the high thermal regime in the upper layers and low food supply in the latter half of the year (Iguchi et al. 1993). *E. pacifica* is a primary herbivore (Ohman 1984) and an extensive diel vertical migrator (Brinton 1962; Iguchi et al. 1993), so it is anticipated that they play a vital role in secondary production and matter cycling in the habitats in which they occur. Based on carbon and nitrogen composition data for euphausiid bodies and cast molts, Lasker (1966) suggested that for the maintenance of growth, metabolism, and molting, the *E. pacifica* population needed to consume 3% of the primary production in the northeastern Pacific. Carbon and nitrogen composition data are prerequisites for evaluating the dynamic role of *E. pacifica* in the pelagic food web. Therefore, elemental composition data for *E. pacifica* have been reported for populations from the subarctic Pacific and Okhotsk Sea (Lasker 1966; Omori 1969; Childress & Nygaard 1974; Ikeda 1974). However, no data are presently available for the euphausiid population inhabiting the Japan Sea.

The present study is aimed at filling the gaps in elemental composition (C, H, N) data on calyptopis larvae, furcilia larvae, and the juveniles and adults of *Euphausia pacifica* and their molts, as part of a study to estimate their contribution to production in Toyama Bay. Water and ash content were also determined. Oblique hauls of a 2-m Isaacs-Kidd Midwater Trawl (1.5-mm mesh) or vertical hauls of Norpac nets (0.33 mm mesh) were made aboard the R.V. *Mizuho-Maru* at an offshore station (37°00'N, 137°14'E) in Toyama Bay during October and December 1991, in March, April, and July 1992, and in April 1994 to collect specimens. Immediately after collection, *E. pacifica* were sorted out from the catches and separated according to their developmental stage. For juvenile and adult specimens, the body length (the maximum distance between the tip of the rostrum and distal end of the telson excluding spines) was measured. Adults were separated into males and females whenever possible, and then each was divided further into three size classes (12 to $<$16 mm, 16 to $<$19 mm, and $\geq$19 mm). Eggs and molts were collected through the laboratory rearing of gravid females and juveniles/adults, respectively, using procedures that have been reported in detail elsewhere (Iguchi & Ikeda 1994, 1995). On board the ship, individual specimens were rinsed briefly with a small amount of distilled water, blotted on filter papers, and deep-frozen (<-20°C). The frozen specimens were weighed (wet weight, WW) and then freeze-dried. After returning to the shore laboratory, the freeze-dried specimens were weighed (dry weight, DW), pooled by developmental stage or size classes in the case of adults, and then ground into a fine powder with a ceramic mortar and pestle. Carbon (C), hydrogen (H), and nitrogen (N) content was measured with an elemental analyzer (Yanaco CHN Corder MT-5) using antipyrine as the standard. A weighed fraction of each powdered sample was incinerated at 480°C for 5 h and re-weighed for ash determination. All measurements were made in duplicate (elemental composition) or triplicate (ash) for each sample. From replicate determinations of the same sample, the precision of these analyses, as expressed by the coefficient of variation (SD/mean, %), was 1% for C, 3% for H, 10% for N, and 14% for ash.

The results from our analyses of intact specimens of *Euphausia pacifica* are summarized in Table 1. Owing to the aforementioned life cycle of *E. pacifica* in Toyama Bay, samples were available year round only for juveniles and adults. First, elemental composition and ash content data for juveniles through to the largest size class of adults were combined and grouped into five sampling periods regardless of the year (i.e. March, April, July, October, and December), and the seasonal variation was analyzed. Although not for ash content, seasonal differences were significant for C, H, N, and C/N ratios (ANOVA, $p<0.05$). LSD-tests (Snedecor & Cochran 1967) between means indicated that the means for March (for C), March and April (for H), and April and July or March, April, and July depending on developmental stage (for N) were significantly less than those for the other months. Analyzing proximate composition (protein, lipid, chitin, and carbohydrate) of the euphausiid *Meganyctiphanes norvegica* over one year in a Norwegian fjord, Båmstedt (1976) noted that lipid (the major source of C and H) exhibited the greatest seasonal variation; low lipid content was associated with an active growth season (summer and autumn) and high lipid with a no-growth season (winter and spring). A similar pattern was found for protein (the major source of N) in the same study by Båmstedt (1976). This close coupling of growth conditions and body composition may explain the observed low C, H, and N contents of *E. pacifica* collected during the period from March through July in the present study, since late winter to early summer is the most active growth season for this euphausiid in Toyama Bay (Iguchi et al. 1993). Lower organic content during active growth in *M. norvegica* in Båmstedt's (1976) study and/or *E. pacifica* in our study would imply higher ash content during the same time, but this is masked by the greater variabilities associated with ash determination in both studies.

