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Decline of the Manila clams stock in the northern Adriatic lagoons: a survey on ecological and socio-economic aspects

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The Manila clam, Ruditapes philippinarum*, introduced in the Venice lagoons in 1983 and rapidly spread to the nearby coastal lagoons represents one of the most important commercially-exploited resources of this area. Abundance, size-class and biomass distribution of the wild population living in the Pialassa Baiona lagoon were assessed and related to the hydrological and sediment characteristics. Despite the lagoon being affected by eutrophication, chemical and thermal pollution, the clams were harvested by about thirty professional fishermen until 2003. The commercially available stock was estimated at 36.8 10^3 kg in July 2002, 29.3 10^3 kg in April 2003, and 10.3 10^3 kg in October 2003. Stock estimations and observed mortality were in good accordance with the fishermen data. The decline of the available stock could be due to both overfishing and the extraordinary summer heat wave occurred in 2003, which may have reduced larval recruitment and increased the mortality. Overall, the juvenile recruitment appeared insufficient to annually restore the natural stock.*

Although the national and regional high relevance of clams market, local harvesting of wild populations appeared marginal and inadequate to support a remunerative commercial activity, due to the variability and unpredictability of the annual yield and the lack of a sustainable management based on a production chain's approach.

Key words: *Clam fisheries, resources, harvesting, alien species, population dynamics, environmental conditions*

INTRODUCTION

The Manila clam (or Japanese carpet shell), *Ruditapes philippinarum* (Adams and Reeve, 1850), is native to the Indo-Pacific region and as a results of aquaculture activities and human transport it is now widely distributed along the Pacific coast of America, the Atlantic coast of Europe, until 50° latitude N, in the northern Adriatic and Aegean Seas (JENSEN *et al.*, 2004; HUMPHREYS *et al.,* 2007). It was introduced for marine farming on the Mediterranean and Atlantic coast of the France at the beginning of '70s of last century (BODOY *et al.*, 1981). Its first introduction in the Venice lagoon, for experimental aquaculture, date back to 1983 (CESARI & PELLIZZATO 1985). Afterwards, this species had rapidly expanded outside the farming areas and colonized most of the nearby coastal lagoons, largely replacing the native carpet shell clam, *Ruditapes decussatus* (Linnaeus, 1758) (OCCHIPINTI AMBROGI, 2000; SOLIDORO *et al.*, 2000; PRANOVI *et al.,* 2006), as happened in many other coastal areas (BIDEGAIN & JUANES, 2013; HUMPHREYS *et al.*, 2015). Sympatric coexistence of the two congeneric species or the predominance of *R. philippinarum* over *R. decussatus* may depend by local environmental conditions and less narrow requirements of the introduced ones (BIDEGAIN *et al.,* 2016; NERLOVIĆ *et al.*, 2016).

Manila clam's favorite habitats are brackish waters with sandy and muddy bottoms, from the intertidal zone to about 4 m depth. Its best growth period is during phytoplankton bloom (spring and autumn) at temperatures between 10 and 20°C, with an optimum around 20°C (MELIÁ *et al.*, 2004), and the reproduction period extends from May to October in the Mediterranean Sea, even if it has different period of spawning by location around the world (MAÎTRE-ALLAIN, 1985; HAN *et al.*, 2008; DANG *et al.*, 2010 and references therein). Major factors limiting the reproduction, settlement and growth are: temperature (maximum survival 31°C), food availability (mainly diatoms), sediment grain size (optimum 70-80% of sand), turbidity, dissolved oxygen (optimum 6-8 mg l^{-1}, minimum 3.5 mg l^{-1}) (PAESANTI & PELLIZZATO, 2000). Although *Ruditapes philippinarum* show high adaptability and resistance compared to *R. decussatus* (GHARBI *et al.*, 2016), the deterioration of the environment due to several anthropic disturbance sources and the overfishing threaten the wild populations.

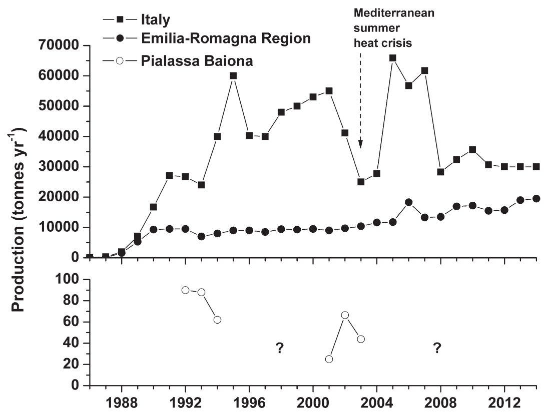

Fig. 1. Temporal trend of Ruditapes philippinarum *Italian and Emilia-Romagna regional production (ZENTILIN et al., 2008; FAO, 2016; OSEPA, 2016), and Pialassa Baiona production (1992-1994: ANGELINI & STRUMIA, 1994; 2001-2003: present study)*

The World leader of Manila clam's production is the China, which rapidly increased from 15 10^3 tonnes yr^{-1} in the early '80s to 4,000 10^3 tonnes yr^{-1} in 2014 (FAO, 2016). Italy, with a mean annual production of 30 10^3 tonnes yr^{-1} (period 2011-2014) is the leading country in Europe (94% in volume and the 92% in value of the communitarian amount) and today competes for the second World place only with Japan and Korea (FAO, 2016). The Italian production comes exclusively from the northern Adriatic Sea, particularly from Venice and other coastal lagoons, like Marano, Scardovari and Goro, where the most of production derives from aquaculture practices (TUROLLA, 2008) managed by local fishermen (SOLIDORO *et al.*, 2000; CHIESA *et al.*, 2011). In fact, in several places it is actively reared by seeding small clams obtained in specialised laboratories by controlled reproduction or collected in the field from sites with high natural settlement. Otherwise, authorized fishermen harvest wild populations.

