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SIZE AT ONSET OF SEXUAL MATURITY OF THE DEEP-WATER ROSE SHRIMP *PARAPENAEUS LONGIROSTRIS* (*Crustacea Penaeidae*) OFF THE SOUTHERN COAST OF SICILY

SUMMARY

Standing stock and corresponding basic biological features of the valuable deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), off the southern coasts of Sicily (Central Mediterranean Sea), are regularly monitored thru experimental trawl surveys (MEDITS and GRUND programs), respectively carried out in spring-summer and autumn-winter. Formal assessment, however, is hampered by the scarce availability of suitable parameters estimates. In this study, a broad (all years combined) size at onset of sexual maturity (SOM, as carapace length; CL_m) has been obtained by analyzing the data on the female ovarian maturity stages gathered in the period 1994-2007. Immature/juvenile specimens represent the bulk of the catch in both kinds of survey, and result well discriminated from the adult components. The SOM has been computed with the logistic approach, with values slightly different for MEDITS (CL_m= 22.4 mm) and GRUND (CL_m= 20.6 mm). Although the more conservative MEDITS value might be precautionarily employed, the GRUND estimation, closer to the spawning peak, should be preferred as reference for assessment and management of the rose shrimp Sicilian stock.

RIASSUNTO

Taglia di prima maturità del gambero bianco, Parapenaeus longirostris *(Crustacea Penaeidae) nella costa meridionale siciliana*. Lo standing stock ed i corrispondenti aspetti biologici del pregiato gambero bianco, *Parapenaeus longirostris* (Lucas, 1846), dello Stretto di Sicilia vengono regolarmente monitorati con campagne sperimentali di pesca a strascico (programmi MEDITS e GRUND), condotte rispettivamente in primavera-estate ed in autunno-inverno. La valutazione puntuale è però resa difficile dalla scarsità di idonee stime dei parametri necessari. In questo studio, la taglia di prima maturità (SOM, valutata come CL_m) è stata ottenuta analizzando i dati complessivi sugli stadi di maturità sessuale delle femmine, raccolti nel periodo 1994-2007. Gli esemplari immaturi/giovanili rappresentano il grosso della cattura in ambedue i tipi di campagna sperimentale, e sono ben separati dagli elementi adulti. Il SOM è stato calcolato tramite l'approccio logistico, ottenendo valori leg-

germente diversi tra MEDITS (CL_m= 22.4 mm) e GRUND (CL_m= 20.6 mm). Sebbene il valore MEDITS, più conservativo, possa essere impiegato come riferimento precauzionale, è preferibile utilizzare la stima GRUND, in quanto più prossima al picco di maturità, come dato per la valutazione e la gestione dello stock di gambero bianco nello Stretto di Sicilia.

INTRODUCTION

The rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), is a demersal decapod crustacean (belonging to the family Penaeidae) with a wide geographical distribution (Eastern Atlantic and Mediterranean), often showing patchy aggregations (LEVI *et al.*, 1995), and occurring over deep sandy–muddy bottoms at 100-500 m of depth (TURSI *et al.*, 1999; ABELLÓ *et al.*, 2002; SOBRINO *et al.*, 2005). Distribution, abundance and biological features life of the rose shrimp in Italian waters are regularly monitored thru international (MEDITS) and national (GRUND) experimental bottom trawl surveys; still, in the waters off the southern coasts of Sicily, where the species represents a valuable target of the trawling fisheries (LEVI *et al.*, 1995; CHAOUACHI & BEN HASSINE, 1998; RAGONESE & BIANCHINI, 2006), only a preliminary stock assessment (LEVI *et al.*, 1995; GANCITANO *et al.*, 2008) and the nurseries definition (FORTIBUONI *et al.*, 2009) have been published yet.

Aim of this paper is a broad study, based on survey data from 1994 to 2007, of some reproductive aspects of rose shrimp females, in particular the size at onset of sexual maturity (SOM or CL_m), an estimate fundamental to assessment (BIANCHINI *et al.*, 1998), given that optimum production and resilience to exploitation are recognized to be strictly related to the maturity and fecundity parameters (BEVERTON, 1992).

