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Energy density of anchovy *Engraulis encrasicolus* L. in the Adriatic Sea

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European anchovy *Engraulis encrasicolus*, with total lengths ranging from 40·0 to 132·5 mm, were sampled during October 2002 and May 2003 in the northern Adriatic Sea in order to estimate their energy densities (E_D). A highly significant ($P < 0{\cdot}001$) relationship between E_D (y) (J g^{-1}wet mass) and per cent dry mass (x) was found: $y = 321x - 3316{\cdot}9$ ($n = 161$, $r^2 = 0{\cdot}82$).

Key words: energy density; *Engraulis encrasicolus*; European anchovy.

During the last few decades, interest in energy density (E_D) has increased with the growing use of bioenergetics models that link basic animal physiology and behaviour with environmental conditions and are used in studies on fish ecology and in fish management (Brandt & Hartman, 1993; Hartman & Brandt, 1995). Energy density is used to measure fish growth and food consumption. Energy density of prey items can also affect fish gastric evacuation rates (Andersen, 1999) and thus should be considered in the gastric evacuation models to obtain food consumption estimates. Fish E_D may change with ontogeny (Arrhenius, 1998; Paul *et al*., 1998*a*), season (Foltz & Norden, 1977; Hislop *et al*., 1991; Wang & Houde, 1994; Arrhenius & Hansson, 1996; Arrhenius, 1998; Pedersen & Hislop, 2001), geographic distribution (Paul *et al*., 1998*b*; Paul & Paul, 1999; Ciannelli *et al*., 2002) and water body content (Pierce *et al*., 1980; Strange & Pelton, 1987). Assuming constant E_D, or using improper values, can greatly affect bioenergetics models and consumption estimates (Stewart & Binkowski, 1986). Hartman & Brandt (1995) presented a series of general empirical models that predict E_D (J wet mass^{-1}) from fish dry mass (M_D) expressed as a

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percentage (100 M_D M_W^{-1}, where M_W is wet mass) for different species, families and orders, and a combined model for fishes in general. The use of these models is improved if applied at the lowest practical taxon. The combined model was significantly different from the independent data for bay anchovy *Anchoa mitchilli* (Valenciennes), suggesting that engraulids might present particular patterns of E_D variability (Hartman & Brandt, 1995).

The European anchovy *Engraulis encrasicolus* L., living in the north-east Atlantic Ocean, Mediterranean Sea, Black Sea and Azov Sea is a strictly planktivorous feeder (Tudela & Palomera, 1997; Conway *et al.*, 1998; Plounevez & Champalbert, 1999) and represents a fundamental link between plankton production and predators of upper trophic levels. Its role as a prey fish is particularly important in shallow seas, where its predators could be pelagic and demersal fishes of high economic value such as *Scomber scombrus* L., *Thunnus thynnus* (L.), *Thunnus alalunga* (Bonnaterre) and *Merluccius merluccius* (L.) (Bombace, 1991). *Engraulis encrasicolus* spawns from March to October and juveniles usually concentrate in shallow waters (<30 m depth) along the Italian coast (Sinovčić, 1978; Gamulin & Hure, 1983; Sinovčić, 2000). In the Adriatic Sea, European anchovy are commercially harvested along the coast from spring to autumn, while they inhabit deeper offshore waters during winter time. In the northern and central Adriatic, European anchovy represent an economically important fishery resource. The harvest of northern and central Adriatic Sea European anchovy averaged 25 000 from 1975 to 1996 (Santojanni *et al.*, 2003) and in 1991 it represented up to 19% of the Mediterranean annual catch (Stamatopoulos, 1993).

Given the ecological and economic importance of the European anchovy, the aim of the present paper was to determine the E_D of *E. encrasicolus* in the Adriatic Sea and to calculate the E_D and % M_D relationship for this species.