Since 1985, the Italian production of *R. philippinarum* has gradually risen reaching the maximum values during the years 1994-2001 (40-65 10^3 tonnes yr^1), also thanks to the increase of the wild populations in the Venice and in other northern Adriatic lagoons (ZENTILIN *et al.*, 2008; FAO, 2016; Fig. 1). Afterwards the Italian production had a fluctuating trend. It experienced a first decline in 2003 (25 10^3 tonnes yr^1), an upswing from 2005 to 2007 (62-66 10^3 tonnes yr^1; FAO, 2016), then a second decline in 2008 (28 10^3 tonnes yr^1) followed by a stabilization around 30 10^3 tonnes yr^1 (Fig. 1). Production declines, especially from the wild populations, were largely attributed to the worsening of environmental conditions, as occurred in the Venice lagoon (ZENTILIN *et al.*, 2008), while the production of reared populations (e.g., in the southern of the Po River Delta, Emilia-Romagna Region), remained quite stable (OSEPA, 2016) see Fig. 1.

The aims of the present study were to analyse the distribution and dynamics of a commercially exploited wild population of *Ruditapes philippinarum* in a small northern Adriatic coastal lagoon: the Pialassa Baiona. An evaluation of the environmental conditions and their influence on the clams' stocks offers an important knowledge base for similar situations in different areas. Stock assessment and natural recruitment were compared to the harvest effort of local fishermen in order to analyze the potential sustainable exploitation from a socio-economic and biological point of view. A long-term natural resources safeguard, the co-operation among fishermen, institutions and all the chain operators represent the basic elements for a sustainable development of the sector, as also requested by the FAO Code of Conduct for a Responsible Fishery (CASTELLINI *et al.*, 2007).

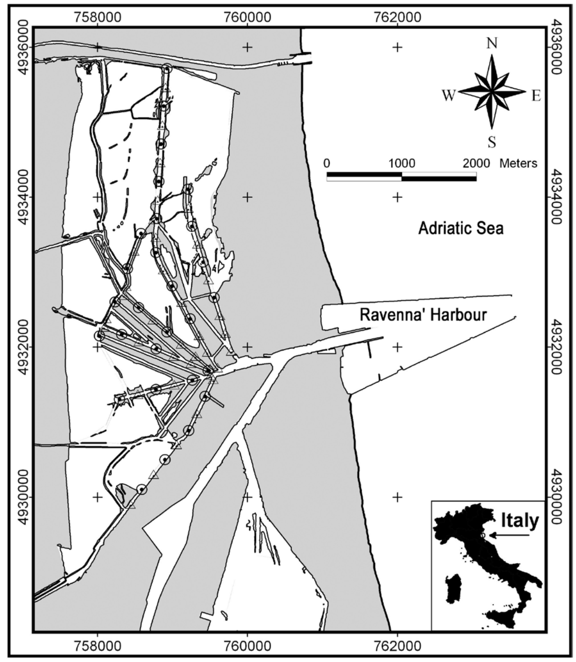

Fig. 2. Map of Pialassa Baiona lagoon, showing sampling sites located along the main inner channels, selected for study clams of commercial size, both circles and triangles, and juveniles, only triangles (geographic grid UTM 32T, European Datum 1950)

MATERIAL AND METHODS

Study area

Pialassa Baiona is an eutrophic micro-tidal lagoon located along the northern Adriatic coast of Italy and connected to the sea through the Ravenna harbor (44° 30' N, 12° 15' E) shown in Fig. 2 (AIROLDI *et al.*, 2016). Discontinuous artificial embankments divide the lagoon into several shallow water ponds with an average depth of 1 m. Main ponds are connected each other and to the sea by channels. In channels, the depth ranges from 1 m to 8 m in the landward and seaward sides, respectively. On average, the water covers an area of 10 km^2, tidal range can exceptionally exceed 1 m, and usually vast shallow areas emerge during low tides. The lagoon receives water inputs from five main channels that drain a watershed of 264 km^2, including urban (9%) and agricultural (87%) areas. The southern channel collects also the wastewater coming from urban and industrial sewage treatment plants and from two thermal power plants. Nutrient inputs are mainly located in the southern area (PONTI *et al.*, 2005). Overall water turnover in the lagoon, mainly due to the tidal marine water exchange, has been estimated in three days (PONTI *et al.*, 2005). Phytoplankton blooms and intense growth of seaweeds (*Ulva* sp., *Enteromorpha* sp., *Gracilaria* sp.) were frequently observed during the summer, especially in the southern part of this area (PONTI & ABBIATI, 2004).

From 1958 to 1976 Pialassa Baiona was heavily impacted by industrial pollution. Mercury, polycyclic aromatic hydrocarbons (PAHs), synthetic polymers were among the most important pollutants which nowadays contaminate the sedimentary compartment, with a total mercury load ranging from 0.2 to 40 mg g^{-1} dry weight, and a south–north pollution gradient was seen as a function of the distance from the southern industrial area (FABBRI *et al*., 2000; MCRAE *et al*., 2000; GUERRA *et al*., 2011; 2014; TROMBINI *et al*., 2003). Natural (e.g., depth, grain size, sediment organic content, and distance from the sea) and anthropogenic disturbance gradients (e.g. sediment contamination, water temperatures, and distance from sewage inputs) affect the distribution patterns of macrobenthic invertebrate assemblages (PONTI *et al*., 2007; 2008; 2011). Moreover, maintenance channel dredging may have local effects on benthic communities (GUERRA *et al*., 2007; 2009; PONTI *et al*., 2009).

Today the lagoon host leisure and cultural activities such as canoeing, guided walking tours, and birds watching, but it is also exploited for Manila clams harvesting, recreational fishing and regulated hunting. From the 90's, and at least until 2003, about 30 authorized fishermen have harvested Manila clams within the Pialassa Baiona lagoon. According to the regulation in force, the collection is allowed in the central and northern areas while it is forbidden in the southern area due to pollution risks. Fishermen mainly operate within the channels; clams are harvested by hand along the banks of the channels during low tides, otherwise from small boat using long broomsticks with a metal rake or even manually by scuba divers.