MATERIAL AND METHODS

Information about the macroscopic gonads condition of females of rose shrimps were obtained from the database of the IAMC of Mazara, holding data from two experimental bottom trawl surveys carried out in the Strait of Sicily in spring-summer (MEDITS program) and autumn-winter (GRUND program); the time range is 1994-2007, but the surveys design (i.e., starting period, area coverage, number of hauls) has not been steady, due to varying administrative constraints (Tab. 1). The general aspects concerning the protocols (statistical design, haul operations, etc.) of the MEDITS program can be found in ANONYMOUS (2001) and BERTRAND *et al.* (2002); those of the GRUND program in RELINI (2000). In particular, the two kinds of survey employed different gear,

but both mounted the same codend (mesh size 20 mm, stretched), which resulted not selective for rose shrimp (RAGONESE & BIANCHINI, 2006).

Table 1 — Calendar of the bottom trawl surveys carried out off the southern coats of Sicily; also reported the number of hauls and of the examined females of *Parapenaeus longirostris*.

survey type	season	year	start	end	n° of hauls	n° of females
MEDITS	spring	1994	11/06/94	15/07/94	56	1722
GRUND	autumn	1994	07/10/94	06/11/94	130	5732
MEDITS	spring	1995	03/06/95	17/06/95	56	2396
GRUND	autumn	1995	10/10/95	12/11/95	123	5230
MEDITS	spring	1996	31/05/96	12/06/96	56	4569
GRUND	autumn	1996	11/10/96	31/10/96	83	4331
MEDITS	spring	1997	03/06/97	14/06/97	56	3082
GRUND	autumn	1997	08/09/97	22/11/97	91	6857
MEDITS	spring	1998	16/06/98	27/06/98	56	6513
GRUND	autumn	1998	17/09/98	12/12/98	90	6614
MEDITS	spring	1999	28/05/99	09/06/99	56	10138
MEDITS	spring	2000	26/05/00	08/06/00	61	7013
GRUND	autumn	2000	05/09/00	11/11/00	75	4679
MEDITS	spring	2001	19/05/01	01/06/01	65	7049
GRUND	autumn	2001	03/09/01	18/11/01	78	4789
MEDITS	summer	2002	11/06/02	24/08/02	120	10561
GRUND	autumn	2002	24/09/02	07/10/02	69	5615
MEDITS	summer	2003	13/07/03	13/08/03	120	8691
GRUND	autumn	2003	12/09/03	06/11/03	116	14278
MEDITS	summer	2004	10/06/04	11/07/04	119	17425
GRUND	autumn	2004	09/09/04	30/10/04	78	32735
MEDITS	summer	2005	05/07/05	13/08/05	120	8107
GRUND	autumn	2005	12/11/05	23/12/05	170	27248
MEDITS	spring	2006	19/05/06	14/06/06	120	7687
GRUND	autumn	2006	14/11/06	22/12/06	170	15203
MEDITS	summer	2007	10/06/07	09/07/07	120	2465
TOTAL	**26**				**2454**	**230729**

Sampled females were measured with a caliper (carapace length, CL; 1 mm), dissected, and the ovary shape and color evaluated. Each specimen was classified simply in immature/adult (MEDITS) or according to an empirical macroscopic 4-color scale (GRUND; Tab. 2); the last one has been supported by histological analyses (BIANCHINI *et al.*, in press).

The *ad hoc*-developed SEATrIM software (DE SANTI *et al.*, 2006) was used for descriptive statistics and data interpolation; the program does exclude from computations the anomalously large animals with "virginal" or inconspicuous gonads (the so-called extra-spent specimens), shrimps which likely skipped the maturation season.

