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Full Length Research Paper

Bioindicators for siting the carpet clam *Tapes decussatus* L. farming in Mediterranean lagoons

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With a worldwide increase in shellfish aquaculture and awareness towards sustainable practices, this paper provides a method based on bioindicators for identifying a suitable site for rearing the carpet clam *Tapes decussatus* in a lagoon of the South Adriatic coast of Italy (Varano lagoon). Although the species is naturally widespread in Italian coastal lagoons, it was in fact absent from Varano lagoon. However, we would like to judge whether Varano lagoon offered a suitable habitat for farming this clam when no local wild population could give us a clue. We applied the indirect method of investigating the indicator species for this purpose. We sampled the benthic macrofauna of Varano lagoon for the presence of species known to be sympatric with the carpet clam, based on our judgement on the bionomic classification of Frisoni et al. (1984). The data analysis on the presence/absence of benthic indicators shows that Varano lagoon is divided into three Zones from among those described by Frisoni. The existence of two areas with the characteristics of a Zone III fulfilled the first prerequisite of our working hypothesis. In October 2002, N° 50,000 seed clams were placed in the park in Zone III. The clams grew from 16 to 35 mm in 21 months with growth concentrated in summer with lost of 20%.

Key words: Bioindicators, site suitable shellfish farming, *Tapes decussatus*; Varano lagoon.

INTRODUCTION

In the recent past, aquaculture has become the world's largest growing food industry (Costa-Pierce, 2002) particularly as landings from world marine capture fisheries have plateaued (Brugere and Ridler, 2004; Muir, 2005). The shellfish farming represented only an annual growth of 10% compared to 2 to 3% of other major food sectors (Karthik et al., 2005; Lovatelli, 2006; Subasinghe, 2006). The objective of this study was to identify a potential area for sustainable farming of the carpet clam, *Tapes decussatus* Linnaeus 1758, in a coastal lagoon guided by the benthic macrofauna as indicator organisms (Cilenti, 2006).

The carpet shell clam is a leading candidate for aquaculture development in Mediterranean lagoons (Chessa et al., 2005). This commercially valuable bivalve mollusc is naturally found distributed from the south and west coast of the British Isles to the Mediterranean Sea and along the Atlantic coast from Norway to Senegal (Tebble, 1966; Breber, 1985a, 1985b, 1985c).

T. decussatus lives in muddy-sand sediments of tidal flats or shallow coastal areas (Parache, 1982). Clams, like most filter feeders living in the intertidal zone, take advantage of the tidal movement in estuaries: Water currents generated by the tides continuously supply a much larger quantity of food than the amount locally available. These sites are of critical interest for primary production (Gutiérrez, 1991). Mid-estuarine areas usually consist of sand or sandy silt, often suitable for clam cultivation. Although outer estuarine areas may be suitable for clam cultivation, the exposure to wave action is of major concern (Britton, 1991). Besides physical

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environmental conditions, clam production is likely to be affected by a wide variety of predators, whose activity and relative importance vary depending on location and season (Anderson et al., 1982). The main interest in developing clam culture within intertidal areas is due to the facilitated access, monitoring and maintenance of] protection devices and therefore the resulting reduced costs (Kraeuter and Castagna, 1989).

In shellfish farming, most of the environmental conditions necessary for success derive from the natural ecology of the site. If the location is not suitable, it is not possible to correct the defects so that it is essential to assess the area in advance. The originality of the work presented here lies in the innovative method of selecting an area through biotic indicators. The characteristics must satisfy the autoecology of the species as well as meet the operator's need to work economically.

The habitat of the carpet clam are lagoons (Britton, 1991), but not all places within these ecosystems are suitable for this porpuse. The method generally followed is to place the clam culture where the species is already present naturally, but in the case of Varano, we could not find a natural population to guide us. We therefore applied the indirect method of indicator species. We sampled the benthic macrofauna of Varano lagoon for the presence of species known to be sympatric with the carpet clam, based on our judgement on the bionomic classification of Frisoni et al. (1984). At the same time we measured the bathymetry and analysed the sediments of the lagoon.

Optimal sites for *T. decussatus* farming are located in water depths not more than 70 cm for easy harvesting and also due to the faster growth of the clams in shallow waters. However, very shallow water may impair *T. decussatus* growth by exposing them directly to air during low tide tide (Breber, 1996; Vincenzi et al., 2006).

Lagoon substrate has a great importance in clam culture. Rocky sediments are unsuitable for clam farming while optimal substrate is characterized by a high sand percentage and the remaining fraction made up of silt and clay (20 to 30%) (Vincenzi et al., 2006).

MATERIALS AND METHODS

Basic concept

According to the scheme of Frisoni et al. (1984), salinity is not the ecological factor that controls lagoon ecosystems. The characteristics of the species assemblages depend primarily on a parameter that these authors call confinement or the degree of marine penetration in the basin. Six possible assemblages or Zones are recognised. Bivalves are present in Zone I to Zone IV (Figure 1). Zones I and II are located near the communication with the sea and their benthos shows little difference with the inshore benthos.

Proximity of sea and their benthos shows little difference with the inshore benthos.