Mean environmental conditions are quite suitable for the growth and reproduction of *R. philippinarum*, except for the sediment grain size, which is too muddy especially in most part of the shallow water ponds, and for the summertime dystrophic crisis (PONTI & ABBIATI, 2004). During the summer 2003 the lagoon, as well as all the Mediterranean Sea, experienced an important thermal anomaly due to a relevant "heat wave" related to anomalous atmospheric high pressure condition over the western Europe together with an exceptional high air temperature and lack of winds (BLACK *et al*., 2004; SCHAR *et al*., 2004; GRBEC *et al*., 2007).

Sampling, measurements and laboratory analyses

Abundances and biomass distributions of commercial size specimens of *Ruditapes philippinarum* were investigated in three dates: July 2002, April and October 2003. While the first sampling was carried out in the middle of the 2002 harvesting season, the second and the third sampling occurred at the beginning and at the end of 2003 harvesting season.

Samples were collected every 250 m along the seven main channels of the lagoon for a total of 65 sampling sites equally distributed on 14.75 km (Fig. 2). At each sampling site and date, one sample was collected on the left and one on the right bank of the channel at about 1 m depth below the mean lower low water (MLLW). Each sample was obtained with the same gear adopted by local fishermen, a sort of 4 m long broomstick with a terminal metal rake large 33 cm and equipped with a grill intended to retain individuals of commercial size (minimum landing size: 2.5 cm shell length, corresponding to about 1 cm of thickness). The rake was dragged in the sediments three times and drew along a distance of 1 m, covering an overall area of about 1 m^2. A sediment samples were also collected for grain size analyses. Sand and silt-clay sediment content was measured as dry weight percentage after wet sieving (0.063 mm mesh), retaining the fine fraction by filter paper, and drying at 80°C for 24 hours (BUCHANAN, 1984).

In order to estimate the amount of recruitment of *R. philippinarum* in the Pialassa Baiona, juveniles were investigated in June 2003. Three replicated samples were collected by a modified Ekman bottom grab (sampling area of 0.0225 m^2) three on the left and three on the right banks of the channels in 37 sampling sites. Sediments were sieved on the field with a 2 mm mesh size. This size should be reached by clams less than two months after their settlement, which occur about 20 days after the spawning (WILLIAMS, 1980; PAESANTI & PELLIZZATO, 2000).

Maximum shell length (L_{max}, cm) of each commercial size specimens was measured by callipers, while the maximum shell lengths of juveniles were measured by a microscope image analysis system using the free available software UTHSCSA ImageTools. Fresh commercial mass (FM, g), including inter-valve water, was estimated from the shell length (L_{max}, in cm) by the following allometric equation provided by PAESANTI & PELLIZZATO (2000):

$$FM = 0.18655 \times L_{\max}^{3.16576} \; (R^2 = 0.90)$$

Wet mass (WM, g), dry mass (DM, g) and ash free dry mass ($AFDM$, g) were estimated both for commercially exploited fraction (L_{max} interval 2.0 – 5.6 cm) and juveniles (L_{max} from 3 to 20 mm) by allometric equations obtained from a sub sample of fresh, dried (80°C, 24 h) and ignited (500°C, 5 h) specimens.

Possible relationship between abundance and biomass of clams and sediment sand percentage, depth and distance from the mouth of the lagoon (measured along the preferential water paths on the digital cartography), were investigated by correlation analyses.

Available clams stock and corresponding confidence limits ($CL_{95\%}$) at each sampling date were estimated from the mean fresh mass (g m^{-2}) found in 130 samples (both side of the channel in 65 sampling sites). These estimations were extended to the exploitable bottom areas measured along each channel stretch from mean upper water level to 2 m in depth (below *MLLW*). On overall, the stock assessment was extended to an area of 34.3 ha, which represent about 3% of the total lagoon, but just under half of the actual exploitable area for clams harvesting.

Socio-economic assessment

In order to evaluate the potentiality of a sector it is fundamental to define its economic viability (CASTELLINI *et al.*, 2011). This phase has been quite difficult because in that area the aquaculture in not well-organized and structured. Mean monthly harvested fresh mass and corresponding working days, from January 2001 to December 2003, were estimated by an anonymous questionnaire filled by 8 of the 30 local fishermen.

A socio-economic survey focused on the consumers' perceptions about clams, and in particular about the northern Adriatic product, was carried out. The adopted methodology was based on an appropriate questionnaire and the interviews conducted face to face (in different retailed points of sale) and by phone. The consumers were requested to express their willingness to pay for certified clams, with particular reference to a "supply chain control" label. In this way it was possible to evaluate the added value provided by the certification. Afterward the collected data was elaborated and examined in order to obtain indications and suggestions about the consumers. Consumer's survey adopted a contingent valuation method (CASTELLINI *et al.*, 2014).

RESULTS

Allometric relationships

The calculated relationships between maximum shell length (L_{max}) and wet mass (WM, g), dry mass (DM, g) and ash free dry mass ($AFDM$, g) for commercially exploited individuals (L_{max} in cm, from 2.0 to 5.6 cm) are:

$$WM = 0.18171 \times L_{\max}^{3.01417} \; (R^2 = 0.9541, n = 291)$$
$$DM = 0.10588 \times L_{\max}^{3.14452} \; (R^2 = 0.9578, n = 294)$$
$$AFDM = 0.01154 \times L_{\max}^{2.97164} \; (R^2 = 0.9463, n = 294)$$

while for the juvenile individuals (L_{max} in mm, from 3 to 20 mm) are

$$WM_{juv} = 0.000264 \times L_{\max}^{2.75678} \; (R^2 = 0.9891, n = 48)$$
$$DM_{juv} = 0.000236 \times L_{\max}^{2.62187} \; (R^2 = 0.9875, n = 48)$$
$$AFDM_{juv} = 0.000019 \times L_{\max}^{2.62462} \; (R^2 = 0.9822, n = 48)$$

Commercial size fraction

Abundance of commercial size specimens of *Ruditapes philippinarum* vary from 0 to 90 ind. m^{-2}, but in most study sites density didn't overcame 10-20 ind. m^{-2} (Fig. 3). In July 2002 no specimens were found in 8 sampling sites, while exceptional density of 80-90 ind. m^{-2} were found in two sites quite close to the seaward confluence of the channels. From April to October 2003 the number of sampling sites without clams increased from 4 to 23, while the maximum densities recorded decreased from 60 to 40 ind. m^{-2}.