Engraulis encrasicolus were collected by the research vessel G. Dalla Porta during two 1 week cruises in October 2002 and May 2003, near the Po River estuary (northern Adriatic Sea; 44° 50′ N; 12° 30′ E). On board, European anchovy were sorted by total length (L_T) class and batches of 10 mm L_T classes were placed in bags, frozen in sea water to slow decomposition and prevent water loss and stored at −20° C until analysed. In the laboratory, fish were thawed, measured ($L_T \pm 0{\cdot}1$ mm) and weighed ($M_W \pm 0{\cdot}01$ g). To prevent loss of water and blood from fish, small numbers of European anchovy were thawed out each time. Fish were oven-dried at 70° C, then weighed individually and the % M_D for each fish was calculated. Ash content was determined on random individual samples ($n = 36$) after combustion at 600° C for 72 h.

Within each sampling period, individuals were selected to cover the entire range of fish sizes caught. An adiabatic bomb calorimeter (Ika C7000, Ika Werke GMBH & Co. KG, Stanfen, Germany) was used to estimate E_D. Each sample (0·5 g) was analysed in duplicate. If the values differed by >3% an additional sample was combusted. Mean values were based on two to three sub-samples. Fish ≥90 mm were processed individually while smaller specimens were processed as pooled samples (five to 20 fish). Moreover, 31 fish caught in May were separated by gender and were individually subjected to E_D determination.

In total, 492 European anchovy were analysed for E_D, 382 caught in October 2002 and 110 caught in May 2003 (Table I). The L_T ranged from 40·0 to 126·8 mm and 70·0 to 132·5 mm in October and May, respectively. Fish M_W ranged from 0·23 to 12·69 g in October and from 1·85 to 13·55 g in May. Mean $\pm$ S.D. ash content was $4{\cdot}5 \pm 0{\cdot}8\%$ ($n = 36$).

The E_D for *E. encrasicolus* ranged between 2667 and 7022 J g^{-1} M_W [Fig. 1 and Table I). These values are within the range of E_D reported in the available literature for engraulids (Theilacker, 1987; Wang & Houde, 1994; Hartman & Brandt, 1995; Bunce, 2001; Takahashi *et al.*, 2001). Moreover energy density linearly increased with fish size between 40 and 90 mm, ranging from 2667 to 5430 J g^{-1} M_W ($r^2 = 0{\cdot}67$, $n = 50$, $P < 0{\cdot}001$) as observed by Arrhenius & Hansson (1996), Arrhenius (1998), Pedersen & Hislop (2001) and Ciannelli *et al.* (2002). Such a relationship was not confirmed for European anchovy >90 mm which were characterized by a more variable E_D: between 4338 and 7022 J g^{-1} M_W in October and 3276 and 6672 J g^{-1} M_W in May (E_D and L_T relationships were $r^2 = 0{\cdot}031$, $P > 0{\cdot}05$ in October and $r^2 = 0{\cdot}013$, $P > 0{\cdot}05$ in May). The higher variability of values for larger-sized European anchovy could be related to the presence of both adult males and females in the samples and to their different states of sexual maturity (presence of sexually mature females with gonads containing hydrated eggs or spent specimens). In fact a significant difference between the E_D of similar-sized males and females was found in May samples: E_D averaged 4867 ± 544 J g^{-1} M_W (mean $\pm$ S.D.) and 4408 ± 5933 J g^{-1} M_W for females and males, respectively (*t*-test, $n = 31$, $P < 0{\cdot}05$) (the L_T of European anchovy sorted by gender, ranged from 101·3 to 118·0 mm). Wang & Houde (1994) observed that gonads generally had higher

TABLE I. Energy density (E_D) of *Engraulis encrasicolus* in the northern Adriatic Sea by size and season

