The impact of hanging-cleaning husbandry practices on Mediterranean mussels, *Mytilus galloprovincialis* Lmk, cultivated in the Mar Piccolo (Taranto, Ionian Sea, Italy)

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**ABSTRACT**

The impact of the stressful hanging-cleaning husbandry practices on the growth conditions of the cultured Mediterranean mussels, *Mytilus galloprovincialis* Lmk, cultivated in the Mar Piccolo (Ionian Sea) was investigated from November 2005 to June 2006. The experimental strings were randomly organized in four groups, with five replications, exposed to different time periods of hanging: Group A, none; Group B, once every 15 days; Group C, once every 30 days; Group D, once every 60 days.

The study, carried out on a total of 2000 mussels, showed that the cleaning of the mussel strings using the hanging-cleaning practice exerted an adverse effect on mussel growth (SGR%=46.62 in Group A; 44.85 in Group D; 43.72 in Group C; 42.12 in Group B). In particular, the highest percentage of meat yield occurred in the mussels more frequently exposed to air (Group B, 4.2±0.43 g) in spite of their lower morphometric variable values. In order to evaluate mussel condition, three different indexes were calculated.

The hanging practice in mussel cultivation, commonly used in the basin of Taranto and in many mussel farms all over the world, would provide an economic benefit to the mussel farmers allowing the greatest production and the highest specific growth rate (SGR%) of mussels, together with a more appreciable aesthetic for the consumer. Our findings suggest that the hanging practice every 60 days would provide an economic benefit allowing an increase of about 30% of total string weight compared to the 30-day hanging practice commonly in use.

**Key words:** *Mytilus galloprovincialis*, Ascidians, Fouling, Air exposure, Condition index.

**RIASSUNTO**

L’IMPATTO DELLA SCIORINATURA NELLA PRODUZIONE DI MITILI, *MYTILUS GALLOPROVINCIALIS* LMK, ALLEVATI IN MAR PICCOLO (TARANTO, MAR IONIO, ITALIA)

Da novembre 2005 a giugno 2006 è stata condotta una prova sperimentale in un impianto di allevamento di mitili, *Mytilus galloprovincialis* Lmk, sito nel Mar Piccolo (Mar Ionio) a nord di Taranto, con il fine di valu-
tare l’effetto stressante della pratica della sciorinatura sulla produzione e sull’accrescimento dei molluschi. Venti reste sperimentali sono state disposte in modo random in quattro differenti gruppi di trattamento, ognuno dei quali replicato per cinque volte, ed esposte all’aria a differenti intervalli: Gruppo A, nessuna esposizione; Gruppo B, sciorinato ogni 15 giorni; Gruppo C, ogni 30 giorni; Gruppo D, ogni 60 giorni. Le valutazioni biomorfometriche e di crescita, tratte raccogliendo e analizzando dati da 2000 soggetti, 100 per ciascuna resta sperimentale, hanno mostrato che la pratica della sciorinatura provoca un effetto avverso sull’accrescimento dei molluschi (SGR% pari a 46,62 nel gruppo A; 44,85 nel gruppo D; 43,72 nel Gruppo C; 42,12 nel Gruppo B). E’ stata riscontrata una maggiore quantità di parte edibile nei molluschi esposti all’aria più frequentemente, Gruppo B (4,2±0,43 g), rispetto ai soggetti sciorinati ogni 30 (3,3±0,28 g) e ogni 60 giorni (3,6±0,43 g), nonostante i valori più bassi dei parametri morfometrici, quali lunghezza, larghezza e spessore (e conseguentemente volume). Sono stati inoltre calcolati tre differenti indici di condizione (CIs, Condition Indexes) riportati in letteratura per quantificare la resa in parte edule e lo stato di benessere dei mitili. A differenza di quanto atteso in relazione alla valutazione dell’SGR, tutti gli indici calcolati hanno mostrato migliori condizioni per il Gruppo B (esposto all’aria più frequentemente), seguito dal Gruppo C (sciorinatura ogni 30 giorni) e dal Gruppo D (sciorinatura ogni 60 giorni). Per questo si ritiene opportuno considerare gli indici di condizione come dei parametri importanti ma assolutamente non sufficienti a dimostrare lo stato di benessere dei molluschi. All’inizio della prova le reste sperimentali avevano pari peso, mentre al termine della sperimentazione le reste pesavano: Gruppo A, 20,29 kg; Gruppo D, 18,60 kg; Gruppo C, 14,34 kg; Gruppo B, 10,68 kg. Le reste del primo gruppo si presentavano fortemente colonizzate da epibionti ed assolutamente non commercializzabili, mentre le reste appartenenti agli altri gruppi non avevano una presenza di epibionti tale da compromettere la commercializzabilità del prodotto. In considerazione dei risultati ottenuti con il presente lavoro, si propone di sostituire nella pratica della sciorinatura la cadenza mensile (gruppo C) comunemente effettuata, con la cadenza bimestrale (Gruppo D), al fine di ottenere il 30% circa di prodotto in più e dimezzare le spese di manodopera.

Parole chiave: Mytilus galloprovincialis, Ascidie, Fouling, Sciorinatura, Indici di condizione.