Fresh exploitable mass vary according to clams density and size from 0 to 1,600 g m^{-2} (Fig. 4). On overall, higher densities and corresponding higher value of fresh exploitable mass were found in the sampling sites close to seaward confluence of the channels. Significant correlation was found between fresh mass in April 2003 and the distances of sampling sites from the mouth of the lagoon (Fig. 5a). Conversely, clams density and biomass appeared not significantly related to depth and sediment sand contents.

Maximum shell length (L_{max}) size class distribution in the commercially stock of *Ruditapes philippinarum* change from unimodal in July 2002 (modal class 3.6 - 3.7 cm) and April 2003 (modal class 3.1 - 3.2 cm) to bimodal in October 2003 (modal classes 2.6 - 2.7 and 3.7 cm; Fig. 6). Size range slightly changed from July 2002

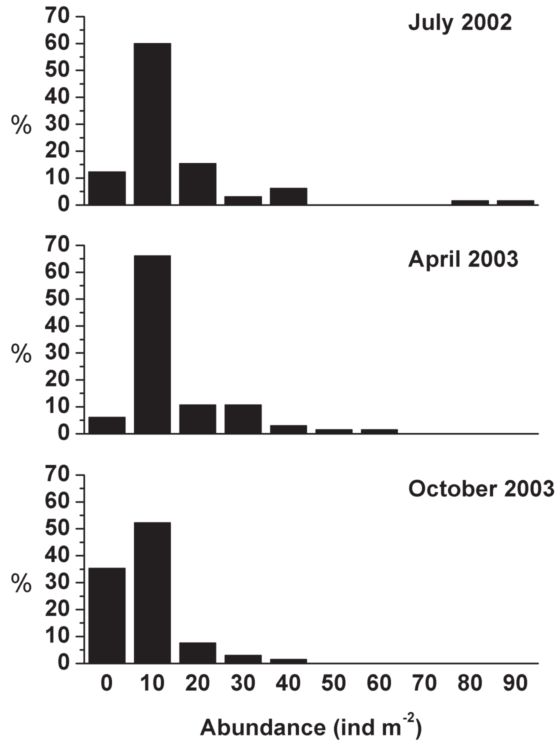

Fig. 3. Frequency distribution of the abundance classes of commercially stock of Ruditapes philippinarum *in the three sampling date*

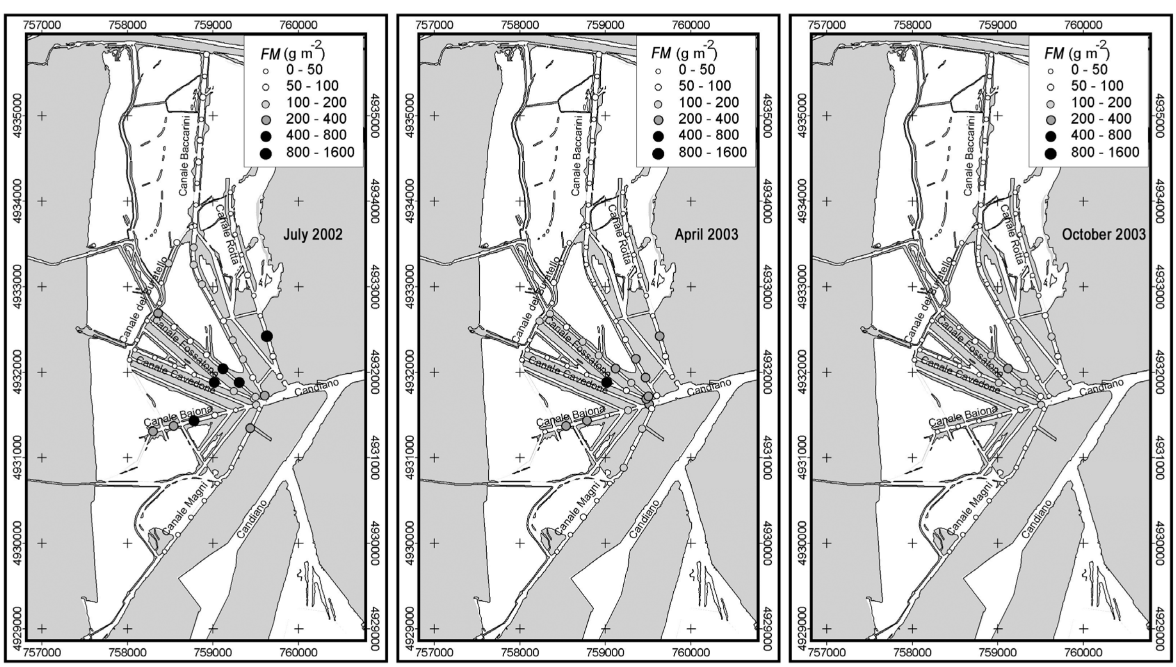

Fig. 4. Distribution maps of Ruditapes philippinarum *fresh mass (FM, g m*$^{-2}$*), obtained by the average between the two banks of the channels in each sampling site, in July 2002, April and October 2003*