Lagoon species begin to appear in Zone III and are exclusively so in Zone IV; bivalves disappear in Zone V where there are only a few gastropods, polychaetes and chironomids; in Zone VI is located into the area of continental waters with the presence of freshwater species or else an evaporitic environment with hyperhaline conditions and absence of benthic macrofauna (Table 1).

In Mediterranean lagoons, typical species of Zone III are *T. decussatus, Gastrana fragilis, Paphia aurea, Scrobicularia plana, Corbula gibba,* and *Anadara diluvii* (Frisoni et al., 1984) but the most regularly recurrent, and therefore, indicative species of this Zone III is the bivalve *L. lacteus*. Our procedure was to sample the bottom of Varano lagoon in order to verify the presence of one or more of the latter species. This would then suggest the existence of Zone III and therefore the possibility of acclimatising *T. decussatus*.

Study area

Varano lagoon is located along the Southern Adriatic Coast (Italy) on the Gargano promontory (41.51°N; 15.47°E) (Figure 2). It is one of the largest lagoons of Italy with its 6500 ha of surface; the average depth is 2.80 m, with a maximum of 5.80 m in the central zone. The lagoon connects with the sea occurs through two artificial channels, Capoiale and Varano, located respectively at the western and eastern end of the coastal barrier. The tidal amplitude is about 30 cm (Caroppo, 2000). In the course of the year water salinity values range from 20 to 30 psu and temperature between 6 and 30°C (Specchiulli et al., 2008). The main freshwater input (87,000 $m^3\ d^{-1}$) is from karst springs but the lagoon also receives urban wastewater and the runoff from agriculture (Spagnoli et al., 2002; Villani et al., 2000).

The economic relevance of Varano lagoon is mostly related to fishing and aquaculture activity. The fish production has been decreasing with an estimated cath of less than 100 t in 1995 again 700 to 800 t during 1960s. Mussel farming, with a production of a few hundred tonnes per year, faces significant problems in summer because of the low oxygen level in the lagoon (Breber and Scirocco, 1998).

Analysis and distribution of the indicator species

In order to determine the distribution of the indicator organisms in Varano lagoon we conducted a survey (October 2001) of the benthos consisting in 53 sediment grabs (sampling units) evenly distributed over the entire surface (Figure 3). In the laboratory, the sample was sorted and the organisms were identified and then classified accordingly. We were thus able to map (Golden Software's SURFER 8.0) the benthos following the Zonation scheme of Frisoni et al. (1984) (Table 2) which then provided us with guidance for suitable carpet clam farming sites.

Environmental parameters

Besides mapping the benthic macrofauna in order to apply the concept of indicator species, we undertook a parallel monitoring of the environment according to conventional procedure (Lovatelli, 1988; Cigarria et al., 2000; Vincenzi et al., 2006).

Particle size analysis of sediments followed the scale of Shepard (1954) where sediments are partitioned into % sand (2000 to 63 µm), % silt (63 to 2 µm) and % clay (<2 µm). Grain-size analyses were carried out, after elimination of the organic fraction with H_2O_2, by wet sieving, to separate sand from the fine fractions. For sandy fractions, a sieve size >63 µm was used. The weight of the sand trapped by the sieves was measured, and the percentage with respect to the total weight of sandy sediment fraction was determined. For fine sediments, a Sedigraph 5100 Micromeritics was employed. This instrument computes the grain size by estimating the transmittance produced by an X-ray beam, which