Introduction

Along the Italian coasts, one of the three most important production sites of Mytilus galloprovincialis is the Mar Piccolo of Taranto, a semi-enclosed basin divided in two inlets; First Inlet (900 Ha, average depth 13 m) and Second Inlet (1,276 Ha, average depth 9 m). It is connected through the Mar Grande to the Ionian Sea (Sarà et al., 1998; Orban et al., 2002; Carriglio et al., 2004). The two major types of mussel culture techniques practised in the Mediterranean Sea are the longline suspension culture system, which is the most common used in Italy, and the longline submerged culture system predominantly employed in France (Bompais, 1991; Mattei and Pellizzato, 1997; Prioli, 2001; Cataudella and Bronzi, 2002). In the suspension culture system, mostly adopted by mussel cultivators in the Mar Piccolo of Taranto, a long line is anchored to the seabed at both ends by a mooring line fixed to bottom by a heavy weight, while the line between them is kept afloat with plastic buoys (Della Ricca and Salerno, 1994; Cataudella and Bronzi, 2002). The ropes, on which the mussels are grown (strings) are hung vertically from the floating headline longline at half a meter intervals (Lutz et al., 1991; Danioux et al., 2000; Cataudella and Bronzi, 2002). Since the beginning of 18th century, M. galloprovincialis Lmk. represents the main filter-feeding mollusc cultured in large quantities in this coastal area, where a very high number of shellfish farms is located (Sarà et al., 1998; Stabili et al., 2005). In the basin of Mar Piccolo, the mussel cultivation process is composed of three stages: seed capture, pre-fattening and fattening, each
separated by a thinning out operation (Della Ricca and Salerno, 1994). The first stage consists in natural capture of mussel seeds from the basin water, by submerging 10 m long ropes up to 50 cm of depth. During winter-spring period mussel eggs and sperm are released into water where the fertilisation takes place. About 2 days later spawning occurs as the planktonic larvae begin to develop shells and byssal threads that tightly attach to ropes disposed perpendicularly to the shoreline (Della Ricca and Salerno, 1994; Danioux et al., 2000). During the thinning out, 1 cm long mussels are stripped from the collection ropes and inserted into a nylon net tube (sock); from each seed rope two new ropes are established. Thus, during the second stage, mussels grow attached to the ropes till they reach the size of 3 cm. The second thinning out process gives rise to the fattening stage during which mussels are cultured until they reach marketing size (Della Ricca and Salerno, 1994). The present study has been designed and addressed to the last two stages (second and third stages) as mentioned above.

Several studies reported biofouling communities as a real problem for mussel production, resulting in reduced efficiency of submerged equipment, direct competition for trophic resources, reduction of meat yields and poor seed collection (Osman et al., 1989; Wahl, 1989; Zajac et al., 1989; Buschbaum and Saier, 2001; LeBlanc et al., 2002; Railkin, 2004). For instance, in the Mediterranean Sea, as well as in the Taranto basin, mussel strings are usually heavily covered with epibionts consisting of mostly ascidians such as Ciona intestinalis (Phlebobranchia, Cionidae) and Clavelina lepadiformis (Aplousobranchia, Clavelinidae) mainly during the summertime (Pastore, 2001; McDonald, 2004). As reported on several occasions, biofouling is a major concern for mussel farmers (Carver et al., 2003; Beaz et al., 2005). Indeed, culture ropes made heavy by foulers need more work to be handled and hoisted, thus increasing the processing costs (LeBlanc et al., 2002; Carver et al., 2003; Beaz et al., 2005). To improve mussel cultivation avoiding the negative impact of epizoic overgrowth on bivalves, the mussel farmers of Mar Piccolo usually expose the strings to air for a variable period. This technique enables the reduction of space competition by preventing the seeds or larvae of other species from settling on the ropes.

Several variables are known to influence meat yield, nutritional characteristics and biochemical composition of M. galloprovincialis such as water temperature, salinity, food availability and reproductive cycle (Fernandez-Reiriz et al., 1996; Aral, 1999; Orban et al., 2002). Previous investigations have shown that both tidal emersion (in terms of time of air exposure and starvation) and mussel colonization by epibionts negatively affect mussel size and growth rates. On tidal coasts, growth rates of mussels are faster at exposed sites than at sheltered ones, and shells are heavily overgrown by barnacles (McQuaid and Lindsay, 2007). On the contrary, subtidal mussels were found larger and less fouled (Buschbaum and Saier, 2001). However, scant information is available from the literature on the impact of the stressful hanging-cleaning husbandry practices on the growth of M. galloprovincialis cultured along the southern Italian coasts. The aim of this study was to evaluate whether the hanging-cleaning treatment adopted by farmers to reduce biofouling might represent a main issue in causing significant differences on mussel growth. The optimum intervals of air exposure that would be effective in removal epizoic growth has also been evaluated, by investigating both mussel sizes and condition indexes in order to individuate the condition promoting the increased production.
and the decreased labour costs. Finally, we aimed to examine whether the presence of epibionts might negatively influence mussel growth and meat yield.

**Material and methods**

**Study site**

The study was conducted on a mussel farm, based on long-line system, located in the Second Inlet of the Mar Piccolo of Taranto (Figure 1) 250 m from the shoreline, as indicated by the black dot in Figure 1. The seabed of this body of water has an average total depth of 11.5 m (Annicchiarico et al., 2007). Water temperature ranged from 10.5-17.8 °C in winter and 26.5-28.0 °C in summer, and average salinity was around 38.3-39.0 (psu). Regarding the nutrient parameters in the basin, it has been recently reported that the daily input of nitrogen and phosphorus account for about 17.2 t/day of nitrogen and 0.3 t/day of phosphorus (Caroppo and Cardellicchio, 1995; Umgiesser et al., 2007). Furthermore, a condition of progressive eutrophication moving from the Mar Grande to the Second Inlet has been pointed out by the Chl-a, dry weight of suspended matter and its content in organic matter data (Alabiso et al., 2005) (data also available at the Italian Ministry of the Environment and Protection of the Territory and Sea; website: http://www.sidimar.ipzs.it/).

The particular hydrography of the Mar Piccolo is characterized by the input of over 40 submarine freshwater springs whose hydrodynamics, along with reduced seawater exchange, stabilizes seawater temperature.

**Figure 1.** Location of experimental trial site. Map of basins of Mar Piccolo of Taranto (Southern Italy) where the sampling stations are located.
HangIng-cleanIng practIceS on muSSelS and salinity (Stefanon, 1984; Pastore, 1993). This hydrodynamic condition provides rich planktonic pabulum propitious for both mussel cultivation and for the development of many epibiotic species (Tunicates, Porifers, Anellids) (Pastore, 2002).

Experimental design

Overall 2000 specimens of Mediterranean mussels were sampled monthly from a site with a typical longline culture system from the beginning of November 2005 to the end of June 2006.