Secondly, differences in the C, H, N contents, the C/N ratios and ash content between male and female adults were examined for the data collected in March, April, and July 1992. Differences were detected only in C (paired t-test at $p=0.05$). Higher C in females (43.3 ± 0.9% of DW) than in males (42.4 ± 1.0% of DW) found in *Euphausia pacifica* in this study is not a consistent feature in euphausiids however. Båmstedt (1976) found that in *Meganyctiphanes norvegica*, males contained a higher percentage of lipids than females early in the reproductive season (males mature earlier than females), while the reverse was the case mid or late in the reproductive season (females' oocytes grow but males' gonads degenerate to a rudimentary condition). The occurrence of mature males of *E. pacifica* in Toyama Bay is limited to mid-summer (August) and winter (December–February) (Iguchi et al. 1993), so C-rich males of *E. pacifica* were not present in our seasonal data sets.

Thirdly, differences between developmental stages and adult size classes were examined by comparing means from different seasons. Water contents of juveniles and three size classes of adults, although only determined on one occasion (December 1991), ranged from 75.9 to 80.0% of WW. These four means were significantly different (ANOVA, $p<0.025$), and subsequent LSD-tests revealed that the juveniles contained less water than adults [no difference between the three size classes, with a grand mean$=$79.1($\pm$2.1)%]. Water contents of juvenile/adult *E. pacifica* were reported as 82.8% (Lasker 1966) or 79.4% of WW (Childress & Nygaard 1974) in the eastern subarctic and 79.3% of WW (Omori 1969) in the western subarctic Pacific, all of

Table 1. Water, ash content, CHN elemental composition, and the C/N ratios of various developmental stages of *Euphausia pacifica* collected from Toyama Bay, southern Japan Sea. Water contents were determined for individual specimens, and other components for pooled specimens. From seasonal data the mean±1SD was calculated for each developmental stage and three size classes of adults (in parentheses). N denotes the number of specimens. ND=not determined.