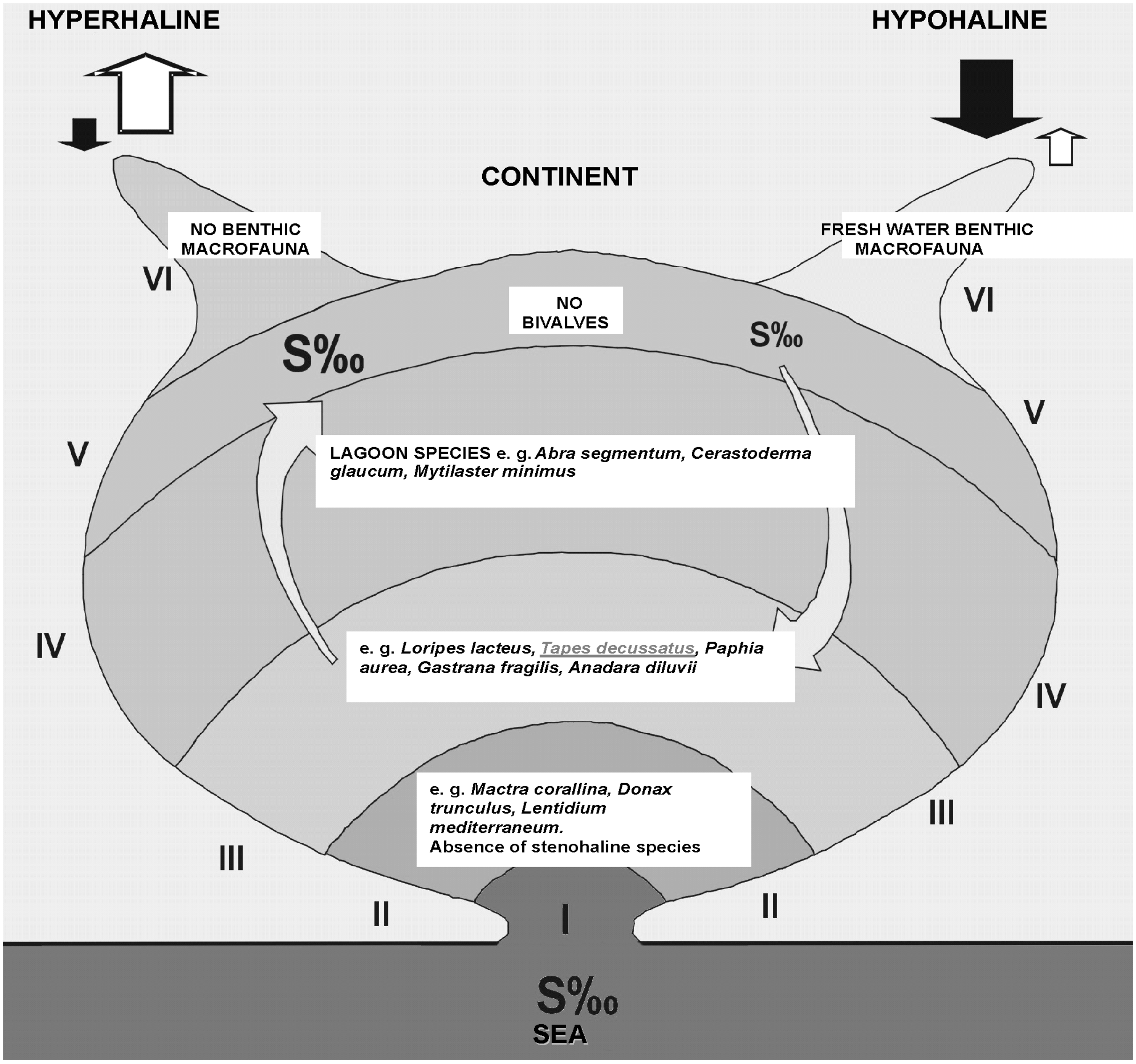

Figure 1. The bionomics of Mediterranean lagoon according to Frisoni et al. (1984).

crosses the sediment scattered in a water sample.

Bathymetry, temperature and salinity were measured with a multiparameter probe (IDRONAUT mod. OCEAN SEVEN 401).

The on-growing operation

Among the areas classified as Zone III within Varano lagoon, we chose the one most convenient for the shellfish-farmer, being close to the shore, shallow (0.7 m) and with sufficiently firm sediment for walking on. A section of bottom (28 × 2 m) was marked out and was raked clean of debris and predators hiding within the substrate (crabs, gastropods, etc.).

In October 2002, N° 50,000 seed clams obtained from an Irish hatchery were placed in the park. We opted for a relatively large individual size (16 mm) so as to limit the predation of crabs and gastropods (Walker, 1984; Peterson et al., 1995). In order to observe any difference in growth related to the density factor, the seeds were distributed in four batches of 1000 (B1), 500 (B2), 250 (B3) and 100 ind/m^2 (B4). Once every two weeks, a 6 mm mesh clam rake was drawn randomly in the clam bed made in order to collect at least 30 living clams for each batch (Peterson et al., 1987). The length (longest axis) of sampled clams was measured to 1 mm using a digital calliper. Mortality was estimated on the basis of the ratio between living and dead clams found in the samples. The data were analyzed with the software SPSS 10.0.

RESULTS

Environmental parameters

Mean results of environmental parameters and characteristics of substrate are presented in Table 3. In Varano, the clay component prevailed at most sites of the central part (mean of 16.36%), the silt component (mean

Table 1. Characterization of species according to their zone of confinement (Frisoni, 1984).

	Zone					
	I	II	III	IV	V	VI
Mollusca						
Mactra corallina		x				
M. glauca		x				
Tellina tenuis		x				
Donax semistriatus		x				
D. trunculus		x				
Acanthocardia echinata		x				
Dosinia exoleta		x				
T. decussatus			x			
Venerupis aurea			x			
Scrobicularia plana			x			
Corbula gibba			x			
L. lacteus			x			
Gastrana fragilis			x			
C. glaucum				x		
Abra ovata				x		
Hydrobia acuta				x	x	
Pirenella conica					x	
Crustacea						
Portumnus latipes		x				
Upogebia littoralis			x			
Gammarus insensibilis				x	x	x
Gammarus aequicaudi				x		
Corophium insidiosum				x	x	
Sphaeroma hokeri					x	
S. rugicauda					x	
Idotea baltica					x	
Annelida (Polychaeta)						
Audouinia tentaculata		x				
Magelona papillicornis		x				
Owenia fusiformis		x				
Phyllodoce mucosa		x				
Pectinaria koreni		x				
Akera bullata			x			
Nephthys hombergi			x			
Glycera convoluta			x			
Nereis diversicolor				x	x	
Echinodermata						
Asterina gibbosa		x				
Holoturia polii		x				
Paracentrotus lividus		x				

of 64.68%) covered the entire eastern side and part of the southern shoreline, while the sites located along the northern shoreline, where current dynamics prevent the accumulation of fine particles, had the coarsest