At the beginning of the survey, 20 experimental strings of mussels were set up using seeds of 1 cm in length in accordance with the site rearing cycle. Each string was approximately 200 cm long and with a total mean weight of about 6.40 kg and was suspended 6 m above the seabed in order to avoid contact with predators (asteroids and crabfish). All the experimental strings were randomly placed with an average distance of 0.5 m between two consecutive ropes, on a single longline disposed parallel to the seashore. The strings were randomly organized in four experimental groups with five replications per group, with the following hanging times: Group A, no air exposure; Group B, once every 15 days; Group C, once every 30 days; Group D, once every 60 days. During the hanging-cleaning operations all mussel strings were exposed to air (d in Figure 2). The time of exposure was variable as a function of season: i.e. 12 hours during the night in spring-summer and 24 hours in autumn-winter. Most fouling organisms die due to the stress of air drying. In this way,

Figure 2. Epibionts and mussel strings.
air exposure provides an indirect cleaning of mussel shells by the passive detachment of the dead invertebrates 2-3 days after the submersion of strings. Even though the mussels lose dead foulers, when passing from one emersion treatment to the subsequent, other ascidian larvae attach themselves directly to mussel shells thus promoting new epibiotic colonization. According to the experimental design, all the strings were subjected to the hanging treatment except the control group.

At the end of the trial, each string of every replicate in each group was weighed; its length was measured and the presence of the epibionts was evaluated. From each string a sample consisting of a 50 cm length of rope was withdrawn just in the middle, and 100 mussels were randomly picked up and individually weighed in the laboratory.

**Biometry and condition indexes**

Mussel shells were carefully cleaned by removing mud, byssus and epibionts under fresh water flow, measured and then opened. Individual mussel biometric parameters were measured according to the three linear shell dimensions described by Seed (1973): Shell Length (SL, mm; identified as the maximum antero-posterior axis), Shell Height (SH, mm; identified as the maximum dorso-ventral axis) and Shell Width (SWh, mm; identified as the maximum lateral axis), using a Vernier calliper to the nearest 0.1 mm. Then, the Shell Volume (SV, mm$^3$) was calculated by multiplying the shell dimension parameters (length x height x width) (Seed, 1973).

Specific growth rate (SGR) was calculated as follows:

$$\text{SGR} (%) = \left[ \frac{\ln \text{SL}_2 - \ln \text{SL}_1}{(T_2 - T_1)} \right] \times 100$$

where, SL$_1$ and SL$_2$ are mean shell length as the time T$_1$ and T$_2$ in days (T$_2$-T$_1$ was 240 days considering an average 30 days per month) (Chatterji et al., 1984).

Subsequently, total weight (TW, g) of individual live mussels, and after opening and draining on filter paper, shell weight (SW, g) and wet somatic weight (WMW, g) were recorded by a technical balance (Hermes, PBI) to the nearest 0.001 g to obtain the Condition Index 1, according to the following equation: CI1=[WMW/(TW-SW)]*100 (Aguirre, 1979; Rayyan et al., 2004).

WMW and shell mean length (SL, mm), recorded by an stainless steel technical calibre to the nearest 0.1 mm, were utilized to obtain the Condition Index 2, using the following formula: CI2=WMW*1000/(SL*10) (Davenport and Chen, 1987; Crosby and Gale, 1990; Lundebye et al., 1997).

WMW, SL, shell mean height (SH, mm) and shell mean width (SWh, mm) were used to obtain the Condition Index 3, calculated according to the following equation: CI3=WMW/[SL*1000/(SWh/SH)] (Seed, 1973; Aguirre, 1979; Lundebye et al., 1997).

Scientific literature reports a variety of Condition Indexes (CIs) that have been used to measure well-being and commercial quality of bivalves (Davenport and Chen, 1987; Crosby and Gale, 1990; Orban et al., 2004). Since in the present study we aimed to verify the percentage of meat yield related to the internal volume of the shell cavity, the previously described Condition Indexes, CI1, CI2 and CI3 were calculated.

Normal distribution and homogeneity of variances were established before statistical analysis (Barlett’s test). Data mean and standard errors (M±SE) were calculated for all the parameters. Two-way analysis of variance (ANOVA) was used to test the differences among the two independent variables, treatment and replicates. In the setting of the analysis of variance, the *post-hoc Duncan’s* multiple comparison Test was employed to determine significant differences between the treatment means of the four experimental groups. All the statistical
tests were carried out using SPSS statistical package (1998). An experiment critical values alpha of 0.05 was used to set the significance of all the statistical tests.

Results

The overall variations of the morphometric and weight parameters obtained over the 8 months of the experimental study are shown in Table 1. Treatments had a significant effect on shell dimension parameters (width, length and height; P<0.01; P<0.001) and a highly significant effect (P<0.001) on mussel weight parameters, except for the shell mean weight (P>0.05). The greatest difference in the mean value of the shell length of mussels was detected between group A and B, while there were no significant differences between group C and D, both greater than B (Table 1). Highly significant differences in the shell height were detected among all the groups: group A was the greatest followed by groups D, C and B (Table 1). Shell height of group A mussels (28.8±0.17 mm) was significantly greater (P<0.001; Table 1) than that of group B mussels (25.9±0.16 mm). Significant differences for width (P<0.01) were detected between the groups A (20.7±0.34 mm) and B (18.8±0.09 mm). The mean value of the weight parameters of mussels showed a singular pattern of variability. Particularly, significant differences were found in total mean weight values among all the groups, with A mussels (16.6±0.32 g) that were significantly heavier (P<0.001; Table 1) than those of the group D (14.8±0.65 g), C (13.7±0.43 g) and B (12.8±0.24 g). The wet mean weight (P<0.05; Table 1) of the group A mussels (4.4±0.21 g) approaches almost that of the group B mussels (4.2±0.43 g). Conversely, the differences among groups for the mean values of the shell mean weight were not significant among groups (P=0.246; Table 1). In a further investigation of the relative weight parameters, we observed that the patterns of shell mean weights (SW) resulted not different and absolutely similar among all the experimental groups. On the contrary, unexpected values were found in wet meat weight (WMW) measures (P<0.05; Table 1) with mussels of group A rather heavier due to the higher water content.