Table 2 — Macroscopic empirical scale for females of *Parapenaeus longirostris*.

stage	maturity definition	color of the ovary	general appearance
1	immature	transparent-whitish	ovary translucid and string-shaped, almost not visible in transparency (if exposed after dissection of tegument, small, whitish or translucid with anterior lobes poorly developed and thin)
2	developing	beige-cream (orange when stored in formalin)	visible ovary with the anterior extensions and the lateral lobes distinguished but not much developed; the abdominal extensions are thin and not much visible but colored
3	advanced development	pale-green or green-gray (orange-yellow when stored in formalin)	ovary well visible even without dissection; it covers a good extension of cephalotorax segments, and the cephalic and lateral lobes are turgid
4	near-ripe and ripe	olive to dark-green (light orange when stored in formalin)	the swollen ovary occupies most of the cephalotorax, hiding the lower organs; the anterior and lateral lobes are well developed, and the abdominal extensions are much evident

The "logistic" size at the onset of sexual maturity (SOM), herein defined as CL_m was derived according to

$$p_{mCL} = \frac{1}{1+\exp -g*(CL_i - CL_m)}$$

where $p_{m,CL}$ represents the proportion of the specimens considered mature/adult in length class i, and g is the steepness parameter; a simple non-weighed least square regression was implemented as fitting procedure.

RESULTS

Overall, 97418 (MEDITS surveys) and 133311 (GRUND surveys) females of *P. longirostris* have been examined. The relative frequency of the different maturity stages and its evolution in time is presented in Tab. 3. In general, juveniles (MEDITS 2-stage scale) and immature-and-developing (GRUND 4-stage scale) specimens represent the largest part of the sample, especially in the autumn surveys. Considering the GRUND surveys, ripe specimens are less than 10%, with a remarkable exception in 2002.

The box plots of Fig. 1, relating size (CL; mm) and maturity (4-stage scale), indicate a good resolution of the immature component, while the other stages largely overlap (especially the 2nd and the 3rd stages); note also the (rare) presence of very large specimens in every maturity stage and the size of the smallest ripe females (CL= 14 mm).

Table 3 — Relative proportions (%) of immature and adults females of *Parapenaeus longirostris* sampled in a) the MEDITS surveys, 2-stage scale; b) the GRUND surveys, 4-stage scale.

	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
MEDITS														
immature	52.8	61.1	67.7	77.2	76.3	74.2	67.6	71.7	50.9	47.7	53.7	36.8	34.2	32.6
mature	47.2	38.9	32.3	22.8	23.7	25.8	32.4	28.3	49.1	52.3	46.3	63.2	65.8	67.4
GRUND														
stage 1 immature	73.9	79.5	79.9	82.0	61.9		71.9	63.9	30.5	65.8	40.0	42.3	42.8	
stage 2 developing	15.5	9.9	12.9	11.8	22.4		18.7	16.0	20.5	23.3	54.6	42.8	52.9	
stage 3 advanced	3.4	2.6	2.9	3.0	5.1		4.3	4.1	4.6	7.9	5.0	8.3	4.1	
stage 4 near ripe	7.3	8.0	4.4	3.2	10.6		5.1	16.0	44.3	2.9	0.4	6.6	0.2	