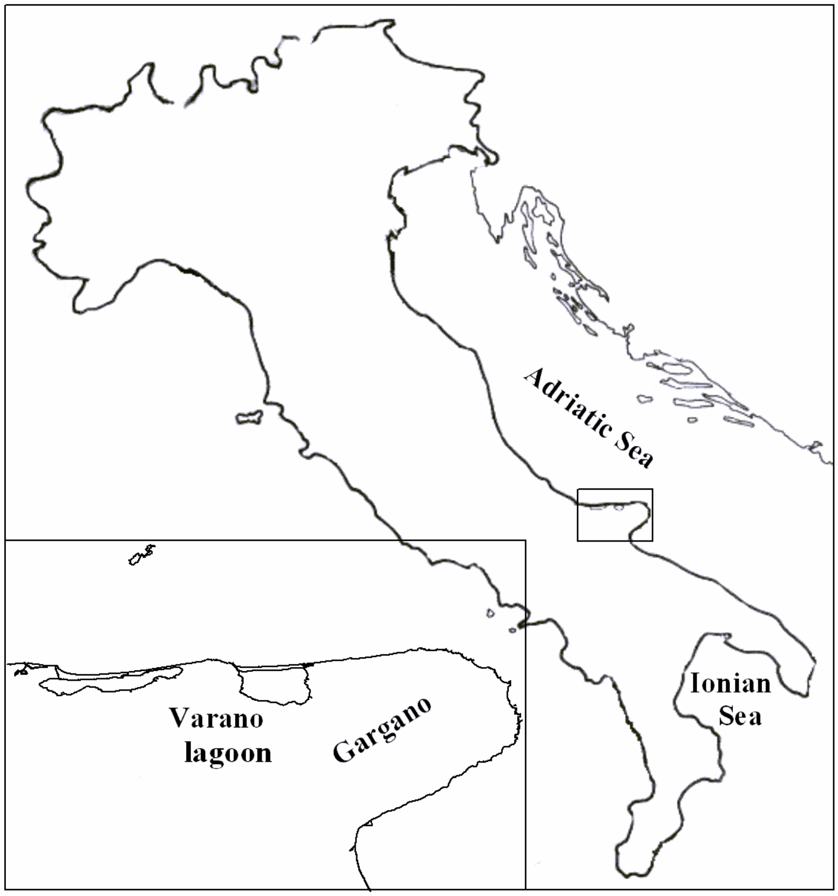

Figure 2. Location of the Varano lagoon.

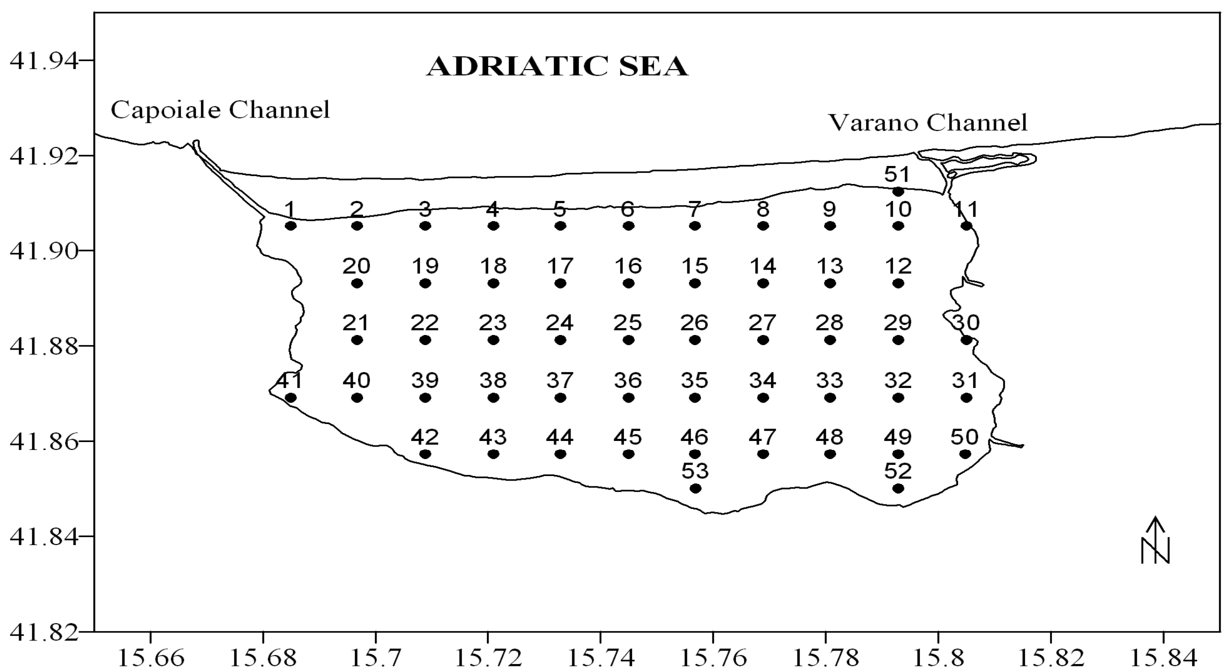

Figure 3. Investigation area within Varano lagoon with 53 sampling sites.