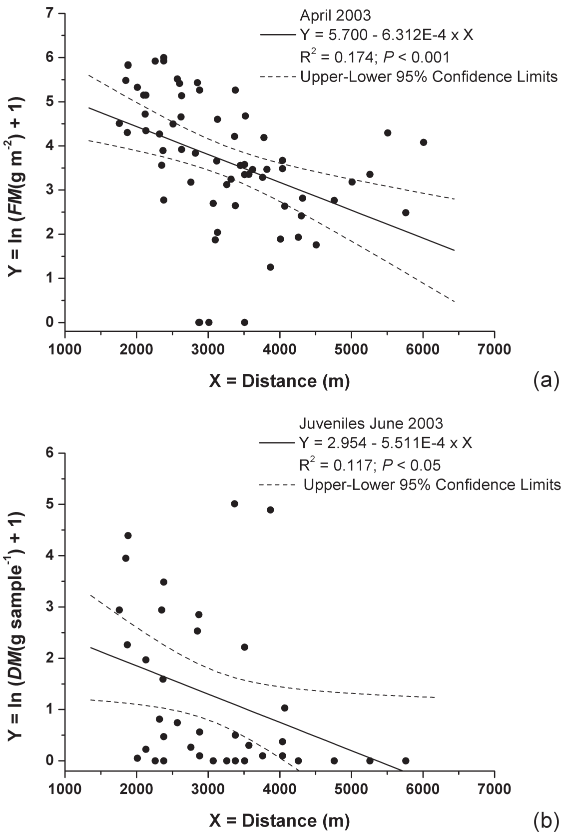

Fig. 5. Relationship between distances from the mouth of the lagoon and: a) fresh mass of commercial size clams per square metre (transformed by Ln (X+1)) found in each sampling site in April 2003 b) dry mass of juvenile clams per sample (transformed by Ln (X+1)) in June 2003

(L_{max}: 1.9 - 5.2 cm, mean 3.5 ± 0.6 cm ± S.D., n = 1321) to April (L_{max}: 2.0 - 5.6 cm, mean 3.3 ± 0.6 cm ± S.D., n = 1200) and October 2003 (L_{max}: 2.0 - 4.9 cm, mean 3.3 ± 0.6 cm ± S.D., n = 458).

On overall, the commercially available stock in the investigated area was estimated at 36.8 10^3 kg ($CL_{95\%}$ 22.2 - 51.4) in July 2002, 29.3 10^3 kg ($CL_{95\%}$ 21.5 - 37.1) in April 2003, and 10.3 10^3 kg ($CL_{95\%}$ 5.9 - 14.8) in October 2003. Within the lagoon, considering the whole exploitable area, these values could be at least double. In the whole exploitable area, it is possible to estimate a stock reduction between July 2002 and April 2003 of about 16 tonnes, and of about 38 tonnes between April and October 2003. These reductions were due to both commercial exploitation and natural mortality. This fact could be fundamental in order to increase the economic profitability of the clams, supporting a steady supply on the sale market.

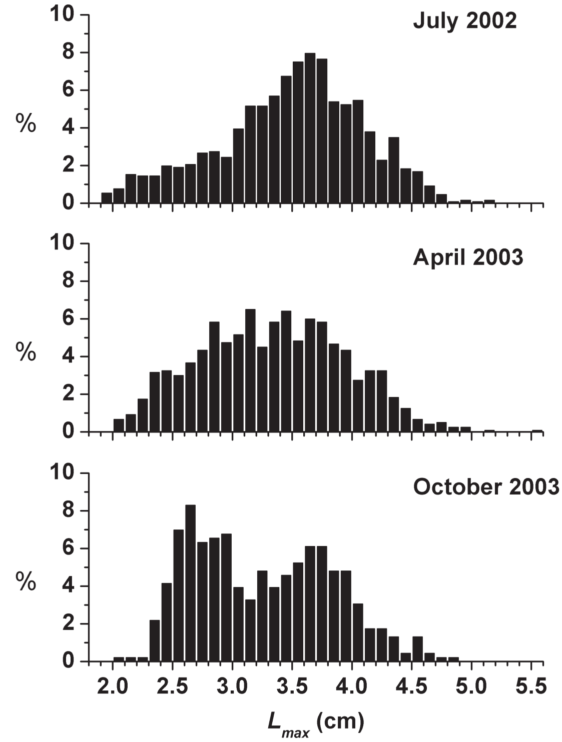

Fig. 6. Frequency distribution of the maximum shell length (L^{max}*, cm) size classes of commercially stock of* Ruditapes philippinarum *in the three sampling date*

Juvenile fraction

Abundance of juvenile specimens of *Ruditapes philippinarum*, considering separately the two banks of the channels, vary from 0 to 2,800 ind. m^{-2}, but in most study sites density didn't overcame 100 ind. m^{-2} (Fig. 7a). On overall, higher densities and corresponding higher value of biomass were found in the sampling sites close to the seaward confluence of the channels. Significant correlation was found between mean dry mass and the distances of sampling sites from the mouth of the lagoon (Fig. 5b).

Maximum shell length (L_{max}) size class distribution of juveniles of *Ruditapes philippinarum* in June 2003 was unimodal, with a modal class of 5 - 6 mm (mean 7.7 ± 3.4 mm ± S.D. (n = 872), corresponding to an age of 3-4 months (Fig. 7b).