Table 1. Morphometric and weight parameters related to the randomly selected mussels sampled at the end of the trial (five replications were made per each group; n=100 mussels examined for each replication).

| Parameter    | Group A       | Group B       | Group C       | Group D       | P-value |
|--------------|---------------|---------------|---------------|---------------|---------|
| Shell length | 57.5±0.67 A   | 49.5±0.40 Ab  | 52.2±0.60 B   | 54.2±0.86 C   | 0.000 ***|
| Shell height | 28.8±0.17 Aa  | 25.9±0.16 B   | 26.8±0.15 Bc  | 27.7±0.45 Ac  | 0.000 ***|
| Shell width  | 20.7±0.34 A   | 18.8±0.09 Ab  | 19.4±0.24 B   | 19.9±0.32 B   | 0.002 ** |
| Shell volume | 35435.6±AxD   | 24659.1±CxD  | 27816.0±BcC  | 31263.9±BcD  | 0.000 ***|
| Total weight | 16.6±0.32 A   | 12.8±0.24 D   | 13.7±0.43 C   | 14.8±0.65 B   | 0.000 ***|
| Shell weight | 5.6±0.13      | 5.2±0.07      | 5.3±0.18      | 5.2±0.27      | 0.246 ns |
| Wet weight   | 4.4±0.21 Aa   | 4.2±0.43 bc   | 3.3±0.28 BcD | 3.6±0.12 BcD  | 0.014 *  |

ns = not significant (when P>0.05); *P<=0.05; **P<=0.01; ***P<=0.001. Superscript letters indicate Duncan’s post hoc comparison test. Values with the same superscript are not significantly different (P>0.05).
(indirectly measured). On the whole, these data indicate that the mussels that were never cleaned showed greater growth both in shell length and in shell height in comparison to the mussels cleaned more often (Table 1). The highest growth rate (SGR%) was found in group A mussels (46.62%) followed by the mussels of the groups cleaned every two months (group D, 44.85%), every month (group C, 43.72%) and every 15 days (group B, 42.12%) as shown in Table 2. In Figure 3, the SGR% and the total mean weight are reported in order to understand the best rearing method considering both production and Specific Growth Rate.

Moreover, the comparison of the Condition Indexes (CI 1,2,3) in the four experimental groups revealed that the most frequently cleaned group (B) showed the best Condition Indexes (Table 2) due to the higher percentage of meat yield in spite of its lower morphometric parameters and water content. This is an unexpected result as the edible part mean weight (WMW) from Group B is statistically similar to those from Group A (P<0.05; Table 1). Slightly lower is the level of meat yield in mussels of groups C and D compared that of the control group (A). Thus, such a result appeared in contrast with the higher total mean weight observed in the mussels that were never hung (A), which otherwise showed the highest values of morphometric parameters, as well as the highest mussel weight, but a lower percentage of meat yield.

The impact of the fouling community has been evaluated on the never-hung mussels (A) on which foulers were left to grow undisturbed (a in Figure 2). Analysing this epibentic community, we observed a minority amount represented by polychaetes, predominantly _Sabella spallanzanii_ (Annelida, Polychaete, Serpulidae) and rare barnacles, with a marked prevalence of several ascidians species (b and c in Figure 2). The most common ascidians species found was _C. intestinalis_, followed by _C. lepadiformis_. Styelidae and Didemnidae were other family present, although the latter was rare.

We recorded at least 6 species of ascidians on the mussel shells further classified in three relative abundance classes, as shown in Table 3. No diversity in epifauna species composition was found in the mussel strings of the three experimental groups in comparison to mussels not exposed to the air.

**Discussion**

**Variation in mass gain and fouling**

Results from the present study showed that epibionts seem to have an adverse effect on the mussel cultivation in the Mar Piccolo given that most frequently cleaned (B) showed higher Condition Indexes than those never cleaned (A), or those cleaned

| Table 2. Condition Indexes and Specific Growth Rate (SGR) in the experimental groups. |
|-------------------|-------------------|-------------------|-------------------|-------------------|
|                   | Group A           | Group B           | Group C           | Group D           |
| Condition Index 1 | 39.96             | 55.56             | 38.90             | 37.55             |
| Condition Index 2 | 7.62              | 8.48              | 6.25              | 6.68              |
| Condition Index 3 | 0.11              | 0.12              | 0.09              | 0.09              |
| SGR%              | 46.62             | 42.12             | 43.72             | 44.85             |

SGR (%)={[ln SL2-ln SL1]/(T2 − T1)}*100.

CI 1=[WMW/(TW-SW)]*100; CI 2=WMW*1000/(SL*10); CI 3=WMW/[SL*(SWh/SH)].
every 30 (C) or those cleaned every 60 days (D) (Table 2). Throughout current literature there are contradictory results regarding the interactions between bivalves and ascidians. Some studies stated that ascidians would act as competitors for the space for the attachment to strings (Osman et al., 1989; Arakawa, 1990) or as trophic competitors for food (Zajac et al., 1989). This latter consideration has been recently challenged since among marine benthic filter-feeders different capture mechanisms of food particles have been recognised. Riisgard and Larsen (2000) showed, for example, that in bivalves the sorting and capture of particles of variable size occurs by cirri trapping through the beating of three different types of gill filaments. Whilst in some species of polychaete worms and ascidians, ciliary or muscular pumps drive water through a mucus net, which entraps the suspended food particles by sieving them into rectangular meshes of fibres (Riisgard and Larsen, 2000). Thus the different particle capture mechanisms along with the different size of engulfed particles (<2-3 µm in ascidians and >4-5 µm in bivalves), and finally the different filtration rates (0.3 mm³/s in C. intestinalis and 1 mm³/s in Mytilus), permit a complementary coexistence of bivalves and ascidians without negative impact on growth, in almost food plenty conditions (Mook, 1981; Riisgard et al., 1996a, 1996b; Petersen et al., 1997; Petersen et al., 1999; Mazouni et al., 2001; Leblanc et al., 2003), as in the case of the nutrient rich water in this study site. In accordance with Leblanc et al. (2003), our findings indicate that epibionts are not competitors in the case of conditions with plenty food. In fact, the never cleaned mussels (group A), which were the most covered with foulers, along with those
most frequently cleaned (group B) bearing no foulers, showed higher wet meat weight compared to C and D groups which were less frequently cleaned. Furthermore, the heavily fouled mussels (group A) showed values of the Condition Indexes lesser than the group B mussels, in spite of its highest wet meat weight and SGR%. These findings provided convincing evidence that mussels overgrown with epibionts need to invest much energy in byssus thread production in order to prevent dislodgement from the ropes, thereby subtracting part of energy budget from somatic growth (Price, 1983; Witman and Suchanek, 1984). Moreover, consumers reject a dirty product resulting in its lesser value.