Table 2. Characterizing of species according to their zone of confinement in Varano lagoon (Frisoni, 1984).

Mollusca	**Zone**		
	III	**IV**	**V**
Hydrobia sp.		*	*
Abra segmentum		*	
C. glaucum		*	
L.lacteus	*		
Mytilaster sp		*	
Gastrana fragilis	*		
Annelida (Polychaeta)			
Nereis diversicolor		*	*
Glycera convoluta	*		
Nephtis hombergi	*		
Artropoda (Insecta)			
Chironomus sp.			*
Crustacea			
Sphaeroma hookeri			*
Idotea baltica			*

Table 3. Mean values and standard deviation (S. D.) of grain size and environmental parameters in Varano lagoon.

	Mean	**S. D.**
% sand	18.96	22.38
% silt	64.68	17.24
% clay	16.36	6.85
Temperature	23.5	0.87
Salinity	28.8	1.1
Depth (m)	2.8	0.81

composition (18.96% sand).

Prerequisite: The existence of zone III

The data analysis on the presence/absence of benthic indicators, shows that Varano lagoon is divided into three Zones from among those described by Frisoni (Figure 4).

Zone III has the bivalves *L. lacteus* and *G. fragilis* and is localized at two places within the lagoon, one to the north and the other to the south; Zone IV inhabits the bivalves *Abra segmentum, Cerastoderma glaucum,* and *Mytilaster minimus*. This area occupies most of the lagoon surface; Zone V is characterized by absence of bivalves and takes up two portions of the lagoon, one in the centre and the other in the western part. The existence of two areas with the characteristics of a Zone III (Frisoni et al., 1984) fulfilled the first prerequisite of our working hypothesis.

Prequisite: Operational requirements

Sediment composition and mean water depth contribute to significant differences between the two Zones III of Varano Lagoon (Table 4). The area to the south offers more difficulty to the operator for conducting a clam culture because the substrate is too soft to sustain the weight of a man and the average depth in any case does not allow wading. Furthermore, the facing shore is a steep cliff which makes the area too far away from a landing base. On the other hand, the Zone III to the north shows suitable features having a sufficiently firm sandy-silt substrate and a convenient depth (ca 0.7 m) for

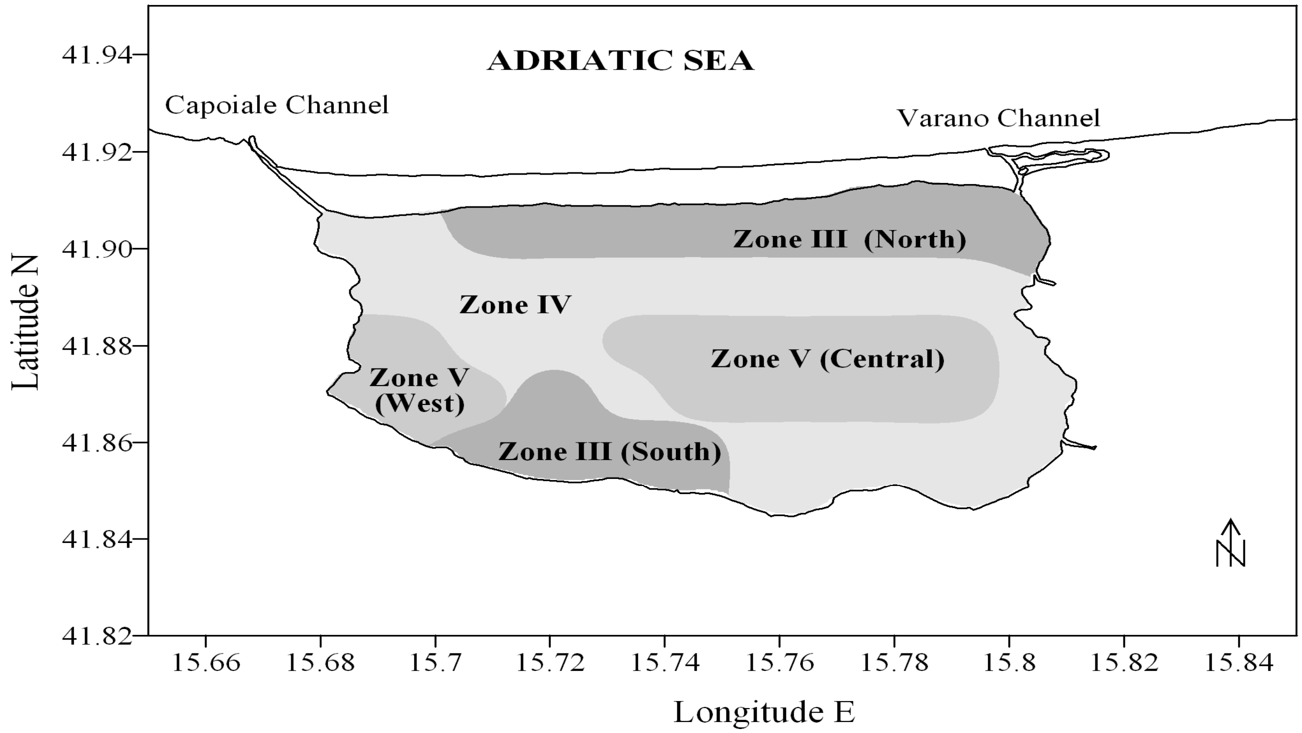

Figure 4. Zonation of Varano lagoon acoording to Frisoni et al. (1984).