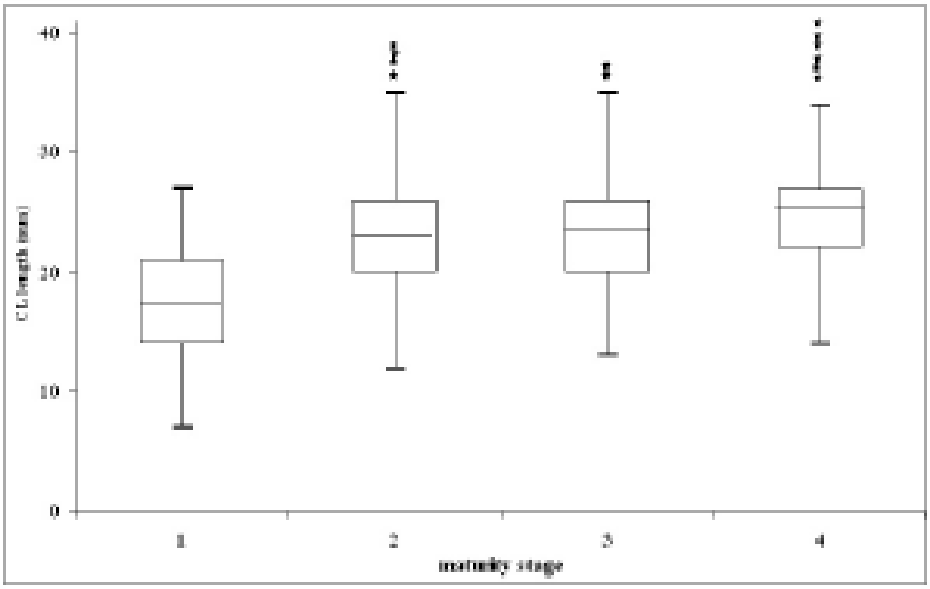
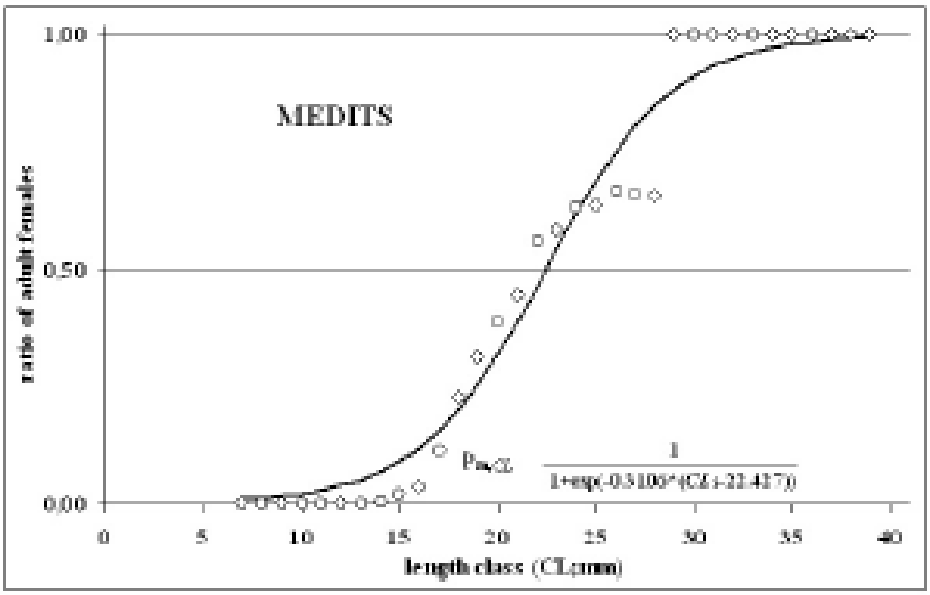


Figure 1 — Box plot representation of *Parapenaeus longirostris* females size structure (median, interquartiles and hinges) by maturity stage according to GRUND data.

The relative proportions of mature *vs*. immature females by size show a similar pattern in the two kinds of surveys (Fig. 2): a sinuous profile with a jump to 100% of maturity above 27-28 mm of carapace length. In spite of this