**Variation in meat and shell growth**

Several studies have reported on the relationship between food availability and mussel growth efficiency (Thompson, 1984; Goulletquer and Bacher, 1988; Sarà et al., 1998; Garen et al., 2004). It has been proven that the south western Mediterranean waters provide hydrobiological features that are favourable for optimal culturing of mussels (Dame, 1996).

In our study, the differences observed in the growth pattern did not seem to be related to either the variations in food supply or to environmental factors, as conversely reported by other Authors (Kiorboe et al., 1981; Mallet et al., 1987; Fuentes et al., 2000; Garen et al., 2004). In fact, in this study all the experimental groups were placed in the same nutrient-rich area of cultivation on the same long-line. In particular, all the mussels had the same seed and site of origin, the same handling, and all were grown in the same environment with the same temperature, salinity, tidal currents, nutrients in water (Caroppo and Cardellicchio, 1995; Alabiso et al., 2005). It has been suggested

| Table 3. Classification of Sea Squirts isolated by mussel strings of Group A and grouped in three frequency classes. |
|---------------------------------------------------------------|
| **Phylum Chordata - Subphylum Tunicata - Class Ascidiacea**   |
|---------------------------------------------------------------|
| **Order Enterogona – Suborder Aplousobranchia**               |
| Family Clavelinidae                                           |
| *Clavelina lepadiformis*                                      |
| X                                                             |
| Family Didemnidae                                             |
| *Didemnum sp.*                                                |
| X                                                             |
| **Order Enterogona – Suborder Phlebobranchia**                |
| Family Cionidae                                               |
| *Ciona intestinalis*                                          |
| X                                                             |
| **Order Plerogona – Suborder Stolidobranchia**                |
| Family Styelidae                                              |
| *Styela placata*                                              |
| X                                                             |
| *Botrylloides leachi*                                         |
| X                                                             |
| *Botryllus schlosseri*                                        |
| X                                                             |

Caracciolo et al. (2001)
that mussels frequently exposed to air and, located at higher tidal levels grew with lower growth rates as consequence of the shorter period of access to food (Seed, 1976; Garen et al., 2004). Possibly, differences in emersion time might contribute to the variations of growth (Seed, 1976; Skidmore et al., 1985; Buschbaum and Saier, 2001; Garen et al., 2004). In our study, the total number of hours of air exposure was not equal for the three strings that experienced emersion treatments. It is likely that differences in growth among these groups cannot be attributed to the inaccessibility to food during emersion times, as claimed by other authors in intertidal mussels. Greseth et al. (2003) found that mussels exposed to air were able to recover the biochemical indices to the pre-treatment levels during the post-exposure period (14 days). We rather hypothesise that a different physiological behaviour in terms of adaptive response occurred along as a periodic physiological stress.

Many authors refer to the Condition Indexes as a good indicator of growth performance (Petersen et al., 1997), giving a comprehensive picture of meat quality for the market value (Orban et al., 2004), and an ecophysiological measure of the mussel well-being, summarizing the physiological status of a bivalve under changed environmental conditions (Lucas and Beninger, 1985; Davenport and Chen, 1987; Crosby and Gale, 1990; Lundebye et al., 1997; Mubiana et al., 2006). Survival in air and Condition Index were considered by Pampanin et al. (2005) as good physiological indicators of the health status of *M. galloprovincialis*. In the present survey, the higher CIs (meat yield) recorded in group B, could have several explanations, including a diversion of energy budget versus the meat growth. Thus, we hypothesise that as meat increases, completely filling the internal shell cavity capacity, the volume of intervacular fluid decreases. This hypothesis is consistent with our findings regarding the lowest water content and the lowest theoretic shell volume found in group B mussels. Our findings agree with the results of Garen et al. (2004) found in *Mytilus edulis* cultivated on longline, pole and bottom systems in France. Authors reported a reduced growth in length as well as better Condition Indexes in intertidal mussels cultured on pole (air exposed during tide), as we found in group B mussels, compared to the longline cultured (never exposed to air) ones. However, the production of mussels hanging-cleaned every 15 days are labour-intensive and time-consuming, thus requiring double labour and operating costs compared to mussels traditionally produced (group C, air exposure every 30 days). Conversely, group D production is very interesting both in terms of SGR% and labour cost.

As regards shell growth, it has been shown to primarily depend on deposition of ions, mostly calcium dissolved in seawater, and only partially on metabolic carbon sources such as food (Alunno-Bruscia et al., 2001). Firstly, this means that shell growth is less influenced than tissue growth by variations in food availability (Tanaka et al., 1986) since the organic content of shell tissue is much lower (<5%) than soft tissue (Jorgensen, 1976; Price et al., 1976). Secondly, one of the earliest prompt responses to a stress event (handling, transport, shaking) in bivalves has been demonstrated to be the immediate recruitment of calcium ions from the tissues to the haemolymph, resulting in higher calcium and glucose levels for haemocytes (Pekkarinen and Suoranta, 1995). This consideration might well explain the lowest length growth in the more stressed mussels (group B) as all the calcium might be diverged for defence and no longer available for the shell mineralization.
**Stress influence**

We further speculate that the hanging treatment could expose mussels to a forced and stressful environmental change, passing them from their natural aquatic environment to the air exposure. Within a few hours, mussels have to cope with a number of critical unnatural conditions such as capture, shaking, food deprivation, osmotic shock, thermal imbalance, changes in oxygen, light and salinity regimen, air and wind exposure. In bivalves, temperature and salinity changes were found to elicit long lasting circulating noradrenaline (NA) and dopamine (DA) increases in response to stress. Lacoste et al. (2001b) detected a rapid catecholaminergic response (<5 min) for acute mechanical stressors, and a long lasting (up to 72 h) response to temperature and salinity variations. Accordingly, soon after the hanging stress episode, several adaptive responses (nervous, biochemical and physiological ones) are engaged by bivalves attempting to cope adverse conditions and to survive in the new environment (Labarta et al., 1998; ICES Mariculture Committee, 2004). Presumably, a series of repeated stressful emersion episodes with a regular and periodic frequency of 15 days (as occurred in group B mussels of our study) induces an adaptation to stress maintaining elevated cortisol levels over the normal baseline (Lacoste et al., 2001a). It is likely that in the subsequent days post-stress metabolic compensation occurs by activating metabolic enzymes (Lesser and Kruse, 2004).