Table 4. Mean values and standard deviation (S. D.) of grain size, depth and % coverage for each confinement zones according to Frisoni (1984) in Varano lagoon.

	Sand%		Silt%		Clay%		Depth (m)		% Coverage
	Mean	SD	Mean	SD	Mean	SD	m	SD	
Zone III Nord	41.55	30.85	47.00	47.00	11.46	11.46	1.47	0.51	19
Zone III Sud	17.91	16.31	64.46	9.88	17.63	7.19	2.8	0.91	9
Zone IV	17.33	18.66	66.62	14.61	16.04	6.66	2.61	1.12	43
Zone V Centrale	1.89	2.41	77.16	3.59	20.95	4.41	3.64	0.64	21
Zone V Ovest	20.05	10.25	63.69	5.81	16.27	5.90	2.37	0.95	8

waders. The shoreline is close (ca 200 m) and is accessible to motorised transport (Breber, 1985a, b, c; Cigarria et al., 2000). This is where we placed our pilot clam culture.

Response of the clams

From the time they were sowed in October 2002 the clams gave the first signs of growth in April 2003 with a new valve rim of about 1 mm. Since then the growth was steady until October 2003, showing minimum growth during the cold months only to pick up again in the second half of March 2004. There were no significant differences in growth between the batches sown at different densities (Figure 5). This is evidenced by the GLM Univariate (General Linear Model) $p > 0.5$ procedure. The graph shows in addition to growth of whole batch, an internal variability for each date. There was a greater variability in the size of clams in the last sampling, whereas it was homogeneus in the first and central growth periods (Figure 6). The summer months were the period when there were more losses. Total mortality estimated at end of the project was 4.4%, with a higher relative incidence in the month of August 2003 with 20% of the sample (Figure 7).

The test was considered completed in August 2004 with the achievement of the average size of 35 mm (Figure 6) which is considered to be a good commercial size.

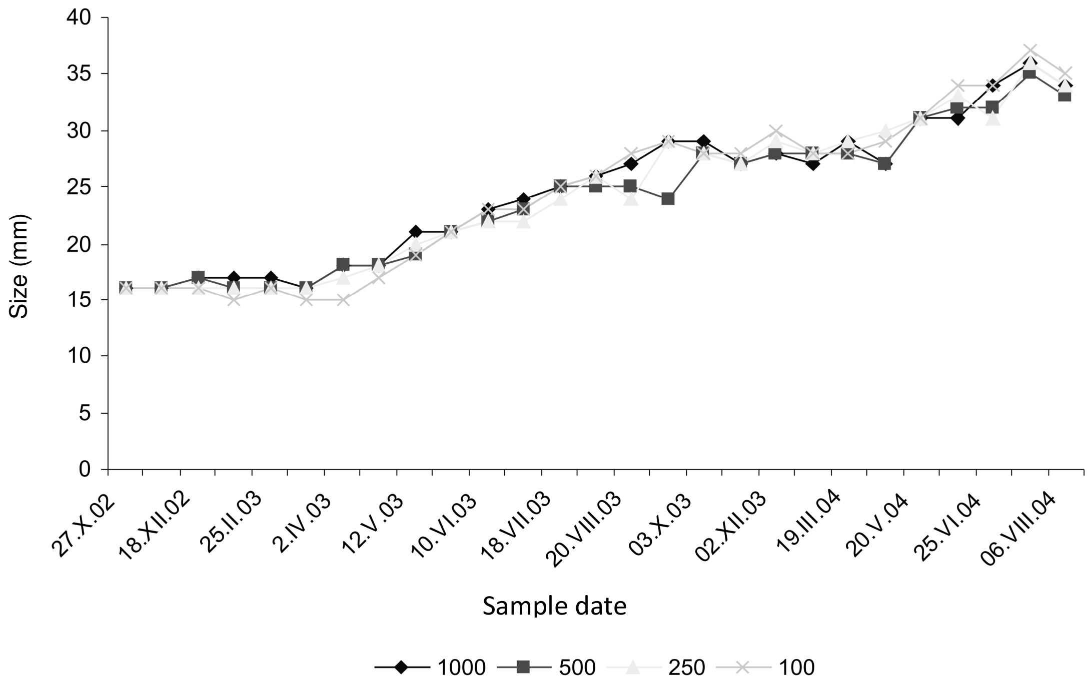

Figure 5. Growth of carpet clams at different densities from October 2002 at August 2004.