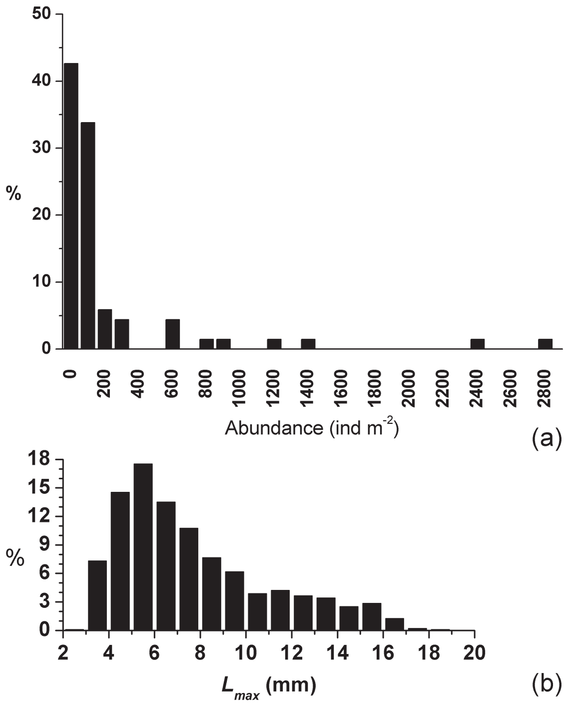

Fig. 7. Frequency distribution: a) of the abundance classes and b) of the maximum shell length (L^{max}, mm) size classes of juveniles of Ruditapes philippinarum *in June 2003*

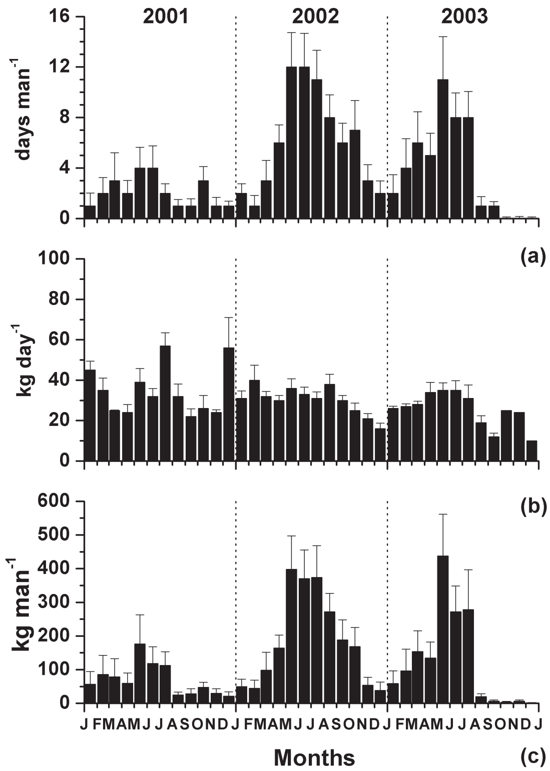

Fig. 8. a) Mean fishing effort in terms of harvesting day per fishermen in each month (+ s.e.); b) mean daily fresh mass harvested by each fisherman (+ s.e.); c) individual mean harvested fresh mass in each month (+ s.e.)

Professional clams harvesting

According to the data provided by fishermen for the period 2001-2003, fishing effort was usually concentrated from April to October, when the mean monthly number of harvesting days per fisherman reaches 12 d man^{-1}, with a maximum declared of 21 d man^{-1} (Fig. 8a). This could be due to both the favorable weather conditions, during the spring and summer, and the more accessibility of the clams, which sink deep in the sediment during the winter. In practice, each fisherman tends to maximize his effort reaching a satisfaction level around 30-40 kg d^{-1}, while below 10 kg d^{-1} they probably renounce to collect clams because the yield become not remunerative. In this way the average fresh mass daily harvested by each one is quite stable through the year (Fig. 8b).

On average, each fisherman harvests from 1 ± 1 to 437 ± 125 kg month^{-1} (± s.e.) of fresh mass of clams. In accordance with the monthly working days, higher yields were obtained each year in the middle of the harvesting season, from May to July (Fig. 8). Extending the mean individual monthly harvested fresh biomass to all the 30 fishermen, working in this lagoon, total yields in the lagoon were 24.9 ± 7.9, 66.4 ± 14.3 and 43.8 ± 10.4 x 10^3 kg year^{-1} in 2001, 2002, 2003 respectively.

DISCUSSION

The present study complements the allometric equations available for length-mass relationships of Manila clams in the northern Adriatic Sea (PAESANTI & PELLIZZATO, 2000). Commercially exploited specimens showed an isometric scaling in terms of wet mass and a positive scaling as dry mass, while juvenile individuals presented a negative scaling, indicating an initial energy investment in lengthening of the shell rather than in biomass. Although these results are very similar to those obtained in

Japan (HASEGAWA & HIGANO, 2010), within species native area, allometric coefficients, as well as population parameters, may slightly change among locations and according to environmental and climatic conditions (ÇOLAKOĞLU & PALAZ, 2014).

Throughout the study period, the highest values of density and biomass have been recorded in the areas toward the sea. Similar patterns were observed for both adult and juvenile specimens. In these areas, best hydrodynamic conditions (higher water speed and turnover) and sandy bottoms (up to 75% of sand) may possibly support relative higher settlement and growth rates of *Ruditapes philippinarum* compared to the rest of the lagoon. Clams settled far from the sea could be affected by the reduced water exchange, which also means high accumulation of organic matter, reduced oxygenation and limited phytoplankton food supply (PAESANTI & PELLIZZATO, 2000; IRATO *et al*., 2007; JUANES *et al*., 2012; MATOZZO *et al*., 2012; MUNROE, 2016).

The size class analysis showed a reduction of adult modal size class from July 2002 to April 2003, which could be due to the spring juvenile recruitment. The bimodal shape of the size class frequency distribution in October 2003 highlighted the presence of two cohorts (ÇOLAKOĞLU & PALAZ, 2014; MUNROE, 2016). The first one (modal class 3.7 cm) was the oldest generation which increased in size of about 0.5 cm compared to April 2003 (modal class 3.2 cm), the second one (modal class 2.7 cm) was the following generation, settled in the 2002, partially escaped to the harvesting and therefore available for the next year.