Month	L_T class (mm)	E_D (J g^{-1} M_W)	S.D.	n	Total number of fish analysed
October 2002	40–49	3403·99	247·83	3	68
	50–59	3344·69	276·84	9	86
	60–69	3568·57	266·27	11	103
	70–79	4081·29	388·28	11	56
	80–89	4788·20	438·38	8	25
	90–99	5264·29	555·07	20	23
	100–109	5600·40	792·73	10	10
	110–119	5537·97	797·72	8	8
	120–129	5577·96	215·88	3	3
May 2003	70–79	4154·20	287·17	3	15
	80–89	4280·41	218·43	5	15
	90–99	4506·96	469·43	10	20
	100–109	4928·91	579·08	32	32
	110–119	4564·97	797·63	20	20
	120–129	4462·24	462·76	7	7
	130–139	3540·84	54·32	1	1

L_T, total length; M_W, wet mass; n, number of samples analysed.

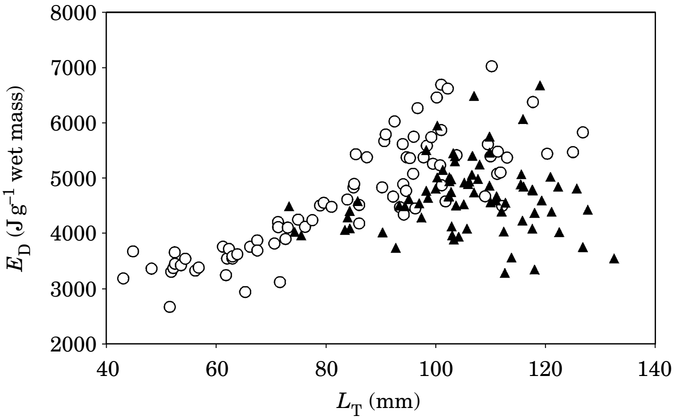

FIG. 1. Relationships between total length and energy density for European anchovy sampled in October (○) and May (▲).

energy values relative to somatic tissue and in particular they found that females gonads had higher energy equivalent than males ones, probably due to the presence of the energy-rich eggs. Moreover, during the spawning season, E_D of bay anchovy females may differ in relation to different conditions. In fact mature bay anchovy with heavier body masses had larger gonads which in turn contained more hydrated eggs (Zastrow *et al.*, 1991). Takahashi *et al.* (2001) showed that E_D of female *Engraulis japonicus* Temminck & Schlegel was 1·4 times higher than that of males.

Sampling period significantly affected E_D of fish ($\geq$70 mm L_T) with higher values detected in October (5092 $\pm$ 785 J g^{-1} M_W) than in May (4650 $\pm$ 643 J g^{-1} M_W) (*t*-test, $n = 138$, $P < 0{\cdot}001$) and more pronounced differences for larger fish ($\geq$90 mm). The E_D of clupeids has been found to vary seasonally (Flath &

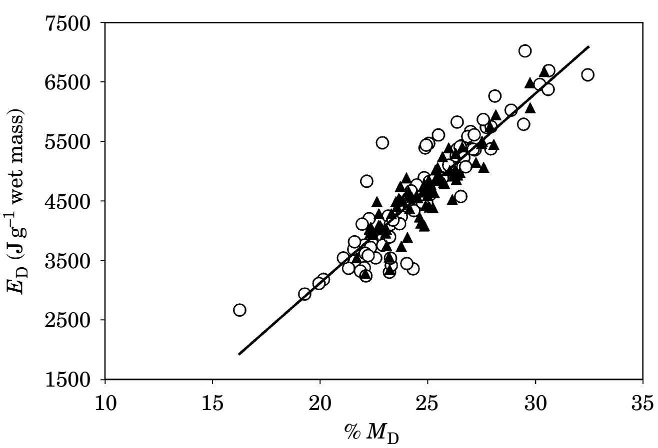

FIG. 2. Relationship between per cent dry mass and energy density for European anchovy sampled in October (○) and May (▲). The curve was fitted for the total sample (see Table II).