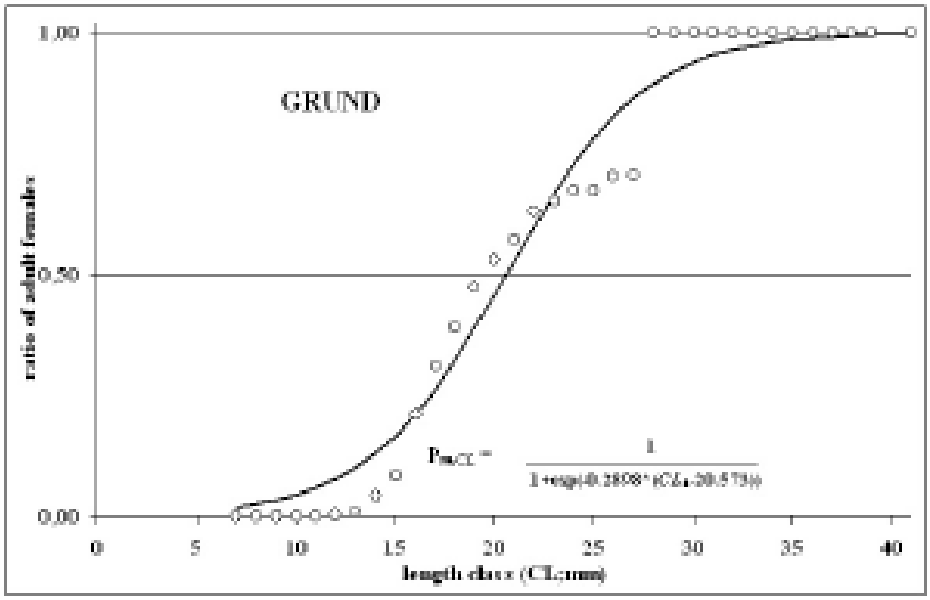


Figure 2 — Logistic interpolation of *Parapenaeus longirostris* females juveniles/adults proportions according to a) the MEDITS surveys; b) the GRUND surveys.

strong similarity, the logistic approach yields in GRUND a CL_m (20.6 mm) lower than in MEDITS (CL_m= 22.4 mm); averaging the two results is feasible (CL_m= 21.5 mm), since the two logistics do not differ substantially in their shape but only in their location. Such an approach is also supported by an almost equal maturity range ($CL_{m25\%}$-$CL_{m75\%}$), which is 7.07 mm in the spring-summer surveys and 7.58 mm in the autumn surveys.

Discussion

The macroscopic analysis of the mature condition of the ovaries, as an index of the spawning activity and a tool to estimate the size at onset of sexual maturity, is a common procedure in the stock assessment of commercial Penaeoid shrimps, which do not incubate eggs and shed directly in the water their fertilized gametes (Demestre & Fortuño, 1992). For female *P. longirostris*, as well as for other shrimps, most of the reproductive data and CL_m estimates are based on the application of empirical two-stage (Anonymous, 2001) up to 5-stage (De Ranieri *et al.*, 1986) macroscopic scales based on ovaries shape and color modifications, from whitish-creamy to dark green-turquoise blue as consequence of the carotenoid pigments (in this specific case, atoxantine; Ceccaldi, 1968) concentration.

Despite some variability, mainly reflecting sampling and methodological heterogeneity, the female reproduction aspects show a common pattern across the geographical distribution: extended spawning activity, with one-to-three prominent peak(s) in spring-summer and autumn-winter (depending on location, water temperature and female size), batch production of eggs, and absolute fecundity ranging between 20 000 and 400 000 eggs (Nouar, 1985; De Ranieri *et al.*, 1986; Tursi *et al.*, 1999; Sobrino & García, 1994; Sobrino & García, 2007). Speaking of the rose shrimps of the Strait of Sicily, an extended spawning activity with one peak occurring from August to March has been identified (Levi, 1991; Levi *et al.*, 1995)

Different problematic hampered, however, both the interpretation and comparison of maturity data in rose shrimp. The bathymetric distribution changes with size, sex and maturity condition; usually, the smallest specimens are captured at the outer edge of the shelf (100-200 m), where females outnumber males. In exploited grounds, ready-to-spawn females occur almost exclusively on the slope (Ardizzone *et al.*, 1990; Tursi *et al.*, 1999; Abellò *et al.*, 2002), while in protected areas large specimens are present on the shelf too (Rinelli *et al.*, 2005). Moreover, the reproductive periodicity and structure of the samples might show wide variations as consequence of natural or fishery-induced fluctuations in growth, mortality and recruitment strength.

That notwithstanding, both the size structure by maturity stages and the size at onset of maturity estimated in the present study are coherent with the general reproductive pattern described in literature for other Mediterranean (HELDT, 1938; NOUAR, 1985; DE RANIERI *et al.*, 1986; TOM *et al.* 1987; ARCULEO *et al.*, 1992; DE RANIERI *et al.*, 1998) and Atlantic stocks (CROSNIER *et al.*, 1970; SOBRINO & GARCÍA, 1994; SOBRINO *et al.*, 2005; SOBRINO & GARCÍA, 2007; GARCÍA-RODRÍGUEZ *et al.*, 2009): a) fluctuations in the relative proportions of the maturity stages, with occasional strong "pulses" of one component; b) strong overlapping between maturing and ripening stages; and c) seasonal variations in CL_m estimates.