Overall, during the eight months of our study, group B mussels underwent up to 16 stressful emersion episodes, whereas mussels of the groups C and D experienced 8 and 4 emersion treatments, respectively. So the question remains: “is it true to consider that Condition Indexes reflect the well-being status of mussels?”

**Conclusions**

The aim of this study was to investigate in mussels the variations of the specific growth rate (%) and Condition Indexes following air exposure treatments by hanging-cleaning mussels for different emersion times, in order to propose to mussel farmers the best way to produce a better product with lower costs. We expected decreased SGR% in the most fouled group (A) relative to treatment groups, according to the general assumption that mussels with an overgrowth of epibionts suffer from food competition (Buschbaum and Saier, 2001). Our findings suggest that heavily fouled mussels of Group A grow faster and show higher growth parameters, even though paradoxically the highest Condition Indexes (meat yield) were recorded in the Group B mussels. Supported by the above mentioned explanations, we can assert that mussels in Group A resulted heavier but with the highest water content and a percentage of meat yield lesser than that of the others groups. Undoubtedly, the more cleaned and stressed mussels (Group B) presented the internal shell cavity capacity completely filled with meat and with the lowest water content, thus more appreciated by the consumer. Probably, the recurrent stress conditions stimulate mussel metabolism in Group B mussel, such as meat growth, in order to cope the adverse environmental factors.

In any case, both mussels of Group A and B present serious problem for commercialization, due to the dirtiness and to the size, respectively. While small size of *M. galloprovincialis* is somewhat disappointing from a consumer’s point of view, larger size is thought appropriate for market size and quality. We should not forget that meat quality and animal welfare are not easily understood by the consumer, and it is very difficult to increase the price of mussels that present better Condition Indexes.
At last, we conclude that the hanging practice every 60 days would also provide an economic benefit by allowing the best SGR% and an increase of about 30% in total string weight compared to the 30-day hanging practice, together with a more appreciably aesthetic aspect for the consumer.

The common hanging practice adopted in mussel cultivation of the Mar Piccolo (every 30 days) could be substituted by the hanging practice every 60 days, and to consider cleaning the mussel strings only 7-10 days before the recollection, in order to permit the commercialisation of a clean product.

REFERENCES

Aguirre, M.J., 1979. Biologia del mejillon (Mytilus edulis) de cultivo de la Ria Vigo. Bol. Inst. Esp. Oceanogr. 5:107-160.

Alabiso, G., Giacomini, M., Milillo, M., Ricci, P., 2005. The Mar Piccolo of Taranto: 8 years of chemical-physical measurements. Biol. Mar. Medit. 12:369-373.

Alunno-Bruscia, M., Bourget, E., Fréchette, M., 2001. Shell allometry and length-mass-density relationship for Mytilus edulis in an experimental food-regulated situation. Mar. Ecol. Prog. Ser. 219:177-188.

Annicchiarico, C., Biandolino, F., Cardellicchio, N., Di Leo, A., 2007. Predicting toxicity in marine sediment in Taranto Gulf (Ionian Sea, Southern Italy) using Sediment Quality Guidelines and a battery bioassay. Ecotoxicology 16:239-246.

Arakawa, K.Y., 1990. Competitors and fouling organisms in the hanging culture of the Pacific oyster, Crassostrea gigas (Thunberg). Mar. Behav. Physiol. 17:67-94.

Aral, O., 1999. Growth of the Mediterranean mussel (Mytilus galloprovincialis Lam., 1819) on ropers in the Black Sea, Turkey. Turk. J. Vet. Anim. Sci. 23:183-189.

Beaz, D.V., Beaz, S., Dürr, J., Icely, A., Lane, J., Thomason, D., Watson, P., Willemsen, P.R., 2005. Sustainable Solutions for Mariculture Biofouling in Europe. ASLO Conference, Santiago da Compostela, Spain. Home page address: http://www.crabproject.com/index.php/57/publications/Bompais, X., 1991. Les filières pour l’élevage des moules – Guide pratique. Publication IFREMER, Paris, France.

Buschbaum, C., Saier, B., 2001. Growth of the mussel Mytilus edulis L. in the Wadden Sea affected by tidal emergence and barnacle epibionts. J. Sea Res. 45:27-36.

Caroppo, C., Cardellicchio, N., 1995. Preliminary study on phytoplankton communities of Mar Piccolo in Taranto (Ionian Sea). Oebalia 21:61-76.

Carriglio, D., Fanelli, G., Rubino, F., 2004. First record of the alien gastropod Melibe fimbriata (Opistobranchia: Tethyidae) in the Taranto seas (Mediterranean Sea). J. Mar. Biol. Assoc. UK 84:1067-1068.

Carver, C.E., Chisholm, A., Mallet, A.L., 2003. Strategies to mitigate the impact of Ciona intestinalis (L.) biofouling on shellfish production. J. Shellfish Res. 22:621-631.

Cataudella, S., Bronzi, P., 2002. Acquacoltura responsabile. Unimar-Uniprom ed., Roma, Italy.

Chatterji, A., Ansari, J.A., Ingole, B.S., Parulekar, A.H., 1984. Growth of Green Mussels, Perna viridis L. in a Sea Water Circulation System. Aquaculture 40:47-55.