In these wild populations, a high juvenile recruitment is essential to restore and maintain the exploitable stock. Considering the high trophic level of the Pialassa Baiona lagoon (PONTI *et al*., 2005) and the natural mortality (50% on average according to PAESANTI & PELLIZZATO, 2000, only the sites with more than 200 juveniles specimens m^{-2} could be promising for the future exploitation, actually a very low value compared to a potential recruitment density of early post-settlement clams greater than 30.000 ind. m^{-2} (MUNROE, 2016). This condition was found only in the 25% of investigated sites. Since the observed low recruitment, population recovery will be very difficult. According to the grow rate under optimal environmental condition (PAESANTI & PELLIZZATO, 2000), most of the juveniles clams recorded in June 2003 having a L_{max} of 6 mm, should reach the commercial size in about 16 month (October, 2004), but considering the overwintering this cohort could be commercially exploited only in spring 2005.

According to the fishermen interview, during the year 2001 the monthly harvest was very low compared to the following year. The production of the 2002 was relative high and similar to those obtained about one decade before (i.e.: 90, 88 and 62 tonnes yr^{-1} in 1992, ’93 and ’94 respectively; ANGELINI & STRUMIA, 1994; see also Fig. 1). The observed stock reduction from July 2002 to April 2003 (about 16 tonnes) was possibly affected by increased harvesting activities occurred in the late summer of the 2002. Harvesting production for the year 2003, estimated from the information provided by fishermen (about 44 tonnes), was in good accordance with the stock reduction, calculated from the field data in the central harvesting period, from April to October 2003 (around 38 tonnes). The observed stock reduction from April to October 2003 should be due to both natural mortality and harvest. In fact, in the year 2003 the initial harvest looks promising but it was drastically reduced in July and August, both in terms of fishing effort and yield. This event seems to be corresponding to an anomalous hot and dry summer season (BLACK *et al*., 2004; SCHAR *et al*., 2004). The exceptional hot summer (air temperature 3-5°C more than the climatic mean) and the possible thermal contribute from the two power plants located in the southern side of the lagoon led to water temperature higher than 31°C, corresponding to the limit of tolerance of the clams, especially if persistent for long time (ANACLETO *et al*., 2014).

Social-economic considerations

Consumers’ interest for clams is increasing during the years but with an inconstant demand. At a current state clams represent the 4.5%

of the total fresh fish consumed at home (in volume) (ISMEA on Nielsen data, Consumers Panel Service, http://www.nielsen.com).

According to the few data available for the past, the production in the small Pialassa Baiona lagoon was very variable probably affected by recurring dystrophic crises. The local stock of Manila clams appeared to be on the wane due to both overfishing and bad environmental condition. The reduced recruitment limited the possibility of restocking for the next years. Actions aimed to improve environmental condition, like the reduction of nutrient load and channel maintaining dredging to improve water circulation, could foster the restocking, but the effects should be expected in 2-3 years (SPILLMAN *et al*., 2009; JUANES *et al*., 2012).

During the latest years, the *Ruditapes philippinarum* harvesting in Pialassa Baiona showed heavy difficulties from an economic and social point of view: the reduced supply and the inadequate production chain's management caused a profits' decrease. The deteriorated economic situation implied the operators' dissatisfaction and removal with social repercussions like the activity loss. Therefore, the economic and productive interest of operators for Pialassa Baiona deteriorated and became marginal causing a risk of land abandonment.

Comparison of the registered annual Manila clam collection for Pialassa Baiona with the data from the whole country shows that it is not very important for the quantity (Fig. 1), still its relevance to social and environmental issues must be bear in mind.

In order to stimulate the renewal of Manila clam sector in Pialassa Baiona area it is not sufficient a habitat evaluation from an environmental point of view but economic revenues, employment and market demand must be considered.

The Manila clam rearing and harvesting activities market-oriented in Pialassa Baiona take energy considering the clams' penetration index in northern Adriatic area and its relevance at a consumption level.

In Italy, although the catches downturned during the recent years, the fishery products consumption has raised up with a rate about 2% thanks to the increased supply from aquaculture and imports. In spite of this trend the clams consumption showed a strong drop falling more than 15% per year (accordingly to the clams and mussels' category in general). In 2002 Italian clams consumption passed from 11,000 tonnes to 6,300 tonnes (-43%), probably due to a sudden rise in the prices (from 6 € kg^{-1} to more than 9 € kg^{-1}); in 2003 the consumption grew up moderately, during the decennial (until 2015) it increased quite steadily but with a variable rate.

So clam consumption in Italy is generally popular; in the northern-east of the peninsula almost the 82% of consumers purchased clams one or more times a month (CASTELLINI *et al.,* 2011). The interviewed consumers declared that the geographical origin of the product is the most important element in a purchase decision and they were interested to a clam with a certificated origin. Two third of them are also available to pay a higher price for the certification.

For what concerns the Emilia-Romagna consumers, region where Pialassa Baiona is located, clams' appreciation level appears quite good: more than 2/3 of the interviewed consumers well know and appreciate this product and its characteristics. Furthermore, the consumers declare to know clams' recipes and their cooking methods.

Actually, at a consumption level the territorial origin's identification has a fundamental role in the purchase approach. The survey's elaborations revealed that in Emilia-Romagna region there is also a widespread awareness of clam production in the northern Adriatic: not only the interviewed consumers are informed about this kind of production but also more than 25% of them believe these clams are better and safer than the others. Furthermore, a relevant part of the surveyed sample assigns a competitive advantage to the local clams and this attribute could be usefully transferred to the Pialassa Baiona product too.

Another reflection related to the geographical position: 38% of the investigated consumers join the clam consumption with holidays or weekends situations. For this, considering that Pialassa Baiona is close to Emilia-Romagna coastal resorts, its clams could take an interesting advantage of this.

All these facts suggest that the clams' activity in Pialassa Baiona, efficaciously planned and organized could have a positive impact on the local economics: the product is locally appreciated and the Emilia-Romagna origin could represent a value added for the clams. However, it is necessary to consider also some constraints: first of all the small level of the production not sufficient in order to satisfy the distribution and consumption requests.