The estimates of the size at onset of maturity (20.6-22.4 mm, with an average of 21.5 mm) obtained in this study fall at the lower bound of the literature range for the rose shrimp (19.5-28.5 mm), a range shared by the Atlantic and the Mediterranean populations (Tab. 4). The different CL_m estimations between MEDITS (22.4 mm) and GRUND (20.6 mm) seem to derive by location variation (likely reflecting fine changes in the size structure or closeness to the spawning peak), instead of a deep change in the maturity pattern between the two kinds of survey. It is worth noting the slightly higher value (CL_m= 24 mm) obtained by GANCITANO *et al.* (2008) in the same area of the present study using commercial landings data; those data, however, are

Table 4 — Size at onset of maturity of *Parapenaeus longirostris* in various geographical areas.

	SOM	remarks and reference
Atlantic	*CL; mm*	
Gulf of Cadiz	21.7	logistic; 21.5-22; SOBRINO & GARCÍA, 2007
southern Portugal	26.0	logistic; RIBEIRO-CASCALHO & ARROBAS, 1987
southern Portugal	24.0	RIBEIRO-CASCALHO, 1988 in SOBRINO *et al.*, 2005
Moroccan coast	26.1	logistic; 24.5-27.7; SOBRINO & GARCÍA, 1994
Gulf of Guinea	25.5	logistic; not exploited; SOBRINO & FERNÁNDEZ, 1991
waters off Congo	21.5	logistic; CROSNIER *et al.*, 1970
waters off Angola	21.6	SOBRINO & DE CÁRDENAS, 1996
Mediterranean		
Gulf of Alicante	25.6	logistic; GARCÍA-RODRIGUEZ *et al.*, 2009
Ligurian & northern Tyrrhenian	25.0	logistic; 24-26; DE RANIERI *et al.*, 1986
northern Tyrrhenian Sea	19.5	logistic; DE RANIERI *et al.*, 1998
southern & central Tyrrhenian	28.4	mean length mature; SPEDICATO *et al.*, 1996
off the southern coast of Sicily	24.0	mean length mature; landing data; GANCITANO *et al.*, 2008
off the southern coast of Sicily	21.5	logistic; 20.6-22.4; present study
northern Tunisia	20.1	logistic; BEN MERIEM *et al.*, 2001
western and eastern Ionian Sea	21.0	logistic; 20-22; TURSI *et al.*, 1999

likely biased, given the high discard rate of specimens smaller than 20 mm (SBRANA *et al.*, 2006).

Present results also confirm in part the reproductive pattern observed by LEVI (1991) and LEVI *et al.* (1995) for the rose shrimp of the Strait of Sicily: presence of mature females and juveniles throughout the year, with a peak in late autumn and winter. Moreover, histological analyses (BIANCHINI *et al.*, in press) indicate that the rose shrimp of the Strait of Sicily is an asynchronous batch spawner, in which all types of oocytes are present in the mature ovary at the same time.

The general low proportion of fully mature specimens (4^{th} stage) in the GRUND samples may reflect a sudden death after spawning (but *P. longirostris* has a generally-accepted life span of 2-3 years; TURSI *et al.*, 1999) or the inaccessibility of spent females (KAO *et al.*, 1999); still, a very rapid process of egg release and recovery (as suggested by the overlapping of the "mature" stages), i.e. the condition of batch spawner, might be a more sound explanation. Batch spawning is supposed to be an adaptive strategy to produce numerous large eggs within the constraints of limited food and/or body-cavity space (MURUA & SABORIDO-REY, 2003); matter-of-factly, the gonadosomatic index of rose shrimps does not exceed 6-7% (SOBRINO & GARCÍA, 2007; BIANCHINI *et al.*, in press).

In conclusion, the present SOMs, based on a wide temporal range and a large amount of specimens, represent consistent estimators to be used in assessment of the rose shrimp stock in the Strait of Sicily; in fact, speaking of the seasonal differences, although the more conservative MEDITS value, or the average figure, might be precautionarily employed, the GRUND estimate (CL_m= 20.6 mm), closer to the spawning peak, should be probably preferred as reference for managing the resource.

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