Crosby, M.P., Gale, L.D., 1990. A review and evaluation of bivalve condition index methodologies with a suggested standard method. J. Shellfish Res. 9:233-237.

Dame, R.F., 1996. Ecology of Marine Bivalves. An Ecosystem Approach. CRC Press, Boca Raton, FL, USA.

Danioux, C., Bompais, X., Loste, C., Paquette, P., 2000. Offshore mollusc production in the Mediterranean basin. In: J. Muir and B. Basurco (eds.) Mediterranean offshore mariculture. CIHEAM-IAMZ - Options Méditerranéennes 30 Série B, Zaragoza, Spain, pp 115-140.
Davenport, J., Chen, X., 1987. A comparison of methods for the assessment of condition in the mussel (*Mytilus edulis* L.). J. Mollusc. Stud. 53:293-297.

Della Ricca, R., Salerno, G., 1994. Aspetti economici della mitilicoltura tarantina. Laguna 22:25-31.

Fernandez-Reiriz, M.J., Labarta, U., Babarro, J.M.F., 1996. Comparative allometries in growth and chemical composition of mussel (*Mytilus galloprovincialis* Lmk) cultured in two zones in the Ria sada (Galicia, NW Spain). J. Shellfish Res. 15:349-353.

Fuentes, J., Gregorio, V., Giràldez, R., Molares, J., 2000. Within-raft variability of the growth rate of mussels, *Mytilus galloprovincialis*, cultivated in the Ria de Arousa (NW Spain). Aquaculture 189:39-52.

Garen, P., Robert, S., Bougrier, S., 2004. Comparison of growth of mussel, *Mytilus edulis*, on longline, pole and bottom culture sites in the Pertuis Breton, France. Aquaculture 232:511-524.

Goulletquer, P., Bacher, C., 1988. Empirical modeling of the growth of *Ruditapes philippinarum* by means of nonlinear regression on factorial coordinates. Aquat. Living Resour. 1:141-154.

Greseth, S.L., Cope, W.G., Rada, R.G., Waller, D.L., Bartsch, M.R., 2003. Biochemical composition of three species of unionid mussels after emersion. J. Mollusc. Stud. 69:101-106.

International Council for the Exploration of the Sea (ICES), Mariculture Committee, 2004. Report Meet. of the Working Group on Marine Shellfish Culture (WGMASC). Page 18 in Report CM 2004/F Meet. ICES, 05, Ref. G, Advisory Committee for Marine Environment (ACME), Portland, Maine, USA.

Jorgensen, C.B., 1976. Growth efficiencies and factors controlling size in some mytilid bivalves, especially *Mytilus edulis* L.: review and interpretation. Ophelia 15:175-192.

Kiorboe, T., Mohlenberg, F., Nohr, O., 1981. Effect of suspended bottom material on growth and energetics in *Mytilus edulis*. Mar. Biol. 61:283-288.

Labarta, U., Fernandez-Reiriz, M.J., Babarro, J.M.F., 1998. Differences in physiological energetics between intertidal and raft cultivated mussels *Mytilus galloprovincialis*. Mar. Biol. Prog. Ser. 152:167-173.

Lacoste, A., Malham, S.K., Cueff, A., Jalabert, F., Gélebart, F., Poulet, S., 2001a. Evidence for a form of adrenergic response to stress in the oyster *Crassostrea gigas*. J. Exp. Biol. 204:1247-1255.

Lacoste, A., Malham, S.K., Cueff, A., Poulet, S.A., 2001b. Stress-Induced Catecholamine Changes in the Hemolymph of the Oyster *Crassostrea gigas*. Gen. Comp. Endocrinol. 122:181-188.

Leblanc, A.R., Landry, T., Miron, G., 2003. Fouling organisms of the Blue Mussel *Mytilus edulis*: their effect on nutrient uptake and release. J. Shellfish Res. 22:633-638.

Leblanc, A., Landry, T., Miron, G., 2002. Fouling organisms in a mussel cultivation bay: their effect on nutrient uptake and release. Can. Tech. Rep. Fish. Aquat. Sci. 2431:7-16.

Lesser, M.P., Kruse, V.A., 2004. Seasonal temperature compensation in the horse mussel, *Modiolus modiolus*: metabolic enzymes, oxidative stress and heat shock proteins. Comp. Biochem. Physiol. A. 137:495-504.

Lucas, A., Beninger, P.G., 1985. The use of physiological condition indices in marine bivalve aquaculture. Aquaculture 44:187-200.

Lundebye, A.K., Langston, W.J., Depledge, M.H., 1997. Stress proteins and condition index as biomarkers of tributylin exposure and effect in mussels. Ecotoxicology 6:127-136.

Lutz, R., Chalermwat, K., Figueras, A.J., Gustafson, R.G., Newell, C., 1991. Mussel aquaculture in marine and estuarine environments throughout the world. In: W. Menzel (ed.) Estuarine and marine bivalve mollusk culture. CRC Press, Boca Raton, FL, USA, pp 57-97.

Mallet, A.L., Carver, C.E.A., Coffen, S.S., Freeman, K.R., 1987. Winter growth of blue mussel *Mytilus edulis* L.: importance of stock and site. J. Exp. Mar. Biol. Ecol. 108:217-228.

Mattei, N., Pellizzato, M., 1997. Mollusk fisheries and aquaculture in Italy. NOAA Tech. Fishe. Bull., U.S. Dept. of Commerce ed., Seattle, WA, USA, 3:201-216.

Mazouni, N., Gaertner, J.C., Deslous-Paoli, J.M.,
HangIng-cleanIng practIceS on muSSelS

Pastore, M., 2001. Composition of biofouling communities on suspended oyster cultures: an in situ study of their interactions with the water column. Mar. Ecol. Prog. Ser. 214:93-102.

McDonald, J., 2004. The invasive pest species Ciona intestinalis (Linnaeus, 1767) reported in a harbour in southern Western Australia. Mar. Poll. Bull. 49:854-874.

McQuaid, C.D., Lindsay, T.L., 2007. Wave exposure effects on population structure and recruitment in the mussel Perna perna suggest regulation primarily through availability of recruits and food, not space. Mar. Biol. 151:2123-2131.