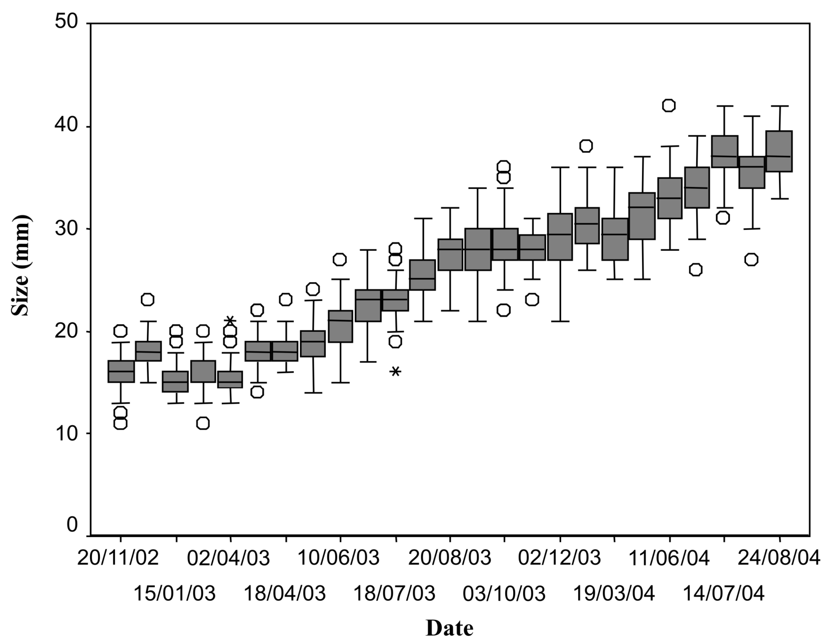

Figure 6. Growth of clams in the whole batch that shows the internal variability throughout the observation period.

Environmental parameters in the on-growing location

The temperature ranged between 5 and 30°C, during October 2002 to October 2003, with the highest values recorded from June to September. Similar conditions were repeated the following year. Salinity values ranged between 20 and 35‰ with highest values in February 2002 and the lowest values in August 2002. Temperature

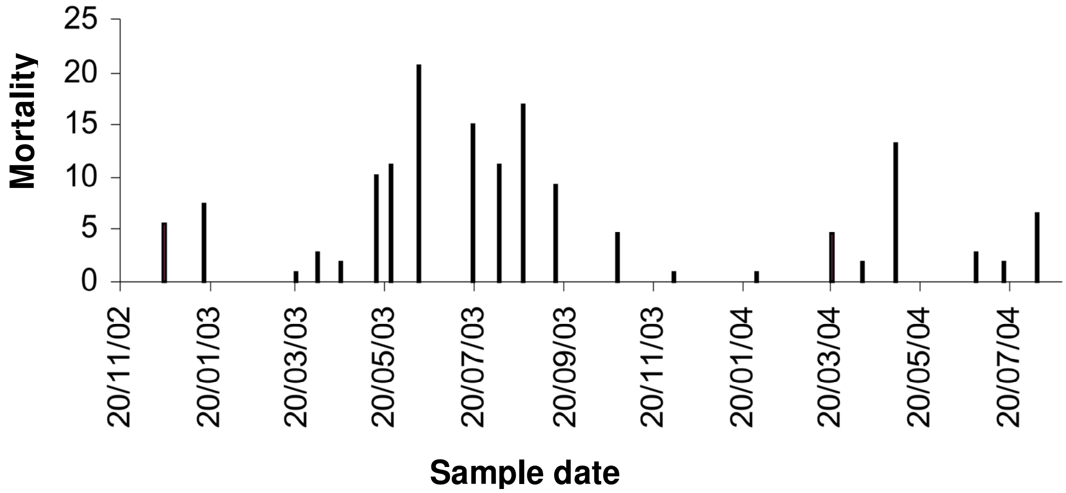

Figure 7. Mortality of carpet clams observed in the experimental period.

appears to be the parameter more closely correlated to the growth rate of the clams with an r (Pearson) = 0.97 (Figures 8 A and B).

DISCUSSION

In Varano lagoon, the only productive activities are fishing and mussel (*Mytilus galloprovicialis*) farming (Breber and Scirocco, 1998). The goal of this project being the diversification of the fishery, we wondered what other aquatic organisms could be reared in an environmentally sustainable way. The native carpet clam (*T. decussatus*) is a good candidate. Besides having a high commercial value compared to the Manila clam (*T. phylippinarum*), it would imply extensive farming compatible with the theories of sustainable development (Herman, 1991).

The results show that our initial hypothesis proved correct. Even though it may be locally absent, this does necessarily mean that the habitat is unsuitable for the carpet clam. By surveying the area for sympatric species it is possible to acclimatise it successfully. In Varano lagoon, we found two areas inhabited by *L. lacteus* which we consider as the key indicator species (Frisoni et al., 1984). These areas are of limited extent, covering only 28% of the entire lagoon. Of these two, only one near the northern shore presented the better combination of requirements. The shallowness of the site, the firm but loose quality of the sandy-silt substrate, and an easily accessible shore provide satisfactory conditions for the operator. The abundant presence of *L. lacteus* was taken as a sign that all the essential environmental factors necessary for the welfare of *T. decussatus* were met (Lovatelli, 1988; Cigarria et al., 2000; Vincenzi, 2006).

Large seeds (16 mm) were used for the experiment in order to reduce losses deriving from initial acclimatisation stress and from predation (e.g. Walzer, 1984; Peterson et al., 1995).

The clams grew from 16 to 35 mm in 21 months with growth concentrated in summer. Overall loss was assessed at 4.4%. Maitre-Allen (1983) in Sète lagoon reports an increase from 15 to 26 mm in 18 months, and Breber (1985a, 1985b, 1985c) mentions an increase from 20 to 35 mm in 17 months during a test in Venice lagoon, results which are comparable to those obtained in this work.