TABLE II. Least-squared regression models for estimating energy density (J g^{-1} wet mass) from per cent dry mass

Fish species	r^2	*n*	Slope	95% CL	Intercept	95% CL	*P*	Reference
Anchoa mitchilli	0·77	26	156·3		691			Hartman & Brandt, 1995
Combined (linear)	0·95	587	375		−3419			Hartman & Brandt, 1995
Clupeiformes	0·85	82	328·6		−2532			Hartman & Brandt, 1995
Clupea harengus	0·99	20	417	7	−4640	189	<0·001	Pedersen & Hislop, 2001
Sprattus sprattus	0·97	3	354	129	−2996	3253	<0·05	Pedersen & Hislop, 2001
Engraulis encrasicolus October	0·82	83	325·01	33·12	−3383·49	822·64	<0·001	This study
Engraulis encrasicolus May	0·82	78	313·7	33·96	−3168·8	848·72	<0·001	
Engraulis encrasicolus Total	0·82	161	321·01	23·49	−3316·91	585·39	<0·001	

Diana, 1985; Hislop *et al*., 1991; Wang & Houde, 1994; Arrhenius & Hansson, 1996; Paul *et al*., 1998*a*; Pedersen & Hislop, 2001), generally peaking in the autumn and declining throughout winter. Seasonal variations in E_D are generally related to the reproductive cycle and seasonal changes in food consumption and diet (Pedersen & Hislop, 2001). European anchovy collected in October might have eaten more during the summer than fish collected in May, after over-wintering. While *E. encrasicolus* have been shown to feed during the spawning period (summer) (Tudela & Palomera, 1995; Plounevez & Champalbert, 1999), evidence of a lower feeding activity of Adriatic European anchovy during winter has not been documented. Nevertheless, during the coldest months, European anchovy move from coastal areas to deeper waters (Sinovčić, 2000) where the temperature is warmer but zooplankton biomass is lower (Benović *et al*., 1984; Fonda-Umani *et al*., 1994). As a consequence, fish in October might have exhibited a higher E_D because of their richer diet.

The relationship between fish % M_D (x) and E_D (y) on a M_W basis was significant: $y = 321\ x - 3316{\cdot}9$ ($r^2 = 0{\cdot}82$, $n = 161$, $P < 0{\cdot}001$) (Fig. 2). The regression model for *E. encrasicolus* appears quite different from that reported for *A. mitchilli* (Table II), confirming the results of Hartman & Brandt (1995) who observed species-specific differences in the E_D relationships. In the range of fish masses studied, the European anchovy model gives lower E_D values compared to herring *Clupea harengus L.* and sprat *Sprattus sprattus* (L.) models presented by Pedersen & Hislop (2001) and the general combined model proposed by Hartman & Brandt (1995), which did not include engraulids. Differences observed from the Hartman & Brandt (1995) model may be partially explained since that their data set was mainly based on freshwater species, but those with herring and sprat need a more accurate interpretation. Lower E_D g^{-1} M_D is generally expected in species with lower basic lipid level or more bony parts (Hartman & Brandt, 1995). In the present study, this second cause may have played an important role. Considering that fish E_D analysis are generally carried out on sub-samples of the entire dried carcass, the lower is the ash content the higher should be the energetic content. Herring and sprat studied by Pedersen & Hislop (2001) had a lower ash content (*c*. 2·5%) than the European anchovy of the present study (ash content of 4·5%).

These data represent the first data set on energy density for *E. encrasicolus*. The strength of the relationship ($P < 0{\cdot}001$) between E_D and fish mass might be used to increase knowledge of seasonal and ontogenetic patterns in E_D of this species on a larger spatial scale, only by collecting, weighing and then drying the fish. Applying the model, might avoid time-consuming and expensive calorimetric analysis. At present, differences observed between *E. encrasicolus* and *A. mitchilli* suggest that it is not possible to have a general model for engraulids and underlines the importance to extend species-specific studies on energy density to other pelagic fishes.

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