Mook, D.H., 1981. Removal of suspended particles by fouling communities. Mar. Ecol-Prog. Ser. 1:279-281.

Mubiana, V.K., Vercauteren, K., Blust, R., 2006. The influence of body size, condition index and tidal exposure on the variability in metal bioaccumulation in Mytilus edulis. Environ. Pollut. 144:272-279.

Orban, E., Di Lena, G., Nevigato, T., Casini, I., Marzetti, A., Caproni, R., 2002. Seasonal changes in meat content, condition index and chemical composition of mussels (Mytilus galloprovincialis) cultured in two different Italian sites. Food Chem. 77:57-65.

Osman, R.W., Whitlatch, R.B., Zajac, R.N., 1989. Effects of resident species on recruitment into a community: larval settlement versus post-settlement mortality in the oyster Crassostrea virginica. Mar. Ecol. Prog. Ser. 54:61-73.

Pastore, M., 2001. Copepods associated with Phallosia mammillata and Ciona intestinalis in the area of Taranto. J. Mar. Biol. Assoc. UK 81:427-432.

Pastore, M., 2002. Istituto Talassografico: Analisi dei sedimenti del Mar Piccolo per la valutazione di eventuali necessità di dragaggi dei fondali. CNR ed., Roma, Italy.

Pekkarinen, M., Suoranta, R., 1995. Effects of transportation stress and recovery and sample treatment on calcium and glucose concentrations in body fluids of Anodonta anatine (L.). J. Shellfish Res. 14:425-433.

Petersen, J.K., Mayer, S., Knudsen, M.A., 1999. Beat frequency of cilia in the branchial basket of the ascidian Ciona intestinalis in relation to temperature and algal concentration. Mar. Biol. 133:185-192.

Petersen, J.K., Schou, O., Thor, P., 1997. In situ growth of the ascidian Ciona intestinalis (L.) and the blue mussel Mytilus edulis in an eelgrass meadow. J. Exp. Mar. Biol. Ecol. 218:1-11.

Price, H.A., 1983. Structure and formation of the byssus complex in Mytilus (Mollusca Bivalvia). J. Mollusc. Stud. 49:9-17.

Price, T.J., Thayer, G.W., La Croix, M.W., Montgomery, G.P., 1976. The organic content of shells and soft tissues of selected estuarine gastropods and pelecypods. Proc. Natl. Shellfish Assoc. 65:26-31.

Prioli G., 2001. Censimento nazionale sulla molluschicultura. Technical Report. Consorzio Unimar, Roma, Italy. Home page address: http://www.unimar.it/pubblicazioni.aspx

Railkin, A.I., 2004. Marine Biofouling: Colonisation processes and defenses. CRC Press, Boca Raton, USA.

Rayyan, A., Photis, G., Chintiroglou, C.C., 2004. Metazoan parasite species in the cultured mussel Mytilus galloprovincialis in Thermaikos Gulf (North Aegean Sea, Greece). Dis. Aquat. Organ 58:55-62.

Riisgard, H.U., Jurgensen, C., Clausen, T., 1996a. Filter-feeding ascidians (Ciona intestinalis) in a shallow cove: implications of hydrodynamics for grazing impact. J. Sea Res. 35:293-300.
Riisgard, H.U., Larsen, P.S., Nielsen, N.F., 1996b. Particle capture in the mussel Mytilus edulis: the role of latero-frontal cirri. Mar. Biol. 127:259-266.

Riisgard, H.U., Larsen, P.S., 2000. Comparative ecophysiology of active zoobenthic filter feeding, essence of current knowledge. J. Sea Res. 44:169-193.

Sarà, G., Manganaro, A., Cortese, G., Pusceddu, A., Mazzola, A., 1998. The relationship between food availability and growth in Mytilus galloprovincialis in the open sea (southern Mediterranean). Aquaculture 167:1-15.

Seed, R., 1973. Absolute and allometric growth in the mussel Mytilus edulis L. (Mollusca, Bivalvia) J. Mollusc. Stud. 40:343-357.

Seed, R., 1976. Ecology. In: B.L. Bayne (ed.) Marine Mussels: their Ecology and Physiology IBP Cambridge Univ. Press, Cambridge, UK, pp 13-65.

Skidmore, D.A., Johnson, K.W., Raven, G.W., 1985. Intertidal, longline culture of Mytilus edulis Linné in Puget Sound, Washington. J. Shellfish Res. 5:54(abstr.).

SPSS, 1998. SPSS Software Base 8.0 for Windows. SPSS Inc., Chicago, IL, USA.

Stabili, L., Acquaviva, M.I., Cavallo, R.A., 2005. Mytilus galloprovincialis filter feeding on the bacterial community in a Mediterranean coastal area (Northern Ionian Sea, Italy). Water Res. 39:467-477.

Stefanon, A., 1984. A review of capture and exploitation of submarine springs by divers. pp 100-110 in Proc. Joint Oceanographic Assembly SCOR, Halifax, Nova Scotia, Canada.

Tanaka, N., Monaghan, M., Rye, D.M., 1986. Contribution of metabolic carbon to mollusc and barnacle shell carbonate. Nature 320:520-523.

Thompson, R.J., 1984. Production, reproductive effort, reproductive value and reproductive cost in a population of the blue mussel Mytilus edulis from a subartic environment. Mar. Ecol. Prog. Ser. 16:249-257.

Umgiesser, G., Scroccaro, I., Alabiso, G., 2007. Mass exchange mechanisms in the Taranto Sea. Transit. Waters Bull. 2:59-71.

Wahl, M., 1989. Marine eubiosis. I. Fouling and antifouling: some basic aspects. Mar. Ecol. Prog. Ser. 58:175-189.

Witman, J.D., Suchanek, T.H., 1984. Mussels in flow-drag and dislodgement by epizoans. Mar. Ecol. Prog. Ser. 16:259-268.

Zajac, R.N., Whitlatch, R.B., Osman, R.W., 1989. Effects of interspecific density and food supply on survivorship and growth of newly settled benthos. Mar. Ecol. Prog. Ser. 56:127-132.