T. decussatus is basically a warm water species (Breber, 1996; Jara-Jara et al., 1997; Sobral and Widdows, 2000). Lucas (1978) reports that the species will still pump at 8°C if food is available but this activity decreases drastically if the water temperature drops below a 6 to 7, according to Serdar et al. (2007). In Varano lagoon we observed marked growth when the temperature was in the range of 15 to 25°C.

During the time of our experiment, salinity varied between 20 and 35 psu which may be considered a totally compatible range of values as compared with results obtained by Jara-Jara et al. (1997).

Conclusions

Results seem to confirm our initial assumption. The approach in choosing a suitable site for on-growing *T. decussatus* by looking for organisms known to be sympatric with the this clam is a step further than the methods given by Breber (1996) which suggest finding a place where the clam is naturally present or, if it is not present, by the trial-and-error method which implies sowing a test batch to see how it fares a significant lapse of time.

The results of this project was useful to identify the sites suitable for clam culture in Varano lagoon, marking

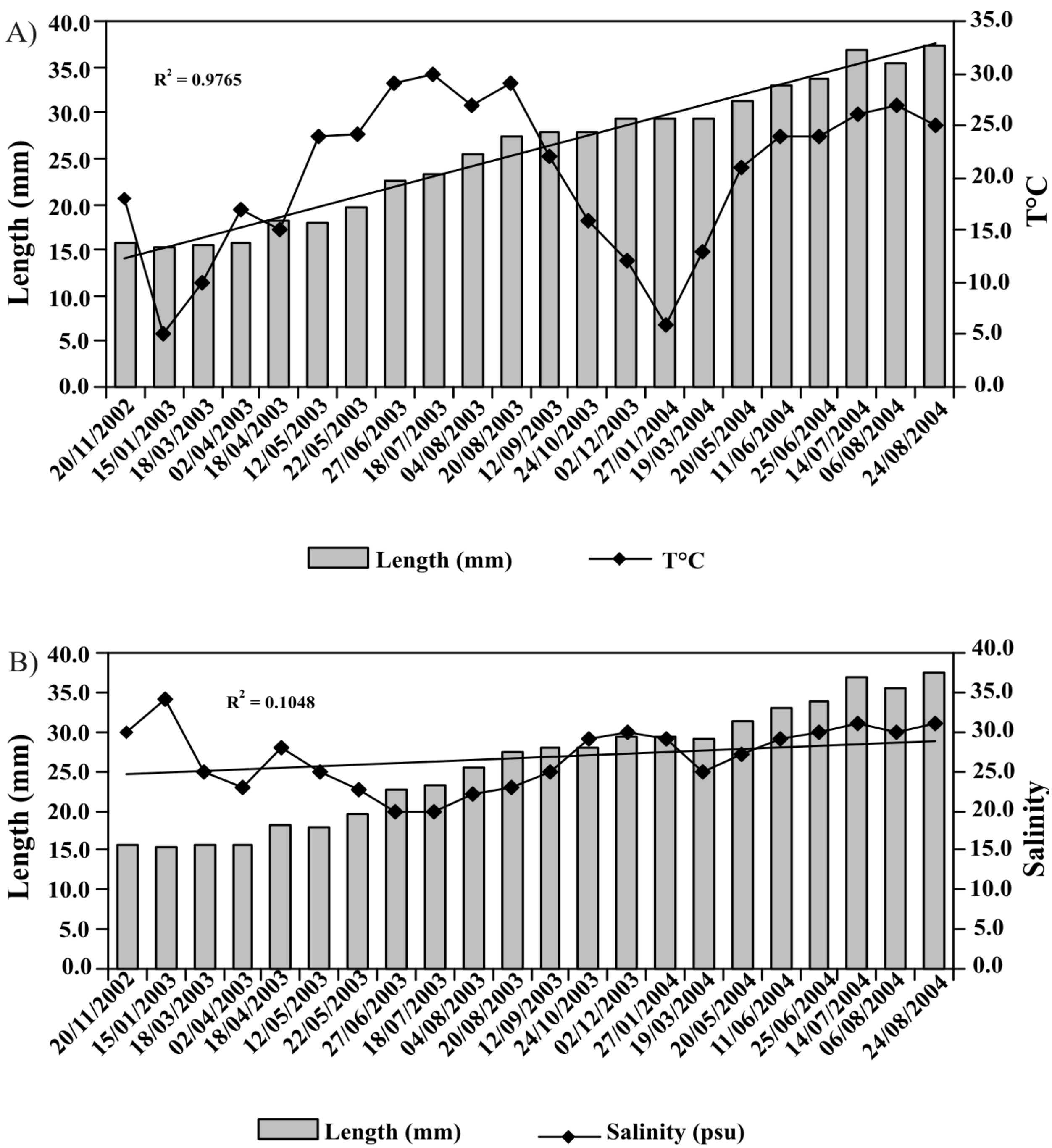

Figure 8. Correlation between growth, shell length (mm) and environmental parameters temperature (A) and salinity (B).

the start of a new fishery production of Varano lagoon .

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