In order to develop this local sector it must pay attention to the technical market needs like traceability, marketing, quality certifications, branding, a constant supply of product, etc., essential characteristics for any food production but expensive and binding. For example, a protected geographical indication (PGI) label could add value to Pialassa Baiona clams and help the demand penetration improving the product image. Furthermore an organized system for the clams harvest and the subsequently market supply should be improved: regular stock assessments, environmental monitoring and shared rules are essential for a sustainable develop of clam's harvesting activities. A well-structured chain is essential in order to achieve a satisfying profitability that is the basic condition for the sector survival.

In terms of productive chain's development it is important to evaluate if the Pialassa Baiona area and its production presented the necessary characteristics for an efficacious value enhance providing a significant spin-off on the social and economic aspects. In this moment the clams' harvesting activities in Pialassa Baiona represents only an occasional profit's integration for the fishermen; for the future if it will be wisely enhanced could cover a more important role. The best way to achieve a development of Pialassa Baiona clams is based on a sustainable production chain's approach: the productive dynamic should be strictly related to the social and economic aspects of this activity (i.e. fishermen' organization, trade channels, marketing strategies, demand's survey, consumers' satisfaction). Pialassa Baiona represents an interesting case study and the considerations arising from it can be extended to many similar situations found throughout the World.

CONCLUSIONS

Despite being a very hardy species, well adapted to the changing conditions that occur in coastal lagoons, Manila clam may be affected by adverse environmental conditions, including the most important as the prolonged anoxia and excessive heating of the water. Paradoxically, the eutrophication of the lagoons of the Po Delta is the basis for the food chain which supports the production of shellfish and simultaneously can lead to dystrophic and anoxic conditions that threaten benthic assemblages and fished resources (ABBIATI *et al*., 2010 and references there in). Increasing water temperature and acidification, as expected under global climate change scenarios, may threaten Manila clam' stocks (XU *et al*., 2016: VELEZ *et al*., 2016).

Adverse climatic conditions may assume greater importance for wild stocks, which is not being replenished by seeding, suffering the effects of local die-offs for several years (DANG *et al.*, 2010), while in the case of managed stocks is possible to optimize the seeding and harvesting in order to balance environmental fluctuations, applying management models (VINCENZI *et al*., 2006; SPILLMAN *et al*., 2009).

Moreover, the clams are subject to various diseases and recent perkinsosis outbreaks have affected the northern Adriatic populations, evidencing new possible threats to both wild and reared stocks with possible socio-economic impacts (PRETTO *et al*., 2015; RUANO *et al*., 2015).

Coastal lagoons, as well transitional waters in general, provide ecosystem goods and services that are essential for the well-being of human populations, and clam production are part of them, even in small aquatic systems (SAUREL *et al*., 2014). These unpredictable aquatic systems, characterized by large environmental fluctuations, are under severe stress due to human activities. Increasing pressures (e.g., over-harvesting, eutrophication, habitat loss) inevitably lead to the degradation of these ecosystems (ABBIATI *et al*., 2010). Worldwide, the introduction in the transitional waters of alien species for aquaculture practice is justify on the basis of the expected economic returns, disregarding the sustainability and all the possible effects on the natural communities, even hundreds of kilometers far from the farming sites. Despite the higher tolerance to the adverse environmental conditions often showed by alien species compared to the substituted native species, as happen for *Ruditapes philippinarum* vs. *R. decussatus*, both anthropic disturbance and global change can make fruitless any aquaculture efforts and dramatically affect the wild populations and their exploitation. The challenge is to couple long-term conservation with exploitation activities. Management of coastal lagoons cannot focus only on improving the trophic and pollution conditions, but should also consider the need to preserve economic activities that rely on the high productivity of such systems. In addition, it is important to consider that the consumers' appreciation for this seafood on the market is to date quite lively. In this context, strong support is required from both ecological and socio-economic research to achieve a sustainable management and exploitation.

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Opadanje stoka školjkaša *Ruditapes philippinarum* u uvalama sjevernog Jadrana: anketa o ekološkim i društveno-ekonomskim aspektima

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SAŽETAK

Školjkaš *Ruditapes philippinarum*, zabilježena u Venecijanskoj laguni 1983. godine gdje se brzo proširila i na obližnje obalne lagune te predstavlja jedan od najvažnijih komercijalno iskorištenih resursa ovog područja. U laguni Pialassa Baiona procjenjene su abundancija, veličina klase i raspodjela biomase prirodnih populacija u odnosu na hidrološke i sedimentne karakteristike. Unatoč tome što je laguna bila pogođena eutrofikacijom, kemijskim i toplinskim zagađenjima, oko trideset profesionalnih ribara sakupljalo je školjke do 2003. godine. Dostupne zalihe stoka komercijalnih vrsta procijenjene su na 36,8 10^3 kg u srpnju 2002. godine, zatim na 29.3 10^3 kg u travnju 2003. godine i na 10,3 10^3 kg u listopadu 2003. godine. Procjene zaliha i smrtnosti bile su u skladu s podacima ribara. Pad raspoloživih zaliha mogao bi biti posljedica prekomjernog izlova i izvanrednog ljetnoga toplinskog vala koji se dogodio 2003. godine, što je utjecalo na smanjenje novačenja ličinki i povećanje smrtnosti. Sveukupno gledano novačenje juvenilnih primjeraka nije bilo dovoljno za godišnje obnavljanje prirodnih zaliha. Iako je na nacionalnoj i regionalnoj razini velika važnost tržišta školjki, lokalna berba divljih populacija jest marginalna i neadekvatna za podupiranje profitabilne komercijalne aktivnosti, zbog varijabilnosti i nepredvidljivosti godišnjeg prinosa i nedostatka održivog upravljanja temeljenog na pristupu proizvodnog lanca.

Ključne riječi: školjkaš *Ruditapes philippinarum*, resursi, žetva, strane vrste, dinamika populacije, okolišni uvjeti