Developmental Stage	N	Sampling date	Water (%WW)	Ash (%DW)	C (%DW)	H (%DW)	N (%DW)	C/N (by wt)
Eggs	76	Apr. 1992	ND	ND	46.9	7.6	9.1	5.2
	73	Apr. 1994	ND	ND	47.4	5.8	10.1	4.7
					(47.2±0.4)	(6.7±1.3)	(9.6±0.7)	(4.9±0.4)
Calyptopis I–III	177	Apr. 1992	ND	ND	37.5	5.5	9.9	3.8
Furcilia I–II	71	Apr. 1992	ND	13.0	42.4	6.3	11.2	3.8
Frucilia III–VI	82	Apr. 1992	ND	12.6	42.7	6.5	11.9	3.6
				(12.8±0.3)	(42.6±0.2)	(6.4±0.1)	(11.6±0.5)	(3.7±0.1)
Juvenile	15	Dec. 1991	75.9±3.7	13.4	42.9	6.6	11.4	3.8
(<12 mm)	2	Mar. 1992	ND	14.2	41.1	6.2	11.6	3.6
	14	Apr. 1992	ND	13.7	42.7	6.4	10.8	3.9
	8	Jul. 1992	ND	13.8	42.9	6.5	10.9	3.9
			(75.9±3.7)	(13.8±0.3)	(42.4±0.9)	(6.4±0.2)	(11.2±0.4)	(3.8±0.1)
Adult ♀+♂	16	Dec. 1991	79.2±2.8	12.7	43.8	6.8	12.0	3.6
(12 to <16 mm)	38	Mar. 1992	ND	12.6	41.3	6.2	11.0	3.8
	5	Apr. 1992	ND	12.8	42.9	6.4	10.6	4.1
	5	Jul. 1992	ND	12.7	44.9	6.8	10.8	4.2
			(79.2±2.8)	(12.7±0.1)	(43.2±1.5)	(6.6±0.3)	(11.1±0.6)	(3.9±0.3)
Adult ♀+♂	6	Oct. 1991	ND	10.3	43.3	6.8	12.2	3.6
(16 to <19 mm)	14	Dec. 1991	78.7±1.4	13.4	42.4	6.7	11.7	3.6
Adult ♀	6	Mar. 1992	ND	12.1	42.4	6.3	11.2	3.8
(16 to <19 mm)	4	Apr. 1992	ND	12.6	43.5	6.5	11.6	3.8
	2	Jul. 1992	ND	12.4	45.1	6.8	11.3	4.0
Adult ♂	2	Mar. 1992	ND	11.6	41.0	6.1	11.3	3.6
(16 to <19 mm)	2	Apr. 1992	ND	13.4	42.5	6.3	11.3	3.8
	3	Jul. 1992	ND	13.2	42.8	6.6	10.8	4.0
			(78.7±1.4)	(12.4±1.1)	(42.9±1.2)	(6.5±0.3)	(11.4±0.4)	(3.8±0.2)
Adult ♀+♂	3	Oct. 1991	ND	11.2	43.9	6.9	11.5	3.8
(≥19 mm)	4	Dec. 1992	80.0±1.8	12.3	43.2	6.8	11.7	3.7
Adult ♀	10	Mar. 1992	ND	12.3	42.7	6.5	11.7	3.7
(≥19 mm)	4	Apr. 1992	ND	12.3	43.1	6.5	11.2	3.9
	8	Jul. 1992	ND	12.6	43.4	6.6	11.3	3.9
Adult ♂	2	Mar. 1992	ND	10.6	41.6	6.2	11.8	3.5
(≥19 mm)	2	Apr. 1992	ND	12.7	43.0	6.4	11.4	3.8
	2	Jul. 1992	ND	13.9	43.6	6.6	11.3	3.9
			(80.0±1.8)	(12.3±1.0)	(43.1±0.7)	(6.6±0.2)	(11.5±0.2)	(3.8±0.1)

which fall within the 95% confidence interval (CI) for our data (68.0 to 83.8% for juveniles, 74.8 to 83.4% for adults). Mean ash contents of furcilia larvae, juveniles, and three size classes of adults, which varied from 12.3 to 13.8% of DW, did not differ significantly (ANOVA, $p>0.25$), and the grand mean was computed as 12.6(±0.9)%. Ash contents of juvenile/adult *E. pacifica* given by previous workers are 8.0–8.5% of DW (Omori 1969), 10.5% (Lasker 1966), and 14.2% (Childress & Nygaard 1974). Compared with the 95% CI for the present results (10.7 to 14.5%), Lasker's (1966) and Childress & Nygaard's (1974) data are similar, but Omori's (1969) values are much lower. A possible cause for the low-ash data of Omori (1969) is his use of a high incineration temperature (800°C as compared with 480–525°C in the other three studies).

A marked change in the C, H, and N contents was seen during the development of eggs to furcilia via calyptopis (Table 1). Of all the developmental stages, eggs contained the highest content of C (47.2% of DW) and the lowest of N (9.6% of DW), resulting in the highest C/N ratio (4.9), while calyptopis larvae have the lowest C (37.5% of DW) and H (5.5% of DW). A C content as high as 50% of DW was observed for the eggs of this euphausiid by Lasker (1966). The C contents of eggs (47.2% of DW) found in this study and by Lasker (1966) (50% of DW) are both greater than the 41.1% found in the amphipod *Themisto japonica* (Ikeda 1991, estimated from the data for newly hatched juveniles), but less than the 66% of the copepod *Pareuchaeta elongata* (Ikeda & Hirakawa 1996), both of which are common members of the zooplankton community in Toyama Bay. The dissimilar C contents of eggs are considered to be closely related to nutritional modes in the early life history of each species; i.e. *T. japonica* starts feeding immediately after hatching, while *P. elongata* does not feed during naupliar development (Ikeda & Hirakawa 1996). In euphausiids, feeding appendages and the digestive system become fully functional during the calyptopis larval stage (Mauchline & Fisher 1969). Thus, the low C and H contents of *E. pacifica* calyptopis larvae found in this study probably reflect the heavy usage, during the course of development, of organic matter stored in the eggs. A similar rapid decrease in C content from eggs to calyptopis larvae was observed in another euphausiid, *Euphausia superba* (Ikeda 1984). During development from furcilia to the largest adults, C, H, N composition and the C/N ratio were all maintained at a constant level (ANOVA, $p>0.1$ or $p>0.25$), as was the case for the ash content mentioned above [grand mean: 42.9(±1.0)% of DW for C, 6.5(±0.2)% for H, and 11.4(±0.4)% for N, and 3.8(±0.2) for the C/N ratio]. C, H, and N contents previously reported for juvenile/adult *E. pacifica* by Lasker (1966), Omori (1969) and Childress & Nygaard (1974) are 38.7 to 42.0%, 6.3 to 7.3%, and 10.1 to 12.3% of DW, respectively, which overlap totally or partially with the 95% CIs of each element as determined in the present study (40.8 to 45.0% for C, 6.1 to 6.9% for H, and 10.6 to 12.2% for N of DW). The C/N ratios of the juveniles/adults calculated from the data of these previous workers (3.3 to 3.9) are comparable to our results (95% CI: 3.4 to 4.2). As a notable exception, Ikeda (1974) recorded high C (46.5% of DW) and H (7.9% of DW) contents for adult *E. pacifica* collected from 283-m depth (temperature: 0.95°C) in the Okhotsk Sea. This result from Ikeda (1974) suggests a moderate accumulation of lipid in the body of *E. pacifica* living in this cold habitat, though the life cycle of this euphausiid in the Okhotsk Sea has not yet been described. High C and H contents accompanied by low N and ash contents in the body tissues are a general feature seen in various zooplankters living in high latitude areas (Ikeda 1974; Båmstedt 1986). The greatest C content ever recorded in

Table 2. Ash content and C and N composition of the molts of *Euphausia pacifica* and other pelagic crustaceans. —: No data.

Group/species	Ash (%DW)	C (%DW)	N (%DW)	Reference
Euphausiacea				
Euphausia pacifca	42.1	23.0	4.4	This study
E. pacifica	45.5	17	2.5	Lasker (1966)
E. superba	—	23.8	4.4	Ikeda & Dixon (1982)
Thysanoessa inermis	—	26.4	5.2	Dalpadado & Ikeda (1989)
Mysidacea				
Metamysidopsis elongata	—	23.5	—	Clutter & Theilacker (1971)
Amphipoda				
Themisto japonica	—	23.7	4.2	Ikeda (1991)
Decapoda				
Pandalus borealis (larvae)	—	20.8	3.8	Ikeda & Aritaki (1991)

euphausiids is the 55.4% of DW found in *Thysanoessa inermis* collected from the Barents Sea during the summer season (Ikeda & Skjoldal 1989).

In Table 2, the elemental composition and ash data for dried molts of *Euphausia pacifica* are shown, together with previous data for the same species (Lasker 1966), other euphausiids *E. superba* (Ikeda & Dixon 1982) and *Thysanoessa inermis* (Dalpadado & Ikeda 1989), a mysid *Metamysidopsis elongata* (Clutter & Theilacker 1971), an amphipod *Themisto japonica* (Ikeda 1991), and the larvae of a decapod shrimp *Pandalus borealis* (Ikeda & Aritaki 1991). It is noted that our results for both the C and N contents of the molts of *E. pacifica* are greater than those of Lasker (1966) for the same species, but are surprisingly consistent with the data for other euphausiids (*E. superba* and *T. inermis*) and non-euphausiid planktonic crustaceans (*M. elongata*, *T. japonica*, and *P. borealis* larvae). Excluding Lasker's (1966) data, the C and N contents of the six pelagic crustaceans in Table 2 fall into the relatively narrow ranges of 21 to 26% and 3.8 to 5.2% of DW, respectively. The lower C and N data of Lasker (1966) may reflect a regional difference in the elemental composition of *E. pacifica*, but this explanation is unlikely since the C (42.0% of DW), N (11.5%), and ash (10.5%) contents of the intact juvenile/adult specimens in his study are similar to those found in the present results (cf. Table 1). Judging from his higher ash content value (45.5% of DW, vs 42.1% of DW in this study) incomplete removal of seawater from molts prior to ash content determination is considered to be a possible source